Individual Differences in Perceiving and Recognizing Faces—One Element of Social Cognition

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Recognizing faces swiftly and accurately is of paramount importance to humans as a social species. Individual differences in the ability to perform these tasks may therefore reflect important aspects of social or emotional intelligence. Although functional models of face cognition based on group and single case studies postulate multiple component processes, little is known about the ability structure underlying individual differences in face cognition. In 2 large individual differences experiments ($N = 151$ and $N = 209$), a broad variety of face-cognition tasks were tested and the component abilities of face cognition—face perception, face memory, and the speed of face cognition—were identified and then replicated. Experiment 2 also showed that the 3 face-cognition abilities are clearly distinct from immediate and delayed memory, mental speed, general cognitive ability, and object cognition. These results converge with functional and neuroanatomical models of face cognition by demonstrating the difference between face perception and face memory. The results also underline the importance of distinguishing between speed and accuracy of face cognition. Together our results provide a first step toward establishing face-processing abilities as an independent ability reflecting elements of social intelligence.

Keywords: face perception, face memory, speed of face cognition

I never forget a face, but in your case I'll be glad to make an exception.
—Groucho Marx

The human face is of supreme importance for many aspects of social interaction and communication. Face-related issues thus receive much attention in current research (see Dekowska, Kuniecki, & Jaskowski, 2008; Hari & Kujala, 2009; Leppänen & Nelson, 2009, for recent reviews). Surprisingly, individual differences in face-related social cognitive abilities have been largely neglected. The present studies establish the abilities of perceiving and recognizing faces and demonstrate their independence from nonsocial cognitive abilities. Although we focus on only two of many possible aspects of face cognition, we regard these abilities as fundamental and highly important for social cognition. We hope their investigation paves the ground for more extended research.

Besides language, to humans as a social species the face arguably represents the most important social signal, conveying a host of highly relevant information. Many emotional facial expressions are universal signals of mental states (Keltner, Ekman, Gonzaga, & Beer, 2003) that may indicate, for example, the presence of danger in the environment (fear expressions) or potentially aggressive behavior (anger expressions). However, facial expressions also serve paralinguistic functions in communicating emotion states to others (Fridlund, 1994). Emotional facial expressions are processed rapidly and with high priority by the observer (Pourtois, Grandjean, Sander, & Vuilleumier, 2004; Vuilleumier, 2005). Facial mimicry—the mutual imitation of facial expressions—is flexibly adapted to the social context and supports social coordination (Bourgeois & Hess, 2008). Additionally, faces are an important basis for classifying people by race (Levin, 1996) and making social evaluations with respect to sympathy (Ito & Urland, 2005), thereby triggering social and racial stereotypes. Finally and most importantly, faces signal the identity of a person, giving

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access to biographical information of social partners and their names and eliciting an affective response to familiar individuals (Breen, Caine, & Coltheart, 2000; Ellis & Lewis, 2001).

In the remainder of the introduction we focus on three aspects. First, we explain why investigating face processing within the broader context of social intelligence is a relevant goal. Second, we describe the theoretical background of the present research in cognitive models of face processing. Third, we describe the methodological requirements for measuring face-processing abilities, specify our general aims, and proceed with describing the present methodological approach in (a) measuring face-cognition abilities and (b) relating them to established cognitive ability factors.

In recent debates it has been suggested that established and validated concepts of human cognitive abilities (Carroll, 1993) should be expanded to include aspects of performance in social and emotional contexts (e.g., Matthews, Zeidner, & Roberts, 2007). Performance subsumed under the labels *social intelligence* (Kihlstrom, & Cantor, 2000; Weis & Süß, 2007) and *emotional intelligence* (Salovey & Mayer, 1990) is intrinsically interpersonal. Capturing the gist of social or emotional intelligence has been one of the major psychometric challenges in the last 2 decades. Taken together, it does not seem that the field of measuring these social faculties has succeeded in terms of strict assessment standards (Matthews, Roberts, & Zeidner, 2004; Van Rooy, Viswesvaran, & Pluta, 2005; Wilhelm, 2005). The core measurement issues are (a) fundamentally diverging measurement concepts, as manifested in self-report versus maximal behavior assessments of emotional intelligence; (b) insufficient evidence on the quality of measurement models and convergent and divergent relations of new measurement instruments; and (c) scoring issues induced through the lack of an unequivocally veridical response standard (Schulze, Wilhelm, & Kyllonen, 2007).

In the two experiments herein, we focused on specific aspects of social cognition: perceiving and recognizing faces swiftly and accurately. These abilities were measured exclusively through maximal behavior assessments. The quality of the measures was evaluated in measurement models, and hypotheses about convergent and discriminant relations were tested. Scoring problems prevalent in measures of emotional intelligence were avoided because for each item in each indicator there was a veridical response. Additionally, the indicators under investigation were derivatives of tasks used in experimental and neurocognitive research as measures of specific processes of face cognition. The indicators therefore had a comparatively strong background in more basic theories of face cognition.

Our pursuit of the core aim—to establish abilities of face cognition as new and hitherto inadequately assessed ability constructs in the social domain—was twofold. We wanted to (a) establish measurement models for face-cognition tasks that had been derived from cognitive theories and (b) show that the proposed abilities cannot be entirely accounted for by established cognitive abilities. Establishing face cognition as a unique social cognitive ability must take into consideration experimental and clinical studies as well as cognitive models of face processes derived from these studies. We now discuss the theoretical background of the present research with regard to cognitive models of face processing.

Experimental and Theoretical Background of Face Cognition

The idea that individual differences in face-cognition abilities need to be distinguished from established abilities, such as reasoning and object cognition, is supported by evidence from several fields. Newborn human infants demonstrate a visual preference for both real and schematic human faces over almost any other category of stimulus (Pascalis & Kelly, 2009). Face processing is supported by dedicated brain systems (Dekowska et al., 2008); thus, Johnson (2005) argued for a subcortical face-detection system—involving the superior colliculus, pulvinar, and amygdala—to support cortical face-identification systems in the fusiform gyrus and inferior occipital gyrus. Kanwisher and colleagues (e.g., Kanwisher, McDermott, & Chun, 1997) suggested the existence of a specialized area for face processing within the fusiform gyrus, the fusiform face area, which is not involved in object processing. The existence of such dedicated brain systems for face processing is supported by clinical studies of brain-damaged patients with double dissociations between the perception and memory of faces and other visual objects (e.g., Farah, Wilson, Drain, & Tanaka, 1998).

The neurocognitive models used as a starting point for the present endeavor make suggestions about the systems and processes involved in perceiving and recognizing familiar faces (Breen et al., 2000; Bruce & Young, 1986; Burton, Bruce, & Johnston, 1990; Ellis & Lewis, 2001) and describe the neuroanatomical substrates underlying these functions (Gobbini & Haxby, 2007; Haxby, Hoffman, & Gobbini, 2000). The processes assumed in most of these models will be briefly outlined below because they were our guidelines for the development of the tasks used in both experiments.

Perceiving faces requires the extraction and short-term storage of structural codes. When a face is seen, *pictorial codes* are derived from the retinal input; these codes are relatively raw images. Following the derivation of pictorial codes, viewpoint- and expression-independent descriptions (i.e., *structural codes*) of the face are extracted. Structural codes are considered to mediate recognition of familiar faces because they incorporate the facial features and their specific arrangement (configuration), which is required to distinguish individual faces. Several aspects of these high-level visual processes are considered to be of special importance. First-order features are extracted, that is, facial elements, such as the size and shape of the nose or mouth, that can be referred to in relative isolation. The spatial relationships between first-order features, such as the distance between the nose and mouth, constitute second-order, or configurational, features. Finally, faces may also be perceived and represented holistically (Farah et al., 1998).

