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Dissertation

Individual Differences in Face Cognition: Using ERPs to Determine Relationships between Behavioral and Neurocognitive Indicators

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German abstract

Zusammenhänge zwischen neurokognitiven Indikatoren und Verhaltensindikatoren der Gesichterkognition können Gehirnsysteme und neuronale Subprozesse identifizieren, die individuellen Unterschieden im Verhalten zugrunde liegen. Diese Dissertation zeigt, dass Ereigniskorrelierte Potentiale (EKPs) als neurokognitive Indikatoren für die Erforschung individueller Unterschiede eingesetzt werden können, denn sie weisen die gleichen hohen psychometrischen Qualitäten wie andere Fähigkeitsindikatoren auf und messen daher individuelle Unterschiede in der neuronalen Verarbeitung zuverlässig und stabil über die Zeit. Auf der Verhaltensebene wurden drei Teilfähigkeiten der Gesichterkognition etabliert: Gesichterwahrnehmung, Gesichtergedächtnis und Gesichtergeschwindigkeit. EKPs wurden in Strukturgleichungsmodellen verwendet, um den Beitrag neurokognitiver Indikatoren an individuellen Unterschieden dieser Gesichterkognitionsfähigkeiten zu schätzen. Für 85 Probanden wurden Beziehungen zwischen den Gesichterkognitionsfähigkeiten und der P100, N170, der sogenannten Differenz aufgrund des Gedächtnisses (Dm) und dem frühen sowie späten Wiederholungseffekt (ERE und LRE) etabliert. Spezifische Anteile individueller Unterschiede in der Gesichterkognition auf der Verhaltensebene wurden durch individuelle Unterschiede im Zeitverlauf der strukturellen Gesichteranalyse (N170 Latenz) sowie in der Reaktivierung von Repräsentationen gespeicherter Gesichtsstrukturen (ERE) als auch personen-spezifischen Wissens (LRE) erklärt. Keinen Anteil an individuellen Unterschieden erklärten hingegen frühe Wahrnehmungsprozesse (P100), die neuronale Aktivierung während der strukturellen Gesichteranalyse (N170 Amplitude) und Prozesse der Gedächtnisenkodierung von Gesichtern (Dm). Diese Ergebnisse zeigen, dass individuelle Unterschiede in der Gesichterkognition von der strukturellen Gesichteranalyse sowie von der Effizienz und Geschwindigkeit des Zugriffs auf Gedächtnisinhalte zu Gesichtern und Personen abhängt.

Schlagworte: individuelle Unterschiede; Ereignis-korrelierte Potentiale; Strukturgleichungsmodelle; N170; P100; Dm; Priming; Gesichter; Gesichtererkennung

English abstract

Individual differences in perceiving, learning, and recognizing faces swiftly and accurately were shown on the behavioral and neural level but were rarely related to one another. By determining relationships between behavioral and neurocognitive indicators of face cognition, brain systems and neural sub-processes can be identified that underlie individual variations on the behavioral level. The present dissertation laid the foundation for using event-related potentials (ERPs) as neurocognitive indicators in individual differences research (Studies 1 and 2). ERP components were shown to possess the same high psychometric qualities as behavioral ability measures and thus to measure individual differences of neural processing reliably and stably across time. On the behavioral level, three component abilities of face cognition were established: face perception, face memory, and the speed of face cognition (Studies 3 and 4). ERP components were used in structural equation models that specified and estimated contributions of neurocognitive indicators to the individual differences in these face cognition abilities (Study 4). Regression analysis was used to determine the contributions of P100, N170, the so called difference due to memory (Dm), as well as early and late repetition effects (ERE and LRE) to face cognition abilities in 85 participants. Certain amounts of variance in face cognition as seen on the behavioral level were accounted for by individual differences in the temporal dimension of structural encoding of a face (N170 latency) and in the re-activation of both stored facial structures (ERE) and person-identity information (LRE). Thus, face-responsive regions in the fusiform gyrus together with temporal brain areas seem to play an important role for normal variations in face cognition. In contrast, processes of early vision (P100), the neural activation of structural face encoding (N170 amplitude), and memory encoding of new faces (Dm) did not show any contribution to individual differences in face cognition. The obtained relationships were in general small to moderate, indicating that the network of mental functions interacting to perceive, learn, and recognize faces cannot be reduced to a few neural sub-processes as measured by ERP components.

