Individual and Age-Related Differences in Face-Cognition

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Zusammenfassung

Experimentelle und neurophysiologische Studien weisen auf eine Spezifität der Gesichterkognition hin. In der differentiellen Psychologie wird ein Schwerpunkt auf die Differenzierbarkeit sozio-kognitiver Leistungen von akademischen Fähigkeiten gelegt. Dabei werden bislang kaum Versuche unternommen, Messmodelle zu etablieren, die in neurokognitiven Modellen verankert sind. Basierend auf neuartigen Versuchen zur Etablierung solcher Modelle ist es das Ziel dieser Dissertation, die Robustheit dieser Modelle aus einer entwicklungspsychologischen Perspektive zu betrachten und diese zu erweitern. Zudem werden altersbedingte Leistungsunterschiede in der Gesichterkognition auf der Ebene latenter Faktoren ermittelt und die Hypothese altersbedingter kognitiver Dedifferenzierung mit modernen Methoden kritisch untersucht. Das Hauptziel ist die Erbringung entwicklungspsychologischer Evidenz für die Spezifität der Gesichterkognition. In einem ersten - primär methodologischen - Manuskript wird erstmalig in der Literatur die Implementierung von Funktionen der Beobachtungsgewichtung aus der nicht-parametrischen Regression für Strukturgleichungsanalysen vorgeschlagen. Diese Methode ergänzt Multigruppenanalysen bei der Untersuchung kognitiver Dedifferenzierung. Weitere vier Manuskripte adressieren Fragestellungen zur Gesichterkognition und zeigen: 1) Gesichterwahrnehmung, Gesichtergedächtnis und die Schnelligkeit der Gesichtererkennung sind separierbare Prozesse über die gesamte erwachsene Lebensspanne; 2) die Schnelligkeit der Gesichtererkennung kann nicht von der Schnelligkeit der Emotions- und Objekterkennung faktoriell getrennt werden; 3) Gesichterwahrnehmung und Gesichtergedächtnis können bis zum späten Alter von allgemeinen kognitiven Fähigkeiten getrennt werden, und 4) eine leichte Dedifferenzierung zwischen Objekt- und Gesichterkognition tritt auf der Ebene von Akkuratheitsmessungen auf. Implikationen sind in den Manuskripten ausführlich diskutiert und im Epilog zusammengefasst.

Abstract

Cognitive-experimental and neuropsychological studies provided strong evidence for the specificity of face cognition. In individual differences research, face tasks are used within a broader variety of tasks, usually with the intention to measure some social skills. Contemporary individual differences research still focuses on the distinction between social-emotional vs. academic intelligence, rather than establishing measurement models with a solid basis in experimental and neuropsychological work. Building upon recent efforts to establish such measurement models this dissertation aimed to extend available models and assess their robustness across age. Furthermore, it investigates mean age differences for latent factors, critically looks at phenomena of dedifferentiation with novel and innovative analytic methods, and attempts to provide more evidence on the uniqueness and communalities of face cognition throughout adulthood. In a first primarily methodological manuscript, we propose for the first time in the literature an implementation of functions to weight observations used in nonparametric regression approaches into structural equation modeling context, which can fruitfully complement traditionally used multiple-group approaches to investigate factorial dedifferentiation. In the following four manuscripts, we investigated individual and age-differences in face cognition. Results show that: 1). Face perception, face memory and the speed of face cognition remain differentiable throughout adulthood; 2). The speed of face cognition is not differentiable from the speed of perceiving emotional expressions in the face and complex objects, like houses; 3). Face perception and memory are clearly differentiable from abstract cognition throughout adulthood; and 4). A slight dedifferentiation occurs between face and object cognition. Implications are discussed in the manuscripts and the epilogue.

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I. Prologue

1. Introduction

Different disciplines of psychology implement particular approaches to investigate the specificity of constructs. In neuropsychology, processes are considered specific if they are localized in distinct areas of the brain. In experimental psychology, processes are considered dissociated if they differentially respond to experimental manipulations. In differential psychology, measures are taken to capture different dispositions if they have different loading patterns in a factor analysis. In developmental psychology, processes are considered distinct if they have divergent developmental trajectories (Oberauer, Wilhelm, & Schmiedek, 2005). Questions regarding the specificity or overlap of cognitive constructs are prevalent in psychological research and the above mentioned approaches to the investigation of constructs' specificity do not necessarily coincide in their conclusions.