Face recognition units (FRUs) for each familiar face are an interconnected set of structural codes stored within long-term memory (Bruce & Young, 1986). A face is recognized as familiar when the structural codes derived during visual perception match the representations stored within an FRU. *Recognizing faces* thus requires the maintenance of structural codes stored within FRUs, the comparison of stored and currently perceived facial structures, and the correct reactivation of the corresponding FRUs.

In the majority of studies, face recognition is tested with preexperimentally familiar faces, for example, faces of celebrities, friends, or relatives (e.g., Bruce & Valentine, 1985; Bruce & Young, 1986).

However, using preexperimentally familiar faces makes it difficult to control both (a) the frequency, intensity, and duration of exposure to these faces between items and participants and (b) the availability and type of additional information about these people. All these potential effects are likely to cause substantial construct-irrelevant variance in test performance. Ideally, one should use initially unfamiliar faces that are learned within an experimentally controlled setting prior to testing. Although using newly learned faces will lack many properties associated with faces that have been learned over many years, it is likely that they not only provide superior experimental control but also allow more pure capturing of essential aspects of face perception and face recognition.

Both experiments focus on individual differences in face perception and face memory, encompassing face learning and face recognition. We consider these abilities as primary and important not only for other aspects of face cognition but also for social cognition. Because of the fundamental characteristic of face perception and face memory, we believe that it is important to better understand these constructs before investigating other face-processing aspects, such as the recognition of facially expressed emotion, facial speech analysis, and access to biographical facts and names of persons. We now outline methodological requirements for measuring face processing from an individual-differences perspective.

Methodological Requirements for Measuring Face-Processing Abilities

Despite the amount of experimental, cognitive, and neuroscientific research, there are no widely accepted psychometric models of individual differences in face cognition. The dimensionality of a mental function such as face cognition can be determined only by studying individual differences in a broad variety of indicators. Existing tests of face cognition are not well suited for this purpose because they use only highly specific performance indicators derived from just one task (e.g., Duchaine & Nakayama, 2006). Through reliance on several indicators it is possible to transcend specificities of single indicators and to measure a more general ability such as face memory. With confirmatory factor analysis (Bollen, 1989) common variances between indicators can be modeled as latent factors, which are considered to reflect mental abilities that cannot be measured directly. Confirmatory measurement models allow for testing the exhaustiveness of a solution and examining the relationships with established abilities. Using several indicators that supposedly measure the same or different abilities allows for strict tests of measurement models.

In addition, it is important that face-cognition indicators draw predominantly on face-specific processes. The recognition of famous faces (Fast, Fujiwara, & Markowitsch, 2005) is conceptually problematic because it neglects differential prior exposure to the stimuli. Many researchers have used portraits that also depict irrelevant objects such as body parts, clothing, or hair (e.g., Benton & Van Allen, 1968; Warrington, 1984)—an objection that also pertains to most memory tests that include subtests for memory of faces (beginning with Moss & Hunt, 1927).

Aims of the Present Studies

It is unclear whether the component processes suggested in models of face cognition correspond to distinct abilities and, if so, how strongly they are related with each other. It is also unclear how abilities of face cognition relate to other cognitive abilities, such as object cognition or mental speed. Our first aim was therefore to establish a model that adequately captures individual differences in the most relevant aspects of face cognition. The second aim was to ensure that face cognition cannot be accounted for by established abilities such as immediate and delayed memory, mental speed, object cognition, and general cognitive ability.

Measurement Model

With respect to the first aim, we proposed a measurement model for face cognition, which suggests two fundamental distinctions that can be applied to indicators of face cognition. The first distinction is based on functional and neuroanatomical models of face cognition. These models postulate a strong dissociation between perception and memory of faces. Functional models (e.g., Calder & Young, 2005) distinguish between a structural encoding stage, which represents processes of face perception, and the stages of FRU activation, which mediate processes of face memory. Neuroanatomical models (e.g., Gobbini & Haxby, 2007) propose different brain areas underlying face perception and face memory. Here we tested the hypothesis that face perception and face memory can also be dissociated on the level of individual differences.

The second distinction is derived from intelligence research. For measures of cognitive abilities, the difference between speed and accuracy performance is the most fundamental distinction (Carroll, 1993; Furneaux, 1952). Speed indicators are variables that are so easy that everyone in the population of interest solves all items correctly, if given enough time. For these indicators, the amount of time required per correct response is the index of performance. Accuracy indicators—scored as the number of correct responses—are so difficult that a substantial proportion of the population solves many indicators incorrectly, even if given unlimited time. The importance of distinguishing speed and accuracy of behavior is well established in ability research (e.g., Carroll, 1993), but it has been neglected in previous face-cognition studies. Therefore, we expected to find two kinds of latent factors for abilities of face cognition: one related to the accuracy, and the other to the speed, of face cognition.

Therefore, we propose that a model of face-cognition abilities should dissociate face perception and face memory within the speed and accuracy indicators. The postulated model can be contrasted to other conceivable models, some of which can be obtained by constraining one or more of the free parameters in the proposed model. Beginning with the simplest one, a family of models can be derived. These models can be compared inferentially and descriptively. Significant difference values in inferential tests indicate that the less restrictive model fits the data better than does the more restrictive model. If this is not the case, the more constrained model has to be preferred because it is more parsimonious.

Figure 1 displays a family of measurement models for face cognition, derived from the distinctions in face cognition be-