Keywords: individual differences; event-related potential; structural equation modeling; N170; P100; Dm; priming; faces; face recognition

1 Introduction

The human face is probably the most investigated visual object. This is hardly surprising because the face is the most important visual object in social life. It provides immediate information like age, gender, ethnicity, health status, mood, and emotional status of a person, and it also serves as a gateway to stored information regarding a person's familiarity, biography, and name. But information provided by faces is just one aspect of face cognition. Variations in face cognition can also originate from such differences among the perceivers as age, gender, sexual preferences, personality, intelligence, perceptual expertise, and neurological diseases. The present dissertation studied the variability of face cognition on the behavioral and neurocognitive level in healthy, young adults. In particular, relationships were determined between individual differences in behavioral performance and neural sub-processes of face cognition as measured by event-related potentials (ERPs).

Face cognition is mainly used as an undifferentiated umbrella term to refer to a collection of many different functions as varied as holistic face processing, face recognition, configural processing, face learning, face discrimination, and processing facial features. Investigating the structure of individual differences in face cognition provides the foundation for separating the umbrella term into component abilities (e.g., discriminating between perception and memory processes) and establishes a classification system for face cognition research. The identification of component abilities is an important step in specifying the extent to which normal variations in the neural processes related to face cognition contribute to variations in perceiving, learning, and recognizing faces on the behavioral level. By linking component abilities of face cognition not only to their neurocognitive underpinnings but also to specific brain systems, the approach used in this dissertation goes beyond the identification of correlations between isolated functions and their neural substrates (e.g., Alexander, Mentis, et al., 1999; Jolij, Huisman, et al., 2007; Rotshtein, Geng, Driver, & Dolan, 2007; Vogel & Machizawa, 2004) and contributes to a deeper understanding of the fundamental neural processes in face cognition.

1.1 Theoretical background

Research on individual differences in face cognition has been done on different subsets of the population. Some studies have looked at individuals with extreme abilities at both ends of the spectrum: super recognizers (Russell, Duchaine, & Nakayama, 2007) and people with prosopagnosia (e.g., Duchaine, & Nakayama, 2005; Farah, Levinson, & Klein, 1995). Others have investigated the variation among normal individuals (e.g., Alexander, et al., 1999; Clark, Keil, et al., 1996; Megreya & Burton, 2006; Rotshtein et al., 2007; Schretlen, Pearlson, Anthony, & Yates, 2001) or among groups within the normal variation, including groups that differ in gender (e.g., Herlitz & Yonker, 2002; Lewin & Herlitz, 2002), sexual preference (e.g., Ishai, 2007), or age (Pfütze, Schweinberger, & Sommer, 2002; Schretlen et al., 2001). Although research on extremes and group differences in face cognition has attracted much more attention and might be viewed as more prosperous, studying individual differences in the normal variation promises enlightening results as has already been the case for research on many other mental abilities like intelligence, working memory, or emotional intelligence.

Some studies have investigated individual differences in the normal variability of face cognition either on the behavioral (e.g., Megreya & Burton, 2006; Rotshtein, Geng, Driver, & Dolan, 2007) or on the neural level (e.g., Alexander, Mentis, et al., 1999; Clark, Keil, et al., 1996). A small number have integrated behavioral and neural perspectives and aimed to establish relationships between independently measured indicators from both fields (Rotshtein et al., 2007; Schretlen, Pearlson, Anthony, & Yates, 2001). These studies explored such isolated processes of face cognition as configural or featural processing (Rotshtein et al., 2007), face recognition (Schretlen et al., 2001), and visual discrimination of faces (Alexander et al., 1999). In each case, only single indicators were used to measure behavioral and neurocognitive processes. Only one study used a sample of participants large enough to make reliable conclusions about universalities and general principles (Schretlen et al., 2001). None of these studies used multivariate behavioral measures of face cognition or ERP components to elucidate relationships of individual differences in behavioral and neurocognitive indicators of face cognition. Because ERP components are only rarely used in this way, the prerequisites governing their application to research on individual differences must first be discussed.

2 Event-related potentials in individual differences research

ERP components have advantages over neuroanatomical (Schretlen et al., 2001) and neuroimaging data (Alexander et al., 1999; Clark et al., 1996; Rotshtein et al., 2007) that can be exploited when investigating individual differences in neural processing of faces. Neuroanatomical data offers information about the properties of the neural substrate (e.g., a large ventrical-to-brain ratio) but not about its underlying function. Because of the high spatial resolution of positron emission tomography and magnetic resonance imaging, brain areas active during a specific task can be localized with such high precision that the individual differences in the structural (e.g., size of the face-responsive regions in the fusiform gyrus) and functional (e.g., amount of activation of face-responsive regions in the fusiform gyrus during familiar face recognition) involvement of these areas can also be measured. ERP components also offer information about the amount of neural activation and indicate the extent to which neurons underlying a particular function are involved. This information is represented in amplitude measures of ERP components. From all neuroscientific methods used to gain information about neural processing, however, only electro- and magnetoencephalography possess the high temporal resolution necessary for statements about the time course of an ongoing neural process in the range of milliseconds. In contrast to the still developing research using magnetoencephalography, several components in the ERP have already been linked to sub-processes of vision, learning, and memory. Most of these processes were shown to be especially sensitive to face cognition (for reviews see Herzmann et al., 2007; Herzmann, Kunina, Sommer, & Wilhelm, in preparation).