In this dissertation, I will investigate the specificity of face cognition from an individual differences and a developmental perspective. Both of these perspectives were neglected in face cognition research. From a neurophysiological point of view the distinctiveness of face cognition is supported by evidence on dedicated brain regions in the fusiform gyrus (fusiform face area), where face processing is mainly carried out (Kanwisher, McDermott, & Chun, 1997). Importantly, this does not imply that individual differences in face, object or abstract cognition are differently organized, because it might happen that the source of variance across people "affects processing efficiency in different parts of the cortex in the same way" (Oberauer et al., 2005, p. 127). Applying the same rational, if aging affects brain activity by changing the localization pattern of processes found in young adults, this does not imply that correlations between tasks measuring different constructs will also change their pattern. Due to the different meanings of research findings based on neuroimaging and brain damage studies, experimental effects or individual differences data, it is essential to investigate the status of a construct from multiple perspectives before classifying a construct as being specific or before deriving conclusions that go beyond what is justified by the available evidence. The debate on the specificity of face cognition is restricted to cognitive-experimental and neurophysiological research. I will argue that the investigation of the specificity of face cognition from an individual differences and developmental perspective with up to date analytical tools is a highly important concern, because it provides critical evidence on the validity and utility of measures of face cognition.

In cognitive experimental and neuropsychology, face cognition is considered a modular (content domain specific) cognitive system (e.g., Kanwisher, 2000). The view of modular systems was coined by Fodor (1983), who discussed the organization of the cognitive system based on a) the involved processing components, not influenced by content domain specificity (horizontal perspective) and b) the content domain specificity of the input (vertical perspective). Within the vertical perspective, autonomous computational systems for different content domains are postulated, associated with specialized brain structures. Fodor (1983) claimed that the mind is modularly organized. His notion of modularity, initially restricted to the visual input (low-level processing), has been revised and extended to so-called "higher-level" processes (see Barrett & Kurzban, 2006, for a review). By now a series of modular systems was proposed beside language (the putative modular system): spatial orientation (Hermer & Spelke, 1996), number (Dehaene & Cohen, 1995), theory of mind (Baron-Cohen, 1995) and face processing (e.g., Kanwisher, 2000) – just to name some of the list revised by Barrett and Kurzban (2006).

The concept of modularity of the cognitive system is debatable, because there is for example vast evidence from individual differences research demonstrating content heterogeneous factors, which are organized by the cognitive demands of tasks. A more appropriate theoretical framework of classifying cognitive tasks was offered within the facet theory (Canter, 1985; Guttman, 1954), suggesting that cognitive performance is organized across several dimensions (facets). For example, the facet model of working memory by Oberauer, Süß, Wilhelm, and Wittmann (2003) postulates function (simultaneous storage and processing, relational integration and supervision) and content facets (verbal-numerical and spatial). In line with the facet view, face cognition will be considered in the present dissertation as being specific by its special content, but overlapping with the processing of abstract material by its function-based facets.

1.1. The Broader Theoretical Context – Fluid vs. Social Intelligence and Social Cognition

In the literature on academic intelligence, ability constructs are primarily categorized according to the cognitive functions they involve and are considered domain general or content heterogeneous. In the influential work by Carroll (1993), abilities within the domain of reasoning, of memory and learning, of visual perception, of auditory reception, of idea production, of cognitive speed, of knowledge and achievement and psychomotor abilities are included. Carroll (1993) claimed that cognitive abilities “are to be explained in terms of concepts of cognitive psychology” (Carroll, 1993, p. 71), thus in terms of “components of cognitive architectures” (Kyllonen, 1995; 2002).