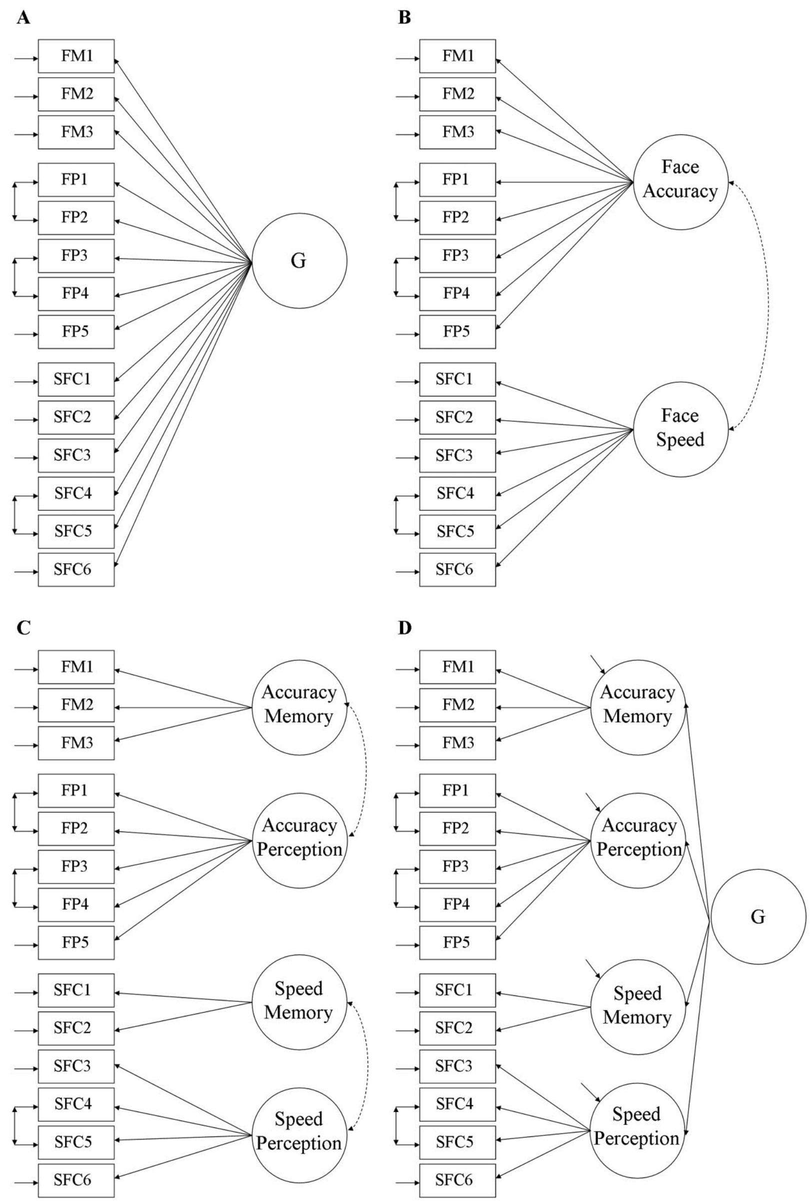

Figure 1. A family of measurement models for face cognition. A: Model 1, the simplest model, postulates a single latent factor of face cognition (G). B: Models 2a and 2b, which postulate two factors: the first accounting for communalities between all speed indicators and the second accounting for communalities between all accuracy measures. The dashed arrow indicates that both factors are uncorrelated in Model 2a and are correlated in Model 2b. C: Models 3a and 3b, which postulate four factors. In these models each of the two factors from Model 2a is split into two factors, one accounting for indicators of perceptual processes and the other accounting for indicators of memory processes. Both accuracy factors and both speed factors are uncorrelated in Model 3a and correlated in Model 3b, again indicated by dashed arrows. D: Model 3c, which postulates the same factors as Model 3a and in addition assumes a higher order factor that accounts for the communality of the 4 first-order latent factors. The second arrow for each of the lower order factors refers to systematic variance not accounted for by the higher order factor. Error variables for indicators from a particular task were allowed to correlate with each other because the latent variables cannot be expected to account for this highly indicator-specific variance. FM = face memory; FP = face perception; SFC = speed of face cognition.

tween face perception and face memory, on the one hand, and speed and accuracy, on the other hand. Panel A shows the simplest model that ignores these distinctions and postulates a single latent factor of face cognition. This factor is assumed to account for the communalities between all 14 indicators used in our experiments. Model 2 (see Figure 1, Panel B) postulates two factors: one accounting for communalities between all speed indicators and the other accounting for communalities between all accuracy measures. These factors are uncorrelated in Model 2a and correlated in Model 2b. Model 3 (see Figure 1, Panels C and D) postulates four first-order factors. Each of the two factors from Model 2a is split into two factors, one accounting for memory indicators and the other for perception indicators. There are only two indicators supposedly measuring the speed of face memory. In order to obviate model identification issues, we constrained the loadings of these indicators to equality if necessary. In Model 3a, all four latent factors are uncorrelated. In Model 3b, the factors for face perception and face memory are correlated within but not across the speed and accuracy domains. In Model 3c, the correlation among the four first-order factors is accounted for by a second-order factor. These three models represent competing theoretical accounts of individual differences in face cognition.

A comparison between Models 1 and 2a tests for the relevance of the difference between speed and accuracy in face cognition. The comparison between Models 2a and 2b tests whether the correlation between speed and accuracy is different from zero. The comparison between Models 2b and 3a tests whether perception and memory need to be distinguished within the speed and accuracy domains. Comparing Model 3c with Models 1 and 2a reveals the relevance of lower order specificities in face cognition. Of course, many more models are technically possible. However, relative to these parsimonious models, more elaborate models would be required to nontrivially improve the fit of the model to the data.

Assessing the Uniqueness of Face-Cognition Abilities

With respect to our second aim—the demonstration of the uniqueness of face-cognition abilities from established ability factors—we need to show that face cognition cannot be accounted for by established ability factors. Neurocognitive models of face cognition postulate specific mechanisms and a distinct neuronal implementation of face cognition. Therefore, face cognition is expected to be distinct from established cognitive abilities. On the other side, there is abundant evidence for a positive manifold between any two indicators of cognitive abilities (Carroll, 1993). Face cognition should therefore be conceived as related to established cognitive abilities. These points taken together, we expected moderate relations between face cognition and established ability factors.

In the following sections, we report two experiments with healthy young adults broadly varying in demographic background. In Experiment 1 we investigated the structure of face cognition with a large set of indicators measuring specific components of face cognition. The objectives of this experiment were to test a theoretically derived measurement model and to compare it with competing models. In Experiment 2 we replicated the measurement model of face cognition and included a broad range of indicators for other cognitive abilities, assessing the specificity of face-cognition abilities within structural models.

Experiment 1

Method

Participants. Participants were 151 young adults (80 women) with a mean age of 24.0 years (*SD* = 4.5). They were heterogeneous with respect to educational and occupational background: 22% were high school students, 32% were university students with a variety of majors, 23% had occupations, and 23% were unemployed. All participants were native speakers of German and of European origin. According to the Edinburgh Handedness Inventory (Oldfield, 1971), 92% were right-handed, 6% left-handed, and 2% ambidextrous. Visual acuity of all participants was normal or corrected-to-normal. Participants were recruited via newspaper ads, posters in various institutions, radio broadcast, and invitations by friends.

Stimuli and apparatus. Photographs of Caucasian faces were obtained from different sources and used as target and practice stimuli. Only portraits with neutral expressions and without distinct features or adornments—such as glasses, moles, beards, obvious makeup, or facial marks—were used (for more details see Herzmann, Danthiir, Schacht, Sommer, & Wilhelm, 2008). All portraits were converted to grayscale and edited to the same format, eliminating all non-face-specific cues—for example, clothing, hair, or ears—by fitting them into vertical ellipses of 300 pixels × 200 pixels (7.6 cm × 5.1 cm corresponding to 8.6° × 5.8° visual angle). Trials with female and male faces were balanced in number for all tasks.

Stimuli were presented on 17-in. computer screens (resolution 1,024 pixels × 768 pixels) with refresh rates of 85 Hz, at a viewing distance of approximately 50 cm. All tasks were conducted using the program Inquisit 2.0.60616 (2006). Technically identical computers were used for group testing.

General procedures. Experiment 1 lasted 4 hr and used 18 tasks to measure face cognition. Groups of up to nine participants completed the tasks under the supervision of a trained proctor. Breaks of 10 min were allowed after every 50 min of testing, and tasks were administered without time limits. Participants in each group worked in parallel on the same task. For all tasks, participants responded by pressing one of two labeled keys that were situated on the right and left sides of a standard keyboard. Participants were instructed to use their left and right index fingers, which always lay on the response keys. Although the performance parameter of prime interest for each indicator was either speed or accuracy, participants were always instructed to respond as quickly and as accurately as possible. For each task, a sequence of trials was randomly generated. These randomized sequences were then fixed for all participants. Each task started with an instruction page on the screen, followed by 10 practice trials, in which participants received trial by trial feedback about their accuracy. After the practice trials, questions from participants were addressed. Once all participants fully understood the instructions, the experimental trials began. No feedback was provided for the experimental trials.

Face images were used twice in some tasks of face perception, such as within Face Perception 1 (FP1) and FP2 and within FP3 and FP4. With this procedure, we followed previous experimental research with these tasks. The rationale behind using the same stimuli in two conditions of the same perception task was to make both conditions as similar as possible, with the only difference between conditions being an experimental manipulation (e.g., turning the face upside-down in FP3 and FP4). Images were also repeatedly shown in the memory tasks that required learning a given face in the study phase and recognizing it in the following recognition phase. Appendix A provides information about the number of stimuli used in each task.

Two of the tasks administered were measures of face space—one task capturing distinctiveness, the other one short-term memory. Measures of face space did not fit into our taxonomy of perception versus memory and are in fact probably best seen as an idiosyncratic amalgam of both dimensions. One face-priming task and one face-specific working-memory task were piloted in this study because we had no prior psychometric experience with these measures. The eliminated measures were dropped from all subsequent analysis. Appendix A provides further information about the tasks. A detailed report about all face-cognition tasks can be found in Herzmann et al. (2008).

Description of individual indicators for face-cognition abilities. Face perception was measured by indicators requiring perceptual comparisons of face stimuli without any reliance on memory processes. Face memory was assessed through measures that required the learning and recognition of face stimuli. Speed of face cognition was measured by indicators that required swift responses for easy perceptual comparisons and recognition of faces.