A brief discussion about the role that ERP components could play in individual differences research can be found in Herzmann et al. (2007, pages 313 and 317). In short, amplitudes and latencies of ERP components can in many instances reflect consequences of experimental manipulations similar to behavioral data. Individual differences in speed or accuracy of performance may thus be reflected in latencies or amplitudes of ERP components as well. Evidence suggests that there are considerable differences among people not only in the structure of the neural substrate (e.g., Clark et al., 1996; Deffke, Sander, et al., 2007; Schretlen et al., 2001) but also in its task related activation (e.g., Alexander et al., 1999; Rotshtein et al., 2007). From these findings alone, however, one cannot directly conclude that differences in neural processing are stable across time, and that these individual differences contribute to good or poor performance in face cognition.

In order to apply ERP components to individual differences research, several methodological prerequisites must be met. (1) ERP components should reflect individual differences in single neural processes (e.g., re-activation of stored facial structures) as purely as possible. Sources of task irrelevant individual variation (e.g., differing amounts of exposure to a familiar face) should be excluded. (2) Individual differences assessed with ERP components should exploit all parameters recorded by electroencephalography: latency, amplitude, and topographical distribution of activity across the scalp. In order to use this information in correlational analyses, single test values must be obtained for each individual. (3) Finally, these neurocognitive test values have to be stable across time. When these prerequisites are successfully met, one can test whether individual differences in ERP components make clear and direct contributions to individual differences in behavioral indicators of face cognition. Individual differences in ERP components can be used as indicators of good or poor performance in face cognition only after being validated in this way.

ERP components have some important differences compared to the behavioral data normally used as indicators of performance in face cognition. Behavioral data, as used to assess mental abilities, index whether or not a person meets the instructions to respond quickly and/or accurately. It provides the end product of mental processing and represents an interaction of such various cognitive functions as attention, perception, decision making, motivation, emotion, memory, strategies, motor programming, and so forth. In contrast, ERP components reflect the change in activity over time of single neural processes thought to contribute to behavioral performance. Because they are less dependent upon response strategies, ERP components may be purer measures of face cognition than behavioral indicators. Although ERP components can provide deeper insight into mechanisms and substrates underlying specific sub-processes of face cognition, it is an open question if they also indicate successful task performance. It is reasonable to assume direct and close relationships between measures of ERP components like amplitude and latency and the quality and speed of performance, but this must be demonstrated before ERP components can be considered purer indicators of performance than behavioral data. A high contribution of ERP components to independently measured task performance would indicate that individual differences in the change in activity of a particular neural sub-process over time are directly reflected in variations on the behavioral level. The existence of such a close relationship is, however, unlikely because ERP components are parameters of single sub-processes in face cognition whereas behavioral data is the product of many such sub-processes. It thus seems more realistic to expect small to moderate relationships between neurocognitive and behavioral indicators of face cognition. Even if a single neural process or a small set of neural processes responsible for face cognition abilities are not found, establishing relationships between neurocognitive and behavioral indicators will still contribute to a deeper understanding of how neural sub-processes and particular brain systems relate to behavioral performance in face cognition.

2.1 Experimentally learned faces

Face recognition research has typically used pre-experimentally familiar faces. For this stimulus material, such aspects as perceptual expertise with the face, amount of personal interaction with the person, feelings towards the person, knowledge about the person’s life, and so forth cannot be controlled and might, in individual differences research, be a source of task irrelevant variance. When assessing individual differences in neurocognitive indicators of face cognition, the source of individual variation should be confined to the neural process of interest; sources of task irrelevant variation should be minimized.

A standardized experimental learning paradigm was therefore developed. Participants learned unfamiliar faces, maintained them for one week, and were then asked to recognize them while the EEG was recorded. This paradigm was used in Studies 1, 2, and 4. Because internal facial features have been shown to mediate familiar face recognition (Bonner, Burton, & Bruce, 2003; Ellis, Shepherd, & Davis, 1979), stimulus material was edited so that only internal facial features (i.e., eyes, mouth, nose, and their configuration; see Figure 1 in Herzmann & Sommer, in preparation, for an example) were visible. This stimulus material was used in Studies 2, 3, and 4.