Why is that important for the present work on face cognition? The papers included in this dissertation attempt to continue establishing ability constructs of face cognition, which are clearly differentiable but expectedly related to fluid abilities and object cognition (Wilhelm et al., in press). Therefore, this dissertation is an attempt to fortify these constructs within the structure of human cognitive abilities, warranted by their special (social) content – human faces. The focus is primarily on lifespan aspects. Supposedly, cognitive demands involved in tasks tapping face cognition are mainly overlapping with the demands imposed by fluid ability measures. They all include perception, encoding and recognition. Given there is fairly well-founded evidence on the specificity of face cognition from neurophysiological and experimental research it is well worth making an attempt to include face cognition into the realm of factor referenced human cognitive abilities.

In social-cognitive research, the assumption of content specificity of intrinsically social stimuli is kind of self-evident. Social cognition was defined as "cognitive function which underlies smooth social interactions by understanding and processing interpersonal cues and planning appropriate responses" (Scourfield, Martin, Lewis, & McGuffin, 1999, p. 559). Within the social-cognitive framework, the distinction between lower vs. higher-level processing is also prevalent. Face cognition (face processing, emotion recognition) has been conceptualized as a lower-level component of social cognition – also referred to as a social function (Yager & Ehmann, 2002). Faces are social cues and their perception and recognition is a prerequisite for completing complex social-cognitive processes, for example understanding mental states (Beauchamp & Anderson, 2010). Herzmann, Danthiir, Wilhelm, Sommer and Schacht (2007) followed an analog rationale as they refer to their research on face cognition and its embedment into the study-field of emotional intelligence as being an "atomistic, hands-on, and down-to-earth" approach (p. 307) in substantiating basic processes of a broad concept like emotional intelligence.

Summing up, face cognition is considered a basic component of social cognition and social intelligence. Furthermore, it can be considered constituting a prerequisite for emotional intelligence. Thus, investigating individual differences in face cognition and its structural change across the lifespan aims to substantiate knowledge about a basic level construct that might help understanding higher-level (more complex) constructs like social and emotional intelligence or even social cognition, as defined in social psychological research.

1.2. The Narrower Theoretical Context – Models of Face Processing

Functional models of face cognition (Bruce & Young, 1986; Burton, Bruce, & Hancock, 1999; Burton, Bruce, & Johnston, 1990; Calder & Young, 2005) offer theoretical accounts for the understanding of the information processing stages involved in recognizing persons. Their postulated architecture goes beyond the processing stages of face familiarity decisions. The focus in this dissertation will be on the stages of face recognition postulated by functional models because these stages are critical for the research presented here. Functional models also address the processing of emotion related information displayed in faces. Predictions from functional models of face cognition concerning such emotion processing will be derived below.

Bruce and Young (1986) proposed a widely cited and popular functional model of person recognition. Their model has two main characteristics. First, it has a branching structure, as it considers two different pathways of processing facial identity information vs. changeable aspects (e.g., expression analysis, facial speech analysis) of a face. Second, it postulates a hierarchical structure, thus a sequence of consecutively occurring processes (e.g., structural encoding, activation of face recognition units), in which earlier steps mediate later processing stages.

Neuroanatomical models were proposed to describe neural underpinnings of face recognition. Haxby, Hoffman, and Gobbini (2000) advanced a model compatible with the functional model proposed by Bruce and Young (1986). The core system, responsible for the visual analyses of faces, bifurcates into two functionally and anatomically distinct pathways of coding changeable vs. invariant facial aspects. Identity coding involves the lateral fusiform gyrus, whereas the coding of changeable facial aspects is mainly carried out in the superior temporal sulcus. The inferior occipital gyrus provides input into both systems, suggesting a hierarchical structure.

More recently, Calder and Young (2005) reconsidered the assumption of early branching of the identity and expression pathways in face processing. They revised the accumulated knowledge in the field, suggesting “some separation” but no completely independent processing pathways. One way to quantify the level of their dependence is to consider individual differences within a multivariate approach of the two information-processing pathways – such an approach is currently missing in research on face cognition.