The tasks were derived from or based on the experimental literature on face cognition and were chosen for their theoretical meaningfulness and the strength of their effects. These tasks are therefore meant to be sensitive for the function in question. We also included some published tests of specific face-cognition abilities. In the following task descriptions, we refer to the use of each measure in cognitive or neuropsychological research.

Face perception.

FP1 and FP2: Sequential matching of part–whole faces, with conditions of part (FP1) and whole (FP2). This measure used the part–whole paradigm (Tanaka & Farah, 1993; Tanaka & Sengco, 1997). The notion of holistic face cognition maintains that faces are perceived primarily as undifferentiated wholes with no (or little) independent representation of individual internal features. The *part–whole recognition effect* refers to the finding that a particular facial feature (e.g., a nose) is recognized better in the context of the face to which the feature belongs than when presented in isolation. This advantage for the "whole" context is not reported for other objects, such as houses.

A target face was presented, and thereafter a facial feature from the target (e.g., its eyes) was shown along with the same feature from a different face. Facial features were presented either in isolation (part condition) or in the context of the whole target face (whole condition). Participants' task was to discern either which face was the target (in the whole condition) or which was the feature belonging to the target (in the part condition). Part and whole conditions were taken as separate indicators.

FP3 and FP4: Simultaneous matching of spatially manipulated faces, with conditions of upright (FP3) and inverted (FP4). Much evidence for the importance of configurational information in face perception comes from the so-named face-inversion effect and from the effects of manipulating the spatial relations between facial features. Many studies have shown that turning a face upside-down impedes face perception and recognition. Importantly, this inversion effect is disproportionately greater for faces than for other objects (e.g., Yin, 1969; see Searcy & Bartlett, 1996, and Valentine, 1988, for reviews). Another important consequence of inverting faces is that spatial (or configurational) displacements of features are harder to detect than in an upright condition, especially when only local features are changed (e.g., Freire, Lee, & Symons, 2000), as is spacing discrimination (e.g., Yovel & Duchaine, 2006). The face-inversion effect is thought to result mainly from a disruption of the processing of configurational information, and therefore processing inverted faces relies on the processing of individual facial features (Maurer, Le Grand, & Mondloch, 2002).

Two faces were simultaneously presented, and participants had to indicate whether they were the same or different. The faces were always derived from the same picture, but in the different condition, one spatial relationship between features (e.g., mouth–nose relation or eyes–nose relation) was changed from the original (see Appendix B, Panels A and B, for an example in the upright condition). Faces were presented either upright or inverted. Upright and inverted conditions were taken as separate indicators.

FP5: Facial resemblance. This task was inspired by the Cambridge Face Perception Task (Dingle, Duchaine, & Nakayama, 2005), proposed as a test of perceptual face cognition that minimizes the reliance on feature matching by using the morphing method. In a pilot study, we used the same experimental settings and the same procedure as did Dingle et al. (2005) but obtained results that were just above guessing probability. Therefore, the procedure was adjusted in order to facilitate the task. We used morphing (Busey, 1998; Preminger, Sagi, & Tsodyks, 2007) with the software Morpher 3.0 (2001). In morphing, a new face (a *morph*) is created from two "parent" faces by combining and averaging their features.

A target face in three-quarter view was presented centered above two morphed faces, shown in frontal view. The morphed faces were derived from the original target face and a second, new face. Participants had to decide which of the morphs resembled the target face more.

Face memory.

FM1: Acquisition curve. In everyday life, face learning is rarely a one-trial process, because most relevant faces are seen repeatedly. Here we used the number of repetitions that are necessary until a face is successfully recognized as an indicator of how well a person learns faces. In the study phase, 30 faces were presented on the screen during a 2-min period. The test phase, consisting of five runs, began 4 s after the study phase was cleared from the screen. Within each run, each studied target face was tested for recognition on a trial by trial basis, alongside a new face. Participants indicated the target face, and immediately after the response, the target face was highlighted by a green frame, regardless of the accuracy of the response, to ensure long-term learning.

FM2: Decay rate of learned faces. This task builds upon FM1. Because everything learned and represented in memory may be forgotten or become inaccessible, the accessibility of previously learned faces after a longer delay is an important indicator for face recognition. A prerequisite for assessing such capabilities is a well-established and uniform memory trace across participants. We aimed to achieve this goal by measuring recognition performance after approximately 2.5 hr for the faces that had been learned to a high degree in task FM1. Two faces were shown in each trial; one had previously been learned, and the other was new. Participants had to indicate the learned face.

FM3: Eyewitness testimony. Eyewitness testimony refers to long-term retention and recognition of an event after a single exposure in circumstances in which the event was not relevant, with either explicit or implicit learning intention. Here, learning was implicit (e.g., Jenkins, Lavie, & Driver, 2005). The targets tested were distractor faces from the immediately preceding test—speed of face cognition 2 (SFC2)—for which no instruction about subsequent recognition testing had been given. Two faces were displayed side by side on the screen in each trial. Participants had to indicate the face that they had seen approximately 5 min before.

Speed of Face Cognition.

SFC1: Recognition speed of learned faces. This task followed typical assessment procedures for recognition memory (e.g., Warrington, 1984). Participants learned a number of faces that were subsequently tested for recognition. In order to increase demands on memory, we included a delay of at least 4 min between learning and recognition. The task had four parts, each consisting of a study phase followed by a delay—during which participants worked on items of an ability test—followed by the recognition phase. In each study phase, four faces were shown simultaneously and had to be memorized. In each recognition phase, four learned and four new faces were shown one at a time. Participants had to indicate whether the shown face was learned or new.

SFC2: Delayed nonmatching to sample (DNMS). These tasks are widely used to investigate visual short-term memory. They require a participant to hold a visual stimulus "on line" over a delay interval before responding to a forced-choice test. A trial-unique target stimulus is presented, followed by a blank-screen delay interval, after which the target is presented together with a novel stimulus that has to be selected. Because adults have a strong bias to match, that is, to identify the familiar target stimulus at the choice stage (e.g., Aggleton, Nicol, Huston, & Fairbairn, 1988; Elliot & Dolan, 1999), the DNMS task requires an additional process of response inhibition. In the unique-trial DNMS task implemented here, an unknown target face was presented, followed by a delay of 4 s, after which the target face was shown together with a new face. Participants had to indicate the novel face.

SFC3: Simultaneous matching of faces from different viewpoints. For faces, structural encoding requires not only the extraction of pictorial codes (e.g., pose) but also the extraction and retention of expression and viewpoint-independent information about features and their configuration. Changing the viewpoint from which a face is depicted between study and test is used to tap the extent to which the face has been structurally encoded. For both matching of faces and recognition of unfamiliar faces, there is a disadvantage in both accuracy and reaction times when faces are shown from different viewpoints or when viewpoints change between initial and test presentation (e.g., Bruce, 1982; Newell, Chiroro, & Valentine, 1999).

Here, two faces were presented simultaneously; one a frontal view and the other a three-quarter view. Participants had to indicate whether the faces depicted the same or different persons.

SFC4 and SFC5: Simultaneous matching of upper-face halves, with conditions of aligned (SFC4) and nonaligned (SFC5). Evidence for holistic perceptual processing of faces is derived from the *composite-face effect* (e.g., Hole, 1994; Young, Hellawell, & Hay, 1987). This effect refers to the phenomenon in which two complementary (i.e., upper and lower) aligned face halves from different people appear to fuse into a new face in which internal features are strongly integrated. This makes it difficult to parse the face into isolated features, which impedes, for example, recognition or naming of one half-face compared with nonaligned faces.

Faces were divided horizontally into upper and lower halves. In the aligned condition, face halves were attached with a complementary half from another face to form a new face. In the unaligned condition, faces were coupled so that the left or right face edge of the top face half was positioned above the nose from the bottom face half. Participants had to decide whether the top halves of two simultaneously presented faces were the same or different; lower halves were always different. Aligned and nonaligned conditions were taken as separate indicators.