In Study 1, priming effects in the ERP were compared for newly learned and unfamiliar stimuli (N = 15). These priming effects, the early and late repetition effect (ERE and LRE), were shown to be sensitive to modulations of familiarity when recognizing faces (e.g., Pfütze et al., 2002; Schweinberger et al., 1995). The ERE is thought to reflect the temporary activation of stored structural representations of faces in long-term memory and has been localized in the fusiform gyrus (Eger, Schweinberger, Dolan, & Henson, 2005; Schweinberger, Pickering, Jentzsch, Burton, & Kaufmann, 2002). The LRE is thought to represent temporary activation of person-related knowledge stored in long-term memory. It can be assumed to originate in regions of the extended neural system (i.e., anterior temporal cortex, precuneus, posterior cingulate cortex) as proposed in the model of familiar face recognition in Gobbini & Haxby (2007).

The ERE and LRE measured in Study 1 showed the characteristic modulations due to familiarity as has been found for pre-experimentally familiar stimuli (e.g., Pfütze et al., 2002; Schweinberger et al., 2002). Results of Study 1 thus provided evidence for the success of the learning paradigm because representations for experimentally learned faces were shown to be established in long-term memory and then re-activated when recognizing these faces one week after learning.

Within-subject comparisons of experimentally learned with pre-experimentally familiar faces were not possible in Study 1. One might therefore argue that priming effects obtained for learned faces are not equivalent to those for well-known faces and do not represent processes of familiar face recognition. Study 2 (N = 23) addressed this issue by comparing priming effects in reaction times and ERPs for experimentally learned and famous faces. Comparable priming effects in ERP components and in reaction times were found for both learned and famous faces. By showing that face recognition processes, as measured with reaction times and ERP components, were essentially identical for learned and famous faces, Study 2 provided the basis for using ERP components of learned faces to determine relationships between neurocognitive and behavioral indicators of face cognition.

2.2 Quantification of ERPs for individual differences research

Individual differences research using ERP components has so far been restricted to measuring peak latency and peak amplitude at a single electrode (e.g., Braverman, Chen, et al., 2007; Hall, Rijsdijk, et al., 2007; Jolij et al. 2007; Vogel & Machizawa, 2004). While it is appropriate, when dealing with circumscribed ERP components like the P100, N170, or P300, to limit the available information to the change in activation at a single electrode over time, this results in a loss of information unacceptable for other ERP components, like priming effects and the so-called difference due to memory (Dm), that are more widely distributed in time and across the scalp. Some methods offer the possibility to integrate the amount of neural activation with its distribution across the scalp into a single measure: factor analysis (e.g., Molenar, 1987; Schröder, Buchsbaum, et al., 2001), independent component analysis (ICA, e.g., Deffke, Sander, et al., 2007), principle component analysis (e.g., Curran & Dien, 2003; Kayser, Tenke, Gates, & Bruder, 2007), and topographic component recognition (TCR, Brandeis, Naylor, Halliday, Callaway, & Yano, 1992). In Studies 1 and 4, TCR was used to obtain individual values for neurocognitive indicators of face cognition.

TCR estimates the contribution of a specific ERP component, characterized by its topography across several electrode sites, to a given individual ERP. To determine individual test values, the covariation at any given point in time is calculated between a standardized template map selected from the grand mean of ERPs and non-standardized maps of ERPs in the datasets of every individual participant. The template map is not derived by a statistical algorithm (as for the ICA) but selected according to a priori knowledge about the component. This template map summarizes the topographical characteristic of a particular ERP component thought to indicate a specific sub-process in face cognition. In order to determine individual indicators of ERP components for each participant, two measures were derived: a) the peak amplitude and b) the peak latency of the covariation between template map and the individual ERP. The peak amplitude of the TCR measure represents the maximal degree to which the individual ERPs resembled the template map. Because TCR was applied to non-standardized maps of individual ERPs, amplitude measures also reflected the amount of activation. The peak latency of the TCR measure represents the point in time at which the individual ERPs most closely resembled the template map.

2.3 Reliability of event-related potentials

When expressing information about both amount and spatial distribution of solely task relevant brain activation in a single individual test value, it is important to show that this measure does not represent a temporary state, but reliably indicates brain activation and is stable across time.