1.3. Sources of Individual Differences in Face Cognition – Established Factors and Outstanding Issues

There are fruitful examples in the literature deriving individual differences constructs based on information-processing models advanced in cognitive psychology (see e.g., Kyllonen, 2002). Thus, functional and neuroanatomical models outlined above can be used to identify possible sources of individual differences in face cognition and multiple tasks can be developed to measure them. Herzmann, Danthiir, Schacht, Sommer, and Wilhelm (2008) and Wilhelm et al. (in press) followed such an approach and developed a multivariate task battery measuring face cognition as postulated by functional models. They differentiated *face perception* – representing structural encoding of feature and configuration based information extracted from faces – and *face memory* (learning and recognition) – representing the establishment and subsequent activation of FRUs. Furthermore, they considered the distinction between the speed and accuracy of performance in order to capture the prominent distinction also made in research on abstract cognitive abilities (e.g., Carroll, 1993). Thus, more difficult perception and learning-recognition tasks were developed as accuracy measures. Less difficult tasks were included in the task battery by Herzmann et al. (2008) in order to capture the speed of perceiving and recognizing faces. Tasks were derived from or based on experimental research on face processing, including the measurement of well-known effects like the *part-whole recognition effect* (e.g. Tanaka & Farah, 1993), the *face inversion effect* (e.g. Yin, 1969) and the *composite face effect* (Young, Hellawell, & Hay, 1987). Wilhelm et al. (in press) established a three factorial model of face cognition that distinguish *face perception*, *face memory* and the *speed of face cognition*. Regarding performance speed there was no need of factorial differentiation between perception and recognition.

Wilhelm et al. (in press) established individual differences factors covering processing stages of face identity information. Further multivariate studies are needed to establish factors postulated within the branching structure of functional models. For example, it is unclear whether or not invariant vs. changeable aspects of faces converge in terms of individual differences or developmental trajectories. Sources of individual differences and differential lifespan trajectories might also be localized at perceptual, encoding, and decoding stages of changeable facial aspects. Subsequent to the establishment of factors for the processing pathway of changeable facial aspects their interdependency from processing invariant facial aspects could be quantified and theoretical assumptions of functional models might be validated on larger samples within an individual differences and developmental approach.

1.4. Specificity of Face Processing in the Light of Age-Related Cognitive Dedifferentiation

Establishing latent factors is a prerequisite to establish individual differences constructs in line with neurocognitive models of face cognition. In order to provide credibility to such factors it is important to provide evidence on discriminant and incremental validity (i.e. evidence that proposed abilities are not redundant with established constructs and predict something of importance over and above the prediction provided by academic ability constructs). Wilhelm et al. (in press) successfully differentiated face cognition from abilities like reasoning, immediate and delayed memory, mental speed and object cognition in a sample of young adults, providing strong evidence on the specificity of face cognition from an individual differences perspective. So far, such evidence was only provided through experimental and neurophysiological studies. We leave research questions concerning incremental validity to future research.

It is unclear, whether or not the specificity of face cognition maintains across the adult lifespan. Behavioral research on age-related cognitive dedifferentiation and evidence of neural dedifferentiation in older brains (see 2.2 and 2.5 and attendant manuscripts for details), makes it conceivable that the factorial structure of face cognition and/or the relation of face cognition with academic intelligence and object cognition increase across adult age.

1.5. Age-Related Performance Differences in Face Cognition

Although, there is evidence on age-related performance decrements in face perception and face recognition (see 2.2 and the attendant manuscript for details), available studies mainly rely on single task design. These studies cannot consider measurement error and potential changes in covariance structures as multivariate approaches like latent variable techniques can. Implementing methodologically more sophisticated approaches and showing measurement invariance across age, eliminates the risk that tasks might measure distinct constructs or distinct abilities across different age groups.

Within experimental research, several efforts were made to explain age-related decrements in face cognition by providing a series of face specific assertions (see Boutet & Faubert, 2006, for a review). We argue that prior to endorsing face specific explanations of processing deficits in older compared to younger age, it has to be shown within multivariate studies, whether such decrements persist after taking age-related general cognitive decline into account. There is no comprehensive approach to this question published in the literature yet.