SFC6: Simultaneous matching of morphs. One of the more basic tasks in face perception research is to determine whether two simultaneously presented faces are the same or different. This task is simple if one face has, for instance, a relatively big nose, because in this case the decision can be based on a single feature. In order to minimize feature-based processing, we used the morphing procedure again (see the earlier FP5: Facial Resemblance section). Morphing allows for precise manipulations of task difficulty through systematic manipulations of stimulus similarity, by creating a continuum of morphed faces from a given pair of parent faces with different relative contribution (e.g., 10% of parent A and 90% of parent B).

Here, two nonidentical morphed faces, derived from the same parent faces, were presented in each trial. Participants had to decide whether the faces were similar or dissimilar. Faces in the similar trials were closer to each other on the morphing continuum than were faces in the dissimilar trials.

Data treatment. For all indicators of face perception and face memory, performance measures were expressed by the proportion of correct responses. For all indicators of face-cognition speed, reaction times for correct responses only were used as performance measures. The proportion of correct responses for all speed indicators was at ceiling. Reaction times for a specific indicator were set to missing if they were shorter than 200 ms or longer than 3.5 intraindividual standard deviations above the individual's mean reaction time. Participants' mean reaction times for a particular indicator were defined as outliers and also set to missing if they were more than 3 standard deviations above the group mean reaction time. Missing data for reaction times, as just defined, were counted across trials in each indicator. If, for a given participant, more than 40 percent of data were missing in a specific indicator, the individual's mean reaction time and accuracy for this specific indicator were set to missing. When we followed these procedures, 1.8% of all values were missing. If, for a given participant, the data for more than five indicators were missing, the participant was excluded from all subsequent analyses. On this basis, two participants were omitted. The missing completely at random (MCAR) test, following Little (1988), was not significant, $\chi^2(158, N = 151) = 180, p = .11$, indicating that the assumption of randomness of missing values could not be rejected. We replaced the missing values using the expectation-maximization (EM) algorithm as implemented in SPSS-15.

The rationale for setting observations that were actually collected to missing and to replace these data with estimates aims to exclude all data from the analysis that probably reflect invalid observations. This might be the case if participants did not fully understand the instructions or did not succeed in finding a way to optimally solve a specific task. Rather than completely excluding such cases with many valid observations from further analyses, it seemed more appropriate to eliminate particular, probably invalid observations and to replace them with the expected adequate values. For the large amount of data and the small proportion of missing data in the present experiments, replacing missing values with estimates affects neither the results nor the conclusions.

Data analysis. Structural equation modeling (SEM) is a statistical technique for testing and estimating causal relationships in observed data. SEM encourages confirmatory rather than exploratory modeling. With an accepted theory or otherwise confirmed model—as was the case here, in which we started from established models of face cognition—SEM is used to estimate the values of free parameters by specifying one or several competing theoretical models a priori. Latent factors can represent abilities that are not measured directly but are estimated in the model from observed variables on the basis of the theoretical assumptions about which indicator (e.g., the performance in the indicator, acquisition curve) contributes to a particular underlying ability (e.g., face learning and recognition). Pairs of indicators, supposedly assessing the same ability (e.g., face learning and recognition), should—other things being equal—correlate higher with each other than with two indicators assessing different abilities (e.g., face memory and face perception). SEM allows for capturing the unreliability of measures in the model and accurately estimating the structural relations between latent factors. Given these methodological features and the research questions derived previously, SEM is the methodological tool of choice in the present context.

Applying SEM, the estimated theoretical covariance matrices representing the relationships between variables in the model can be compared with the actual empirical covariance matrices (Bollen, 1989; Mulaik, 2009). Various formal statistical tests and fit indices have been developed for this purpose. Because different measures capture different aspects of the model fit, it is appropriate to report several fit measures. Some of the more commonly used fit measures are the chi-square test, root-mean-square error of approximation (RMSEA), and comparative fit index (CFI). A chi-square test is a fundamental measure of fit used in the social sciences. In the SEM approach it is a function of the sample size and the difference between the observed covariance matrix and the theoretical model covariance matrix. The significance level of the chi-square test is compared with the corresponding value of the chi-square distribution. Competing models are frequently compared by evaluating their chi-square value and their degrees of freedom. CFI values of .95 or higher are usually taken to indicate excellent model fit, whereas CFI values below .90 are frequently deemed unacceptable and therefore lead to the rejection of the model. RMSEA values in the range of .05 to .08 are often taken as expressing acceptable fit, whereas values higher than .08 are mainly considered as indicating unacceptable fit (Hu & Bentler, 1999). RMSEA values below .05 are usually taken as indicating good or very good model fit.

The quality of model fit in confirmatory factor analysis can also be expressed by comparing competing models via likelihood ratio tests (e.g., by constraining correlations or factor loadings). If the introduction of constraints (e.g., the correlation between latent factors for memory and perception is fixed to be one) causes a significant decline of the model fit, one should consider accepting the less parsimonious model (e.g., a model in which perception and memory indicators load on two not perfectly correlated factors). The comparison of the model fits can be based on a chi-square distributed test value by taking into account the difference between the chi-square values and the difference of the degrees of freedom in the competing models. The estimation of the confirmatory measurement and structural models was conducted with AMOS 17 (Arbuckle, 2008).

Results

In all models, correlated error terms were theoretically expected and were specified for indicators that were derived from different experimental conditions of the same task. Table 1 summarizes the fit indices for all models of Experiment 1. The general-factor model of face cognition was the most parsimonious, theoretically meaningful model that could be specified. The fit of Model 1 was unacceptable. More elaborate models were required in order to account for the covariances in the data. Models 2a and 2b postulated two factors, which were uncorrelated in Model 2a and correlated in Model 2b. The first factor accounted for communalities between all speed indicators, and the second, for communalities between all accuracy measures. The fits of Models 2a and 2b were barely different. The correlation between the latent factors was estimated at r = .13 but was not statistically distinct from zero. Although the fits

Table 1
Competing Structural Equation Models in Experiment 1 (N = 151)

Model	Factors	χ^2	*df*	CFI	RMSEA
1	G	287.0	74	.716	.139
2a	Speed vs. accuracy (uncorrelated)	139.1	74	.913	.077
2b	Speed vs. accuracy (correlated)	137.4	73	.914	.077
3a	Speed perception vs. speed memory vs. accuracy perception vs. accuracy memory (uncorrelated)	190.5	75	.846	.101
3b	Speed perception vs. speed memory (correlated) vs. accuracy perception vs. accuracy memory (correlated)	128.9	73	.925	.071
3c	Second-order general factor, 4 first-order factors	117.2	70	.937	.067
3d	Speed vs. accuracy perception vs. accuracy memory (correlated)	100.6	71	.960	.057

Note. CFI = comparative fit index; RMSEA = root-mean-square error of approximation; G = a single latent factor of face cognition.

of Models 2a and 2b were considerably better than the fit of Model 1, indicating that the distinction between speed and accuracy is relevant, there was still substantial room for improvement. Models 3a, 3b, and 3c postulated 4 first-order factors. For these models, each of the two factors from Model 2a was split into two factors. One accounted for indicators drawing on perception of faces, and the other, for indicators relying on memory for faces. In Model 3a, all four latent factors were uncorrelated. The fit of this model clearly indicates that some factor correlations were strongly required in order to achieve a sufficient fit. In Model 3b, the factors for face perception and face memory were correlated within but not across the speed and accuracy domains. The two speed factors revealed a perfect correlation. Model 3b showed substantially better fit than did Model 3a. Nevertheless, the CFI and RMSEA indicated that there was still room for improvement of the fit of this model. In Model 3c, correlations of the 4 first-order factors were attributed to a second-order factor. In this solution, the second-order factor loaded more strongly on the first-order speed factors than on the accuracy factors. The speed factors essentially determine this second-order factor. Therefore, the correlation between both accuracy factors was hardly captured by it. The fit of this model was not sufficient, although it constituted a slight improvement over Model 3b. We therefore specified Model 3d, in which we dropped the distinction between perception and memory for the speed indicators but kept this distinction for the accuracy measures. Note that Model 2b would result if the distinction between perception and memory among the accuracy indicators were dropped. Model 2b and Model 3c can be compared inferentially, as can Models 3b and 3d. These comparisons clearly indicated that Model 3d represented the best approximation to the data; the fit of this model was acceptable. The reliability of the three latent factors in Model 3d was estimated using coefficient omega. Omega was computed through principal axis factor analysis, whereby a single latent factor was specified for each indicator on the basis of its group of indicators. Omega represents the proportion of variance in the scale score that is common to all scale indicators and accounted for by the latent variable; this is expressed as the scale's general-factor saturation (McDonald, 1999) and represents the most appropriate estimator of internal consistency (Revelle & Zinbarg, 2009). Omegas were estimated at .67, .77, and .83 for face perception, face memory, and the speed of face cognition, respectively. Figure 2 presents the final measurement model from Experiment 1.