In Study 1 (N = 15), parallel-test reliabilities of priming effects for newly learned faces were calculated. Reliabilities for peaks of the TCR measure were higher than $r_{ij} = .63$. In Study 4 (N = 85), internal consistencies (measured as Cronbach's α) for all ERP components were above α = .50. Measures of ERP components were shown to be reliable indicators of brain activation stable across time and thus feasible markers for assessing individual differences in neural sub-processes of face cognition.

The next section shifts focus to the behavioral level. It outlines how a multivariate approach was used to determine component abilities of face cognition that will ultimately be linked to neurocognitive indicators in the dissertation's main study.

3 Face cognition: A set of distinct mental abilities

Previous studies have explored neural correlates of single tasks to establish brain-behavior relationships in face cognition (e.g., Alexander et al., 1999; Rotshtein et al., 2007; Schretlen et al., 2001). Findings in these studies are only the first step towards understanding the complex interplay of neural processes underlying face cognition abilities. In contrast to using single tasks, multivariate approaches explore individual differences in many tasks. By distinguishing which tasks correlate with one another and which do not, this approach provides the means to determine component abilities in face cognition and their relationships to one another (Bollen, 1989)

Methodological considerations for the multivariate assessment of individual differences in face cognition can be found in Herzmann et al. (2007; in press) and Wilhelm et al. (in preparation). The procedure for developing a broad collection of indicators for face cognition is described in detail in Herzmann et al. (in press). In short, established models of face cognition (Breen, Caine, & Coltheart, 2000; Bruce & Young, 1986; Burton, Bruce, & Johnston, 1990; Burton, Bruce, & Hancock, 1999; Ellis & Lewis, 2001; Gobbini & Haxby, 2007; Haxby, Hoffman, & Gobbini, 2000) were used to derive possible component abilities: face perception, face learning, and face recognition. The development of a variety of indicators supposedly measuring these abilities was founded on established experimental paradigms that tap into such aspects of face cognition as holistic processing (e.g., inversion effect, part-whole effect, or composite face effect), face perception (e.g., face discrimination from different view-points), face learning (e.g., short-term learning), and face recognition (e.g., priming, eyewitness testimony). Because individual differences in face cognition can be manifested in both correctness and response time of performance, independent indicators were developed for each parameter.

In Study 3 (N = 153), psychometric qualities of these newly developed indicators were assessed. Reaction time measures showed high internal consistencies. Accuracy measures yielded somewhat lower reliabilities, yet high enough to support their use in a battery of face cognition. Those indicators with established experimental effects (Task 6 – part-whole effect, Task 2 – composite face effect, Task 7 – inversion effect, Task 13 – priming effect, Herzmann et al., in press) were mostly confirmed in Study 3. In many cases, however, they showed poor internal consistencies. Individual differences in experimental effects were thus not reliable, and these difference measures were not used as indicators of face cognition abilities. The single conditions of these experimental effects nonetheless represent face-related processes and were therefore included as separate indicators of face cognition abilities.

For data obtained from 153 participants in Study 3 and from 209 participants in Study 4, measurement models of face cognition were established using confirmatory factor analyses (Wilhelm et al., in prep.). In Study 3, a family of measurement models was tested ranging from one that postulated a single latent factor of face cognition to models that distinguished between processes (perception and memory) and dependent variables (speed and accuracy). Comparisons of these models revealed among the accuracy indicators two related yet separable factors: face perception and face memory. Face memory united common variance from indicators for face learning and face recognition. Thus, it was not possible to establish the proposed distinction between these component abilities. Indicators for face speed required no further distinction between perceptual and memory processes. They were clearly separated from the two latent factors of face cognition accuracy. Figure 1 in Wilhelm et al. (in prep.) presents the final measurement model from Study 3.

The three component abilities in face cognition can be characterized as follows. Face perception expresses the ability to holistically perceive facial stimuli and to extract from them such relevant aspects as facial features and their configuration. Face memory represents the ability to encode facial stimuli, and to store them in and retrieve them from long-term memory. The speed of face cognition captures the ability to process facial stimuli swiftly.

Study 4 aimed to replicate the measurement model of face cognition from Study 3 and to distinguish the factors of face cognition from such established abilities as immediate and delayed memory, mental speed, general cognitive ability, and object cognition. Critical distinctions obtained for the measurement model in Study 3 were successfully replicated. Although the correlation between factors of perception and memory was higher than in Study 3 (.74 vs. .50), the factors were still sufficiently independent to be considered separate abilities. Models for face cognition abilities and established cognitive abilities were integrated in a structural equation model that tested the relative independence of face cognition abilities from other cognitive abilities. The structural model (Figure 3 in Wilhelm et al., in prep.) showed that none of the three latent factors of face cognition could be essentially reduced to established abilities like immediate and delayed memory, mental speed, general cognitive ability, and object cognition. This very strong evidence for the relative independence of individual differences in face cognition from established cognitive abilities indicated that face cognition is a set of distinct mental abilities in their own right.