2. Research Questions and Overview of the Included Manuscripts

A series of five manuscripts are included in the present dissertation. The first manuscript considers analytical issues regarding invariance testing along continuous context variables like age. The following four manuscripts examine different substantive research questions regarding the structure and specificity of face cognition from an individual differences and cross-sectional lifespan perspective. They all aim to fill some of the gaps in the literature on the specificity of face cognition abilities, outlined above.

2.1. Manuscript 1: Complementary and Competing Factor Analytic Approaches for the Investigation of Measurement Invariance

Traditionally, research questions concerning measurement and factorial invariance are investigated by means of multiple-group models. Such models build upon natural (e.g. gender) but often also artificial categories of contextual variables (e.g. age), defining groups for analytical purpose. In cross-sectional aging research, there is a vast literature implementing an extreme-group design, comparing younger vs. older adults by means of multiple-group models. There are also studies based on observations along a continuous age variable (for example where persons between 20 and 80 years were tested). In such studies, multiple-group models that build upon artificial age groups are commonly used. However, such an approach is usually associated with severe information loss.

In the first manuscript, we present and discuss two novel analytical approaches of invariance testing for continuous context variables: Latent Moderated Structural Equations and Local Structural Equation Models, both allowing contextual factors to be treated as continuous variables and both are adequate tools to detect non-linear relations. These analytical approaches were implemented in the manuscripts investigating face cognition across age (manuscript 2, 3 and 5). The paper was peer-reviewed and published in *Review of Psychology*.

2.2. Manuscript 2: Structural Invariance and Age-Related Performance Differences in Face Cognition

Based on previous research by Wilhelm et al. (in press) in this manuscript we investigated age-related changes in the covariance structure of face cognition abilities, considering the relationship of face perception, face memory and the speed of face cognition, after establishing measurement invariance. Furthermore, we aimed to examine age-related performance differences using multivariate parametric techniques. With such an approach, possible covariance changes can be taken into account before investigating age-differences at the level of means. Given, currently available studies on age-differences in face perception and face recognition are single task studies based on small samples and restricted to mean comparisons of observed variables, the present paper aims to go beyond all of these obstacles. The manuscript was submitted to *Psychology and Aging* – where it went through a peer review process and was accepted for publication.

2.3. Manuscript 3: Face and Object Cognition across Adult Age

There is a vast experimental and neuropsychological literature debating the specificity of face relative to object cognition. Individual differences and developmental approaches are completely neglected in this field. Manuscript 3 aimed to investigate the relationship of three face cognition factors (perception, memory and speed) to object perception and the speed of object cognition across age. The manuscript was submitted for publication.

2.4. Manuscript 4: Measuring the Speed of Recognizing Facially Expressed Emotions

Functional models of person recognition postulate different pathways of processing invariant vs. changeable facial aspects. However, available (predominantly clinical and experimental) data from mostly small samples suggest that there might be a partial independency of those pathways. Manuscript 4 aimed to investigate the relationship of processing neutral faces vs. faces with emotional expressions, by considering individual differences in the speed of performance. This manuscript also feeds into our new research plans of studying the interdependency of the invariant vs. emotion based processing pathways of human faces based on individual differences in accuracy measures. This manuscript was submitted for publication.

2.5. Manuscript 5: On the Specificity of Face Cognition across Adult Age

In a previous paper, Wilhelm et al. (in press) showed that individual differences in face cognition processes could not completely be accounted for by individual differences in abstract cognition. There are controversial findings regarding cognitive dedifferentiation in older age and such studies are restricted to abstract cognitive abilities. In order to more profoundly understand age-related changes in face cognition, it is therefore important to investigate the dedifferentiation of these abilities across age. In manuscript 5, we aimed to examine this issue. In this paper, we also carefully look at age-related performance differences in face cognition after accounting for age-differences in general cognitive functioning. The manuscript was submitted to *Psychology and Aging*, where it was peer-reviewed and recently invited to be resubmitted in a slightly revised form.