Discussion

Experiment 1 yielded three main results. First, for each of the 14 indicators there were substantial correlations with several other measures, indicating that latent factors were a good approach to abstract from individual measures and to focus on latent abilities that determine the behavioral performance, rather than considering highly task-specific scores of single tasks. Second, the distinction between speed and accuracy of face cognition was warranted. Third, an additional distinction between face perception and face memory was necessary for only the accuracy indicators.

With this experiment, we have established, for the first time, a measurement model of individual differences in face cognition by assessing the abilities to perceive, learn, and recognize human faces using indicators well grounded in experimental work. On the basis of current models of face-cognition and psychometric-measurement principles, the measures were intentionally compiled to allow testing for the expected distinctions between (a) the speed and accuracy of performance and (b) perceptual and memory demands of the tasks. The results unequivocally show that it is important to distinguish between the speed and the accuracy of face cognition. Within the speed of face cognition, a distinction between face perception and

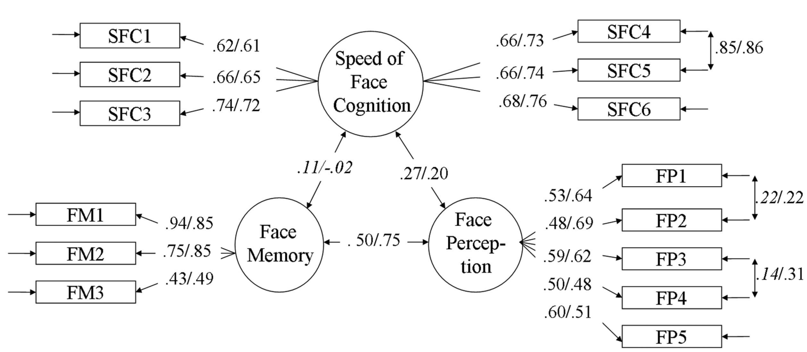

Figure 2. Final measurement model for face cognition in Experiment 1, $\chi^2(71, N = 151) = 101$, RMSEA = .057, CFI = .960, and in Experiment 2, $\chi^2(71, N = 209) = 115$, RMSEA = .055, CFI = .967. Values for the model in Experiment 1 are before the slashes, and values for the model in Experiment 2 are after the slashes. Coefficients that did not reach the significance level $\alpha = .05$ are italicized. Some tasks in Experiments 1 and 2 contained two different conditions. The common variance between two conditions from a single task is not expected to be captured completely by a latent factor. Thus, error variables for indicators from a particular task were allowed to correlate with each other (FP1 with FP2, FP3 with FP4, and SFC4 with SFC5). These covariances reflect task specificity that is of no substantive interest. SFC = speed of face cognition; FM = face memory; FP = face perception; RMSEA = root-mean-square error of approximation; CFI = comparative fit index.

face memory was not supported by the data. Among the accuracy measures of face cognition, a clear distinction between face perception and face memory was found. The speed of face cognition was unrelated to the two accuracy factors. Face perception and face memory were correlated substantially. Although the specification of Model 3d was partly data driven, the core distinctions in Model 3d reflect simply the theoretical considerations of Model 3b and Model 3c. The only difference between both models is the distinction between perception and recognition among the speed indicators.

Investigating the first aim, in Experiment 2 we should replicate the measurement model established in Experiment 1. Investigating our second aim, in Experiment 2 we also tested whether the newly established human ability factors could be regressed completely on established constructs of intelligence research. The finding that perception and memory could not be distinguished for the speed measures and that the speed factor was unrelated to the other two factors might indicate that the speed of face cognition simply captures mental speed (Danthiir, Wilhelm, Schulze, & Roberts, 2005). This possible alternative explanation for the speed of face cognition was tested in Experiment 2.

Experiment 2

Method

Participants. Experiment 2 involved 209 participants (109 women) with a mean age of 25.0 years ($SD = 4.1$). Participants were heterogeneous with respect to educational and occupational background: 11% were high school students, 56% were university students with a variety of majors, 17% had occupations, and 16% were unemployed. According to the Edinburgh Handedness Inventory (Oldfield, 1971), 92% of the participants were right-handed, 6% left-handed, and 2% ambidextrous. Visual acuity of all participants was normal or corrected-to-normal. Participants were recruited via newspaper ads, posters in various institutions, radio broadcast, and invitations by friends.

Stimuli and apparatus. Apparatus, face stimuli, and face tasks were the same as in Experiment 1—apart from minor adjustments of some task parameters. Only the face-cognition tasks selected in Experiment 1 were included in Experiment 2. Besides the face-cognition tasks, tasks that measured relevant criterion abilities were also included in Experiment 2. The stimuli of these tasks, together with the corresponding indicators, are described next.

General procedures. Experiment 2 lasted approximately 5 hr and used the same 14 indicators of face cognition as in Experiment 1 but in a different sequence. Some of these indicators were slightly modified on the basis of descriptive results from Experiment 1 (Herzmann et al., 2008). In indicator FM1, faces in the study phase were presented for 1.5 min on the screen. Trials in indicators FM3 and SFC2 were increased from 30 in Experiment 1 to 46 in Experiment 2.

The criterion indicators included in this experiment were five indicators for object cognition and three indicators each for immediate and delayed memory, general cognitive ability, and mental speed (see Appendix A for further information). General procedures were the same as in Experiment 1.

Description of criterion indicators.

General cognitive ability.

General Cognitive Ability 1 (GCA1): Raven's Advanced Progressive Matrices. Sixteen odd-numbered items from the matrices section of the original full test (Raven's Progressive Matrices and Vocabulary Scales; Raven, Court, & Raven, 1979) were included in this task. An item consisted of a 3×3 matrix of symbols with the bottom right-hand symbol missing. The task was to logically complete the matrix by choosing the correct symbol from the options given below the matrix.

GCA2: Memory updating. This task (adapted from Oberauer, Süß, Schulze, Wilhelm, & Wittmann, 2000) measured working memory. Participants had to remember a series of digits and mentally update them according to instructions. In each item, a 3×3 grid was displayed. Two to seven of the cells were white, whereas the others were black. In each white cell, one digit was displayed once, for 1 s, immediately before the next digit appeared in another cell. One second after the presentation of the last digit, four arrows pointing vertically up or down appeared, one at a time, in the white cells. The arrows were displayed for 1 s, and the next arrow immediately followed. An upward-pointing arrow indicated that the participant should mentally add 1 to the digit presented in that cell, and a downward-pointing arrow indicated that participants should decrease the digit by 1. Then 2 s after the last computing instruction was given, the recall cue appeared. The participants then responded to question marks appearing one at a time, in each white cell, by typing the resulting number for the specific cell. Five practice trials were given, in which feedback was provided, prior to the 18 experimental items.