4 Relationships between behavioral and neurocognitive indicators of face cognition

Building on the previous results, Study 4, the main study of this dissertation, sought to determine relationships between behavioral and neurocognitive indicators of face cognition using ERP components. In addition, correlations among individual differences in neurocognitive indicators were estimated. ERP components sensitive to processes of vision and face cognition were used as neurocognitive indicators. The occipital *P100* component is generated in the early extrastriate visual brain areas (cf. Doi, Sawada, & Masataka, 2007) and commonly taken to reflect processing of domain-general, low-level stimulus features independent of stimulus familiarity. The face-specific occipito-temporal *N170* component was related to the configural encoding of facial features and to their integration into a holistic percept. It is thought to be generated in the fusiform gyrus (Deffke et al., 2007). The *Dm* is measured in the paradigm of subsequent memory and taken to reflect encoding of facial structures into long-term memory (e.g., Guo, Voss, & Paller, 2005; Sommer, Schweinberger, & Matt, 1991) in a network of different neural structures (see Otten & Rugg, 2002; Paller & Wagner, 2002, for reviews). In addition, the ERE and LRE were measured, which were already used in Studies 1 and 2 (pages 6-8).

A subset of 85 participants from Study 4 accomplished two EEG sessions in addition to the behavioral testing session. In the first EEG session, P100, N170, and Dm were measured in the Dm paradigm. Forty novel faces were learned in a standardized learning paradigm and used as target faces in EEG session two, which was conducted exactly one week later. ERE and LRE for the newly learned faces were measured in a priming paradigm.

For this subset of participants, the measurement model of face cognition revealed a very high correlation between face perception and face memory (*r* = .90), making it impossible to view both as separate abilities (Figure 2 in Herzmann et al., in prep.). These factors were therefore integrated into a single latent factor that represents accuracy of performance in face perception and face memory. It can be safely assumed that the high correlation of the two accuracy factors resulted from the relatively small number of participants; for the correlation was lower in the sample as a whole (*r* = .74). Differential experiences with experimental paradigms could also be a possible reason for the high correlation. In contrast to the entire sample, which had no prior experience with similar experimental tasks, 90 % of the subset took part in two EEG sessions and had thus acquired familiarity with the experiments before completing the behavioral test study.

ERP components showed high internal consistencies and normal distributions. Measurement models of ERP components (Figure 4 in Herzmann et al., in prep.) were successfully established using confirmatory factor analysis and indicated high unidimensionality of the neurocognitive indicators. Unidimensionality reveals that only one latent factor (i.e., a common source of variance) accounted for individual differences in a particular ERP component. Contributions of ERP components to face cognition abilities were determined as regressions in structural equation models (Figure 5 in Herzmann et al., in prep.), which make it possible to judge directly the reliability of estimated relationships between multiple measurement models (i.e., ERP components and face cognition abilities).

Regression analyses of neural sub-processes and face cognition abilities revealed that neurocognitive indicators made small to moderate contributions to behavioral ones. No contribution to individual differences in face cognition on the behavioral level was found for the P100, the N170 amplitude, the Dm, or ERE and LRE for unfamiliar faces. Other contributions were as expected: A shorter N170 latency was related to better performance in face perception and memory. Earlier or larger ERE and LRE were associated with better and quicker face processing. From all investigated ERP components, individual differences in the amplitude of the ERE for learned faces explained the highest amount of variance in face perception and memory as well as face speed. In general, individual differences in neurocognitive indicators accounted for less than 22 % of the individual differences in face perception and memory and for less than 14 % in face speed. Unexpectedly, individual differences in latency measures of ERP components did not explain any individual differences of face speed.

Pearson product-moment correlations of latency and amplitude measures of all ERP components showed a less clear picture than were found by correlations of behavioral indicators in the measurement model of face cognition (Wilhelm et al., in prep.). Thus, the structure of individual differences on the neurocognitive level of face cognition seems to be more complex than on the behavioral level.

Correlations of latency and amplitude measures within ERP components indicated that short latencies were accompanied by large amplitudes only for the Dm. For all other ERP components, individual differences in latencies and amplitudes were not related to one another. Faster processing can accompany either high or small neural activation.

Correlational data also provided evidence that priming effects for learned and unfamiliar faces are generated by different neural sources. In addition, the correlation of ERE and LRE for learned faces was sufficiently low to suggest different underlying neural processes.