II. Manuscript 1

Complementary and Competing Factor Analytic Approaches for the Investigation of Measurement Invariance

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Status: Published (*Review of Psychology*)

Abstract

Sample-related invariance is an important topic in psychometric research. The generalizability of findings in a broad range of application samples requires equivalence of interpretations based on the measurement outcomes across respective samples. Contextual factors like gender, age, culture, ethnicity, socio-economic status etc. may affect the meaning and interpretation of psychological measures. Sample-related invariance is frequently investigated using Multiple-Group Mean and Covariance Structure (MGMCS) analyses. This method builds upon natural or artificial categories of contextual variables. Many contextual variables are continuous variables and their categorization is associated with an information loss and potentially overly simplistic data analyses. We present and discuss two complementary analytical approaches – Latent Moderated Structural (LMS) Equations and Local Structural Equation Models (LSEM). Both approaches allow treating contextual factors as continuous variables and are appropriate to detect non-linear relations. The use of these methods is exemplified based on real data. We investigated measurement equivalence of a battery of cognitive tests across age (N = 448; age range 18-82 years). Based on a higher-order factor model of cognitive abilities factorial equivalence could be established – contradicting the age-dedifferentiation hypothesis. Advantages and disadvantages of MGMCS, LMS, and LSEM and further implementations beyond aging-research are discussed.

III. Manuscript 2

Structural Invariance and Age-Related Performance Differences in Face Cognition

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Status: In press (*Psychology and Aging*)

Abstract

Perceiving and memorizing faces swiftly and correctly are important social competencies. The organization of these interpersonal abilities and how they change across the lifespan are still poorly understood. Here we investigate changes in the mean and covariance structure of face cognition abilities across the adult lifespan. A sample of 448 subjects, with age ranging from 18 to 88 years, completed a battery of 15 face cognition tasks. After establishing a measurement model of face cognition that distinguishes between *face perception*, *face memory*, and the *speed of face cognition*, multiple group models and age-weighted measurement models were used to explore age-related changes. The modelling showed that the loadings and intercepts of all measures are age invariant. The factor means showed substantial decrements with increasing age. Age-related decrements in performance were strongest for the speed of face cognition but were also salient for face perception and face memory. The onset of age decrements is visible in the sixties for face perception, in the late forties for face memory, and in the early thirties for the speed of face cognition. Implications of these findings on a theoretical and methodological level are discussed and potential consequences for applied settings are considered.

IV. Manuscript 3

Face and Object Cognition across Adult Age

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Status: Submitted for publication

Abstract

Face cognition has been suggested to be domain-specific and distinct from object cognition. Individual and age differences research can contribute to this question by determining the amount of overlap between these abilities at the level of constructs. We used confirmatory factor-analytic models to investigate the specificity of speed and accuracy measures for face and object cognition. For an age-heterogeneous sample (*N*=448; Age-range 18-82 years), we found no evidence for a face-specific speed factor. Accuracy measures of face and object cognition were distinguishable and dedifferentiated slightly across the adult lifespan. Vision do not account for dedifferentiation. Theoretical implications are discussed.

V. Manuscript 4

Measuring the Speed of Recognizing Facially Expressed Emotions

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Status: Submitted for publication

Abstract

There is a need for multivariate investigations of face processing abilities. The present study investigated the status of speed tasks of emotion recognition. Analyses are based on a sample of *N* = 151 young adults. First, we established a measurement model with a higher-order factor for the speed of emotion recognition (SER). This model has acceptable fit without specifying emotion-specific relations between indicators. Next, we assessed whether SER can be reliably distinguished from the speed of face cognition (SFC) and found latent factors for SER and SFC to be perfectly correlated. In contrast, SER and SFC were both only moderately related to a latent factor for perceptual speed. We conclude that the processing of facial stimuli – and not the processing of basic emotions – is the critical component of SER. These findings are at variance with suggestions of separate routes for processing facial identity and emotional facial expressions.