GCA3: Rotation span. This task (adapted from Shah & Miyake, 1996) measured working memory and required remembering and recalling a sequence of short and long arrows, which radiated out from the center of a circle in eight directions, while concurrently engaging in a letter-rotation task. Each item consisted of a sequence of screens that alternated between the processing task and the storage task. For the processing part of the item, each screen displayed either a normal or a mirror-reversed *G*, *F*, or *R*, rotated at 0, 45, 90, 135, 180, 225, 270, or 315 degrees. The task was to mentally rotate the letter and to indicate immediately, by a key press, whether the letter was normal or mirror-reversed. Half of all letters used were mirror-reversed. The response to the letter-rotation task was followed by a 750-ms intertrial interval, after which a short or long arrow pointing in one of the eight directions was presented for 1 s. Immediately thereafter, the next letter of the rotation task was displayed, then the next arrow, and so on. At the end of the sequence of letter–arrow pairs, the recall cue appeared, along with a stimulus depicting the 16 possible arrows radiating out from the center of the circle. Participants used the mouse to indicate the arrows that were displayed, by clicking on the arrows in the correct order of presentation. The list length of each item ranged from two to five letter–arrow pairs. Three practice trials preceded the start of the 12 experimental items. The score was the average of the proportion of arrows correctly remembered at the correct list position, across items.

Immediate and delayed memory. Three indicator pairs (IDM1–IDM2, IDM3–IDM4, IDM5–IDM6)—each with immediate (IDM1, IDM3, and IDM5) and delayed (IDM2, IDM4, IDM6) recall—served as measures for general memory. Two of these indicator pairs—visual (IDM1–IDM2) and verbal memory (IDM3–IDM4)—were taken from the Wechsler Memory Scale (Härting et al., 2000) and computerized. For these indicators, the number of trials was increased from six to eight because the original indicators were expected to be too easy for the mentally healthy participants in the present experiment. A third indicator pair for name memory (IDM5–IDM6) was adapted from a task of the Wechsler Memory Scale. In this newly generated indicator, first and second names had to be learned and memorized, instead of the originally used word pairs.

Object cognition. Five indicators—Object Cognition 1 (OC1) to OC5—were used to measure object cognition. These indicators were procedurally identical with the corresponding indicators for face cognition (indicators OC1 and OC2 corresponded to indicators FP1 and FP2; indicators OC3 and OC4 to indicators FP3 and FP4, and indicator OC5 to indicator FM3), but instead of face portraits we used grayscale pictures of houses as stimuli. Pictures were 300 pixels wide × 260 pixels high (7.6 cm × 6.6 cm). All pictures were taken by the authors in the suburbs of Berlin, Germany.

Just as in indicators FP1 and FP2—wherein eyes, nose, and mouth were manipulated—in indicators OC1 and OC2, windows, doors, and roofs were manipulated. For indicators OC3 and OC4, the spatial manipulations by means of pixels were identical to those of indicators FP3 and FP4 (see Appendix B, Panels C and D for an example). Here, windows instead of eyes were moved up or down as well as in or out. The equivalent for moving the mouth up or down was realized by moving the door to the left or right.

Mental speed.

Mental Speed 1 (MS1): Finding As. Participants saw meaningful German words on the screen, and for each word they had to decide whether it contained an *A* or not and to respond as quickly as possible. Six practice trials were given, with accuracy feedback, before the 80 experimental trials began.

MS2: Symbol substitution. One of the four symbols "?," "+," "%," or "$" appeared on the screen. The task was to press the appropriate response code corresponding to each symbol. Participants were required to respond to "?" with the upward-pointing arrow key, to "+" with the right-pointing arrow key, to "%" with the down-pointing arrow key, and to "$" with the left-pointing arrow key. Six practice trials were given, with accuracy feedback, before the 80 experimental trials began.

MS3: Number comparison. Participants were presented with two number strings, varying from three to 13 digits in length. For each item, participants were required to decide whether the number strings were identical and to press the corresponding button. Six practice trials, with accuracy feedback, preceded the start of the 80 experimental trials.

Data treatment. For all indicators of immediate and delayed memory, general cognitive ability, and object cognition, performance was expressed by the proportion of correct responses. For all indicators of mental speed, reaction times for correct responses only were used as the performance measure. As expected, the proportion of correct responses for indicators of mental speed was at the ceiling. The same rationale as in Experiment 1 was used to set reaction times for a specific indicator to missing. When we followed these procedures, 2.2% of all values were missing. No participants were omitted due to missing values. The MCAR test, following Little (1988), was not significant, $\chi^2(295) = 332$, $p = .07$, and indicated that the assumption of randomness of missing values could not be rejected. We replaced the missing values using the EM algorithm as implemented in SPSS-15.

Data analysis. The estimation of the measurement and structural models was conducted with AMOS 17 (Arbuckle, 2008) and followed the same rationale as in Experiment 1.

Results and Discussion

The first objective of Experiment 2 was to replicate the measurement model from Experiment 1, because this model was derived partly in a data-driven way. The second objective was to investigate whether the variance in the latent factors of face cognition can be explained by established cognitive abilities. The failure to do so would indicate the relative independence of face-cognition abilities from established abilities.

We first computed the same measurement models as in Experiment 1, with the aim of replicating the final model from Experiment 1 as the best theoretically meaningful representation for the tasks. Thereafter, we extended this measurement model into a structural model and regressed the latent factors of face cognition on relevant predictors. Considering the evidence for the distinctness of face-cognition abilities from established abilities such as reasoning and object cognition, as reviewed in the introduction, we suggested that individual differences in face cognition cannot be captured in their entirety by established ability constructs. Thus, we expected that a substantial proportion of individual differences in face cognition would be unique and would not be accounted for by established abilities.

We successfully replicated the critical comparisons between competing measurement models tested in Experiment 1. Table 2 summarizes the results from Experiment 2 for the same model family also tested in Experiment 1. The fit of Model 3d was good and superior to all competing models. Model 3d, the final measurement model of Experiment 2, is shown in Figure 2, which also compares loadings and correlations between Experiments 1 and 2. All loadings were substantial and clearly distinct from zero. All of the correlations between error terms postulated and specified a priori were approximately as large as in Experiment 1. The correlation between the factors for face perception and face memory was slightly higher than in Experiment 1 (.75 vs. .50). However, as in Experiment 1, the comparison between Models 2b and 3d showed that constraining the correlation to unity harmed the model fit substantially. Face perception and face memory were still sufficiently independent from one another and can clearly be considered as separable abilities. Taken together, the evaluation of Tables 1 and 2 supports the conclusion that Model 3d derived in Experiment 1 and replicated in Experiment 2 is the best representation of the observed variables. The reliability of the three latent factors in Model 3d was again estimated through coefficient omega. Omegas were estimated at .73, .79, and .85 for face perception, face memory, and the speed of face cognition, respectively.

In order to distinguish factors of face cognition from established abilities, in Experiment 2 we included indicators for established abilities that were expected to be related to, or

Table 2
Competing Structural Equation Models in Experiment 2 (N = 209)

Model	Factors	χ^2	*df*	CFI	RMSEA
1	G	487.2	74	.689	.164
2a	Speed vs. accuracy (uncorrelated)	148.2	74	.944	.069
2b	Speed vs. accuracy (correlated)	148.1	73	.943	.070
3a	Speed perception vs. speed memory vs. accuracy perception vs. accuracy memory (uncorrelated)	325.7	75	.811	.127
3b	Speed perception vs. speed memory (correlated) vs. accuracy perception vs. accuracy memory (correlated)	125.3	73	.962	.058
3c	Second-order general factor, 4 first-order factors	184.7	70	.914	.089
3d	Speed vs. accuracy perception vs. accuracy memory (correlated)	115.3	71	.967	.055

Note. CFI = comparative fit index; RMSEA = root-mean-square error of approximation; G = a single latent factor of face cognition.

might even be causal for, individual differences in face cognition. These indicators were measures of immediate and delayed memory, general cognitive ability, mental speed, and object cognition. General cognitive ability was expected to be moderately related to both accuracy factors and, to a smaller degree, the speed of face cognition factor. Immediate and delayed memory was expected to be highly correlated with face memory and, to a smaller degree, with face perception. Object cognition was expected to be highly related with face perception and, to a lesser degree, with face memory. Mental speed was expected to be substantially but not strongly related to the speed of face cognition.