5 Summary and conclusion

This dissertation used ERP components to determine relationships between neural processing and face cognition performance on the behavioral level. A highly standardized learning paradigm was developed to study individual differences in neurocognitive indicators of relevant (e.g., familiar face recognition) as opposed to irrelevant processes (e.g., varying degrees of perceptual expertise) (Studies 1 and 2). In contrast to other studies that addressed relationships between neural processing and mental abilities, the ERP components used in this study, apart from P100 and N170, were not just measured as peak latency and peak amplitude at a single electrode. Using the TCR method, individual test values exploited the information that electroencephalography recordings offer and combined data of the change in activation over time with the spatial distribution of the activation across the scalp. ERP components quantified in this way reliably indicated brain activation and were stable across time (Study 1). They are thus well-suited not only to monitor temporally transient brain events but also to measure individual differences of neural processes. This notion was further supported by the results from Study 4. Here, internal consistencies for ERP components were generally high, and reliable measurement models were established that demonstrate the unidimensionality of the neurocognitive indicators. These findings are a solid basis for using ERP components in latent variable techniques to determine relationships between neurocognitive and behavioral indicators of face cognition and in other areas of human information processing.

On the behavioral level, a multivariate test battery was developed to comprehensively assess individual differences in face cognition. Confirmatory factor analysis indicated that three separable component abilities account for variations between people when perceiving, learning, and recognizing faces (Studies 3 and 4): face perception, face memory, and face speed. In Study 4, the relative independence of all three face cognition abilities from such established cognitive abilities as immediate and delayed memory, mental speed, general cognitive ability, and object cognition was demonstrated.

A set of ERP components sensitive to neural sub-processes of vision and face cognition was used to determine contributions of individual differences in neural processing to face cognition abilities. Contributions were small to moderate and in general accounted for less than 22 % of the variance in face cognition abilities. A considerable portion of individual differences in behavioral performance was thus not explained by individual differences in ERP components. These findings could indicate that ERP components represent individual differences in a single sub-process of face cognition, whereas multiple sub-processes contribute to individual differences in behavioral indicators. In fact, suggesting a very close relationship between a single ERP component and complex cognitive functions would assume that restricted brain areas are solely responsible. Such a view clearly neglects the evidence of interacting neural networks for such complex mental abilities as face cognition (Haxby, Hoffman, & Gobbini, 2000; Gobbini & Haxby, 2007). In addition, not all processes underlying variations in face cognition on the behavioral level can be measured with ERP components (e.g., activation of subcortical structures).

In conclusion, this dissertation establishes new evidence for neurocognitive underpinnings of individual differences in face cognition. Individual differences in some neural sub-processes, especially the temporal dimension of structural face encoding (N170 latency), but also re-activation of representations in long-term memory for both facial structures (ERE) and person-identity knowledge (LRE), contributed to certain amounts of individual variation of face cognition on the behavioral level. These findings emphasize the role that face-responsive regions in the fusiform gyrus, together with temporal brain areas, play for normal variations in face cognition. Other sub-processes like the early domain-general, low-level processing (P100), the neural activation of structural face encoding (N170 amplitude), and memory encoding of faces (Dm), did not show any contribution. Thus, a large proportion of the normal variation in face cognition could not be explained here. Such other cognitive functions as attention, emotions, decision processes, memory consolidation, evaluation processes, or response selection can be thought to contribute to individual differences in face cognition and should be investigated in future studies. Because contributions of neurocognitive indicators to individual differences in face cognition were only small to moderate, ERP components appear to be less direct indicators of good or poor performance in face cognition abilities. They can rather be taken as indicators of the change in activation of particular neural sub-processes over time that contribute more or less to variations on the behavioral level.

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Theoretical considerations

Herzmann, G. & Sommer, W. (2007). Memory-related ERP components for experimentally learned faces and names: Characteristics and parallel-test reliabilities. *Psychophysiology, 44,* 262-276.

Study 1

Herzmann, G. & Sommer, W. (in preparation). Biographical knowledge affects face recognition at multiple levels: An ERP investigation of newly learned faces.

Study 2

Herzmann, G., Danthiir, V., Schacht, A., Sommer, W., & Wilhelm, O. (2008). Towards a comprehensive test battery for face processing: Assessment of the tasks. *Behavior Research Methods, 40,* 840-857.

Study 3

Wilhelm, O., Herzmann, G., Kunina, O., Danthiir, V., Schacht, A., and Sommer, W. (in preparation). Face cognition: A set of distinct mental abilities.

Studies 3 and 4

Herzmann, G., Kunina, O., Sommer, W., & Wilhelm, O. (submitted). Understanding individual differences in face cognition with event-related brain potentials. *Journal of Cognitive Neuroscience*.