VI. Manuscript 5

On the Specificity of Face Cognition across Adult Age

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Abstract

Face cognition is considered a specific human ability, clearly differentiable from general cognitive functioning. Its specificity was primarily suggested by cognitive-experimental and neuroimaging research, but very recently also from an individual differences perspective. No comprehensive behavioral data are however available, which would allow an estimation of lifespan changes of the covariance structure of face cognition abilities and general cognitive functioning and test age-differences in face cognition after accounting for interindividual variability attributed to general cognition. The present study aimed to fill this gap. Based on an age-heterogeneous sample of N = 448 adults, ranging between 18-82 years, we show that no factorial dedifferentiation between face and general cognition occurs and age-related differences in face recognition are also salient after taking general cognitive functioning into account. We conclude that face cognition remains a specific human ability until old age and age-related decrements in learning and recognizing faces cannot be completely explained by age-differences in general cognition. Implications for models on cognitive aging are discussed.

VII. Epilogue

In the epilogue, I will first provide a short summary of the central findings and their theoretical and practical implications described and discussed in detail in the included papers. Second, I will point out lingering gaps in research on individual differences and developmental trajectories regarding face processing abilities. Finally, I will conclude with an overview of future research directions.

1. Summary of Findings

Measurement Model of Face Cognition across the Adult Lifespan

A first research question addressed in this dissertation concerned measurement and structural invariance of face cognition across adult age. In manuscript 2, we showed that *face perception*, *face memory* and the *speed of face cognition* are differentiable processes throughout adulthood. Second, we pointed out age-related performance decrements in face cognition, strongest and earliest occurring for the speed of face cognition, but also noticeable for face memory – salient in the late forties – and face perception – which were visible from the sixties.

Face and Object Cognition across the Adult Lifespan

Third, we pursued the question whether the three face cognition abilities remain differentiable from two object cognition processes (perception and speed) across age. Our findings show that factorial differentiation is not even needed in younger age for speed measures and a slight dedifferentiation along accuracy measures seems to occur across the adult lifespan.

Face and Abstract Cognition across the Adult Lifespan

Fourth, we asked whether face perception and face memory are differentiable from immediate and delayed memory, mental speed and general cognition across adult age. We showed that no age-related factorial dedifferentiation between face and abstract cognition occurs. Fifth, we were able to show that age-related mean differences in learning and recognizing faces are still salient after controlling for age-related decline in general cognitive functioning.

Non-differentiable Speed Factors

Sixth, speed measures seem to be non-differentiable not only regarding the processing of face vs. house stimuli, but also between face cognition and emotion recognition in a sample of younger adults.

2. Implications

Age-Related Cognitive Dedifferentiation and the Specificity Debate of Face Cognition

We pointed out in the introductions of manuscript 2 and 5 that the evidence of ability dedifferentiation in older relative to younger adults is equivocal. The investigation of factorial dedifferentiation was limited to the domain of abstract cognitive abilities until now. A few studies on neural dedifferentiation in older age were carried out, including the investigation of face processing. The results of these studies suggest that neural specificity in the fusiform face area might be maintained until old age, despite occurring co-activation in the frontal cortex (see manuscript 5). Our findings, suggesting lack of age-related factorial dedifferentiation between face and abstract cognition presented in manuscript 5 and results suggesting a slight dedifferentiation between face and object cognition are informative for both, the age-related cognitive dedifferentiation hypothesis and for the debate on specificity of face cognition (i.e. the broader theoretical context of several suggested modularly organized cognitive systems).

In developmental and lifespan psychology, it was argued that domain-specific processes influence cognitive growth that leads to less related abilities in later, compared to younger childhood age. Conversely, general mechanisms cause cognitive decline, leading to more strongly related cognitive abilities in older age. Our results suggest that the influence of general cognitive functioning on face specific abilities does not increase across adult age. Furthermore, our data also suggest a lack of dedifferentiation within the domain of abstract (general) cognition. Thus, the data provide further empirical support *against* the dedifferentiation hypothesis. The results are in line with neuroimaging data, which endorse dedifferentiation of the *place* area within the ventral visual cortex, however partly maintained activation within the face area in old age (see manuscript 5 for details).