Study 4

Liste der Publikationen und wissenschaftlichen Beiträge

A) Zeitschriften (referiert)

1. Herzmann, G., Danthiir, V., Schacht, A., Sommer, W., & Wilhelm, O. (2008). Towards a comprehensive test battery for face processing: Assessment of the tasks. *Behavior Research Methods, 40,* 840-857.

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3. Herzmann, G., Schweinberger, S. R., Sommer, W., & Jentzsch, I. (2004). What's special about personally familiar faces? A multimodal approach. *Psychophysiology, 41*, 688-701.

B) Zeitschriften (nicht referiert)

1. Wilhelm, O., Herzmann, G., Kunina, O., and Sommer, W. (2007). Face cognition: A set of distinct mental abilities. *Available from Nature Precedings <http://hdl.handle.net/10101/npre.2007.1385.1>*

C) Beträge in Fachbüchern

1. Herzmann, G., Danthiir, V., Wilhelm. O. Sommer, W., & Schacht, A. (2007). Face memory: A cognitive and psychophysiological approach to the assessment of antecedents of emotional intelligence. In G. Matthews, M. Zeidner, & R. Roberts, *The Science of Emotional Intelligence: Knowns and Unknowns*. Oxford: Oxford University Press, Chapter 12, 305-336.

D) Veröffentlichte Konferenz-Abstracts

1. Herzmann, G., Kunina, O., Sommer, W., & Wilhelm, O. (2008). Individual differences in face processing: Psychophysiological indicators. *Abstracts of XXIXth International Congress of Psychology*, Deutschland, 2008.

2. Herzmann, G., Kunina, O., Sommer, W., & Wilhelm, O. (2008). Individual differences in face cognition: Distinct component abilities and basic neural processes. *Abstracts of 8th meeting of the Vision Science Society*, USA, 2008.

3. Herzmann, G., Kunina, O., Sommer, W., & Wilhelm, O. (2007). Individual differences in face processing: Behavioral and psychophysiological indicators. *Abstracts of the 48th meeting of Psychonomic Society*, USA, November 2007.

4. Herzmann, G., Kunina, O., Sommer, W., & Wilhelm, O. (2007). Measuring face processing II: Psychophysiological data. In: Henning, J. et al. (Eds.), *ISSID 07,*

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5. Herzmann, G. & Sommer, W. (2006). The reliability of the Dm as a measure of face encoding into memory. *Journal of Psychophysiology, 20,* Supplement 1.

6. Herzmann, G. & Sommer, W. (2006). Die Reliabilität der Dm – ein Maß der Enkodierung von Gesichtern in's Gedächtnis. In: Hecht, H. et al. (Eds.), *Experimentelle Psychologie. Beiträge zur 48. Tagung experimentell arbeitender Psychologen*, Lengerich: Pabst Publisher.

7. Herzmann, G. & Sommer, W. (2005). The build-up of structural representations for faces and names in long-term memory. *Journal of Cognitive Neuroscience,* Supplement, 66.

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9. Herzmann, G., Schweinberger, S. R., Sommer, W., & Jentzsch, I. (2003). Dual-Routes to face recognition: Evidence from a normal population for a Functional dissociation of affective and cognitive pathways. *Journal of Cognitive Neuroscience*, Supplement, 64.

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E) EINGELADENE VORTRÄGE

Herzmann, G. (2008). Individual differences in face cognition: Using ERPs to determine relationships between neurocognitive and behavioral indicators. Universität Jena, Deutschland

Herzmann, G. (2005). The built-up of new representations for faces and names in long-term memory. Universität Bern, Schweiz

Herzmann, G. (2004). Investigating familiar face recognition using SCR and ERPs. Waseda University, Tokyo, Japan.

F) ORGANISIERTE SYMPOSIEN

Herzmann, G. (2008). Vorgeschlagenes, organisiertes und angenommenes Symposium "Individual Differences in Face Processing" für den XXIX. Weltkongress der Psychologie, 2008, Berlin, Deutschland.

Erklärungen

Hiermit erkläre ich,

- dass ich die vorliegende Arbeit selbstständig und ohne unerlaubte Hilfe verfasst habe,
- dass ich mich nicht anderwärts um einen Doktorgrad beworben habe und keinen Doktorgrad in dem Promotionsfach besitze, und
- dass ich die zugrundeliegende Promotionsordnung vom 3. August 2006 (Amtliches Mitteilungsblatt 34/2006) kenne.

Berlin, den 14. April 2008 Grit Herzmann