The debate on the specificity of face processing was restricted to experimental and neurophysiological studies and we extended this debate to psychometric and developmental research, in the context of social vs. abstract abilities. Lifespan changes of the relation between face cognition abilities and other cognitive abilities were not investigated in prior research. We filled this gap, and provided evidence on the sustained specificity of face perception and face memory processes. It is important to note that this evidence does not entail the speed of face cognition (i.e. speed of face cognition is not specific). The factorial distinctiveness of a basic social ability construct like face cognition is only salient for accuracy measures. It should be however mentioned, that our data do not dispel the expertise view, suggesting that the brain- and behavior-based specificity of face cognition might be due to the fact that humans are experts in face recognition (see manuscript 3). However at this point, our results support the specificity view of face cognition from an individual differences and lifespan perspective.

Distinct Pathways of Processing Invariant vs. Changeable Facial Aspects

Functional models of person recognition postulate distinct pathways of processing invariant vs. changeable facial aspects such as emotion recognition. Data presented in manuscript 4 strongly endorse completely overlapping pathways for speed measures with regard to individual differences. It would be interesting to pursue the idea of a partial distinctiveness of the pathways based on accuracy measures in future research. Another important implication of manuscript 4 was that measures of facial emotion recognition should not be restricted to speed measures.

Implications for Applied Research

The specificity of the accuracy of perception and memory for faces is a mandatory prerequisite for achieving incremental validity in applied settings. Given the intrinsically social nature of face perception and face memory, the use of such measures might provide utility in a variety of settings. In personnel selection, face perception and face memory might contribute to the prediction of job performance in professions in which the accuracy of face perception and face memory is important. Our findings of age-related decrements in face memory after accounting for a broad variety of further cognitive abilities suggest that training programs for older adults might also include specific tutorials for basic social abilities, like face memory. On the other side, available evidence on the trainability of face memory is sparse, but reported results might be to some extent due to insufficient measurement of face cognition abilities in pre- and posttest (see also the discussion in manuscript 2).

3. Future Directions

Measuring Object Cognition

Conclusions regarding dedifferentiation between accuracy measures of face vs. object cognition presented in manuscript 3 are somewhat limited by the fact that only object perception but no object memory measures were included in the study. Thus, investigations of the specificity and lifespan changes of the relation between face and object cognition should be extended to object memory tasks in future research.

Expertise View and the Specificity of Face Cognition

The specificity of face cognition within neurophysiological and experimental research was mainly challenged by the expertise view. Investigating individual differences in large samples of experts of say greebles, trained under laboratory conditions, and subsequently comparing their ability structure of face vs. object cognition with the structure established for "only" face experts (not trained for greebles), might be an important contribution to the specificity debate from the expertise point of view. This would go beyond hitherto available conclusions in the literature based only on comparisons of mean level performance (see manuscript 3).

Extension to Longitudinal Design

Conclusions regarding lifespan changes of the relation of face, abstract and object cognition are limited by the cross-sectional nature of the presented data. These cross-sectional results are only proxies of intra-individual changes. All things considered, we would however not expect major changes of the present results in such longitudinal studies.

Measuring Facial Expression Processing

The marrowy conclusion made in manuscript 4, regarding non-differentiable pathways of processing face identity information vs. facially expressed emotions, invalidate a series of studies on emotion recognition, using intrinsically speed measures in order to overcome the measurement problem due to high accuracy levels in recognizing basic emotions. Furthermore, it should be noted that a series of cognitive-experimental studies aiming to validate functional models of face processing rely on speed data and all these are challenged by the findings presented in manuscript 4.

Our conclusions regarding non-differentiable pathways of processing faces with neutral vs. emotional expressions are limited by the fact that only speed measures were included in the study described in manuscript 4. There is need for extensions to accuracy tasks in future research in order to provide more founded conclusion regarding the specificity of facial emotion processing. This is an aim of our ongoing research.

Embedding Face Cognition into the Broader Context of Measuring Social and Emotional Abilities

Finally, there is need to embed the present research on face cognition into the broader context of measuring social and emotional abilities and provide evidence on incremental validity of the specific measures proposed in our research so far. Based on progress in the field of measuring social and emotional skills, it is an aim of our ongoing studies to embed face cognition abilities into their structure.

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