Cognitive abilities were expected to show positive manifold (Carroll, 1993). Therefore, a hierarchical factor model with one general and four orthogonal nested factors was specified for the predictor side. This model allowed testing for contributions from a general cognitive ability factor and orthogonal factors of specific abilities to the prediction of the three face-cognition abilities. Because all predictor factors were orthogonal to each other, their relative contribution in accounting for face-cognition abilities would be additive, and thus there would be no collinearity issues among the predictor variables.

As expected, the measurement model of established abilities distinguished between factors representing immediate and delayed memory, mental speed, object cognition, and general cognitive ability (see Figure 3). The fit of this model was good, $\chi^2(100, N = 209) = 152$, RMSEA = .05, CFI = .956.

The measurement models for face cognition and for established abilities were integrated into a structural model that critically tested the relative independence of factors of face cognition from other factors in the regression model. Figure 4 shows the structural model of Experiment 2. The fit of this model was good and unequivocally indicated that none of the three latent factors of face cognition could be essentially reduced to established abilities. It is important to stress that the proportion of explained variance in the latent factors of face cognition was not close to unity for any of the three factors of face cognition. About 48% of the variance of face memory was accounted for by the four predictors; about 64% of the face perception factor and only 50% of the speed of face cognition factor were accounted for by the four predictors. This provides strong evidence for the relative independence of individual differences in face cognition from other cognitive abilities. The prediction of face memory was primarily attributable to the object cognition and to the memory factor. General cognitive ability was not a strong contributor to the prediction. The prediction of face perception was primarily due to object cognition and general cognitive ability—and only a smaller but significant contribution came from the memory factor. Prediction of the speed of face cognition factor was primarily due to mental speed. The four regression weights between the factors on the predicted and predicting side not specified in this model were not significant when assessed relative to a Bonferroni corrected critical chi-square value of 6.24. The standardized factor loadings of this model are provided in Figure 4.

In the structural model (see Figure 4), the relation between face perception and face memory dropped from .75, as estimated in Model 3d, to .60 once other cognitive abilities were controlled for. This indicated that, after statistically controlling relevant criteria, a substantial face-specific relationship between the accuracy of face perception and the accuracy of face memory remained.

Overall, the objectives of Experiment 2 were achieved. The measurement model from Experiment 1 was successfully replicated. Minor changes such as the increase in the correlation between face perception and face memory might be due to random fluctuations in the samples or to the adaptations and improvements in the measures. Individual differences in the speed of face cognition, face perception, and face memory could not be reduced to individual differences in immediate and delayed memory, general cognitive ability, mental speed, and object cognition. This conclusion is not changed when alternative measurement models for the predictor side are estimated and used in the structural model. It is important to note that the object-cognition tasks primarily assessed perceptual abilities. These tasks were identical to the face-cognition tasks except that they used houses as stimuli. The fact that such an object-cognition factor does not account for a large proportion of individual differences in face cognition strongly speaks for the distinctiveness of these factors.

General Discussion

We began this article by arguing that the measurement of intrinsically interpersonal abilities is a major challenge in furthering the understanding of human abilities. The main prob-

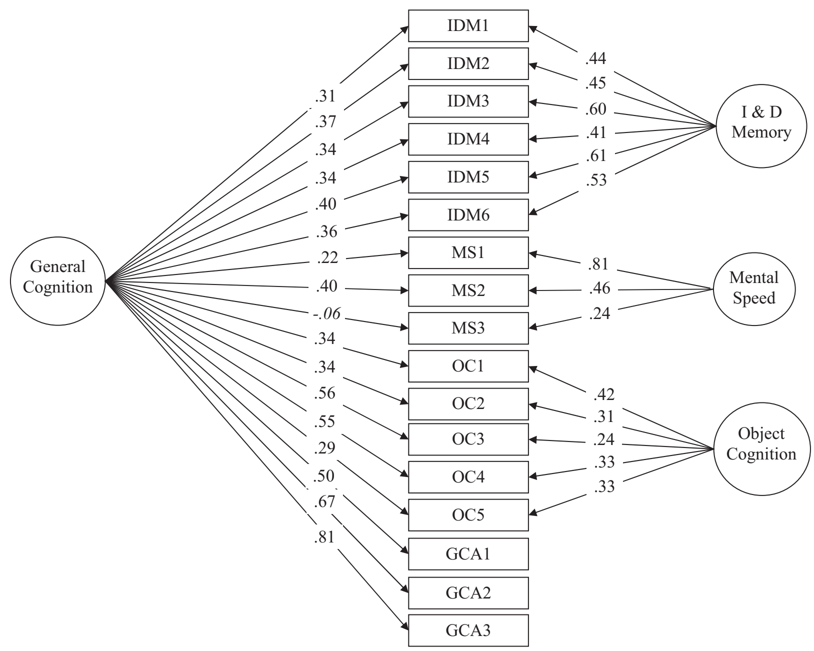

Figure 3. Measurement model of established abilities in Experiment 2. Coefficients that did not reach statistical significance at $\alpha = .05$ are italicized. Effects of different experimental conditions within a particular task were captured by correlated error terms for these indicators. IDM and I & D Memory = immediate and delayed memory; MS = mental speed; OC = object cognition; GCA = general cognitive ability.

lems are fundamentally diverging measurement concepts in the literature, insufficient evidence on measurement models and the validity of latent variables postulated in such models, and scoring issues due to the lack of veridical responses. In the present experiments, we aimed to overcome these problems by (a) selecting a circumscribed interpersonal ability (i.e., face cognition) that (b) has a profound and elaborate basis in experimental and neurocognitive research that (c) is relevant and important in everyday life and (d) is restricted to measurement approaches based on factually correct response options. The specific aims we pursued were to establish a measurement model and to ensure that the abilities proposed in this model are not a function of established cognitive abilities.

In order to ensure strong nomological breadth of the tasks subsumed under the latent variables, we constructed the ability indicators to reflect important conceptual and theoretical distinctions. Following this approach, we derived two critical distinctions from theories of face cognition and ability research. The first critical distinction was assumed between tasks taxing primarily perception or memory of faces. This distinction was based on the unanimous assumption in face-processing models, derived from experimental work and clinical case studies, that a perceptual stage, encompassing among others the structural encoding of faces, has to be distinguished from a memory stage, including the access to face representations stored in memory. The second critical distinction was expected between the speed and the accuracy of responses. This distinction is well established in individual-differences research in cognitive abilities. Both distinctions were found to be necessary to account for the data from Experiments 1 and 2.

The Status of Face-Cognition Abilities

The three latent variables identified in Experiments 1 and 2 represent varieties of individual differences in face cognition. Face perception expresses the ability to perceive facial stimuli and to discern information about 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.

The measurement model of face cognition derived in Experiment 1 and replicated in Experiment 2 is a necessary prerequisite for arguing that new ability constructs were established. However, more sufficient evidence for this statement comes only from Experiment 2, in which the measurement models of face cognition and of established cognitive abilities were integrated into a structural model. In this model, the new latent variables of face cognition were regressed on relevant predictor abilities. It showed that none of the latent variables of face cognition could be essentially reduced to established cognitive abilities. We provide strong evidence that individual differences in face cognition constitute separable abilities that belong alongside other human cognitive abilities. We thus met the psychometric part of our two research aims: (a) to establish abilities of face cognition and (b) to establish them as new, hitherto not adequately assessable ability constructs sufficiently distinct from established ability constructs.

Methodological Concerns

The latent variable approach applied here partly transcends issues and problems inevitable in research relying on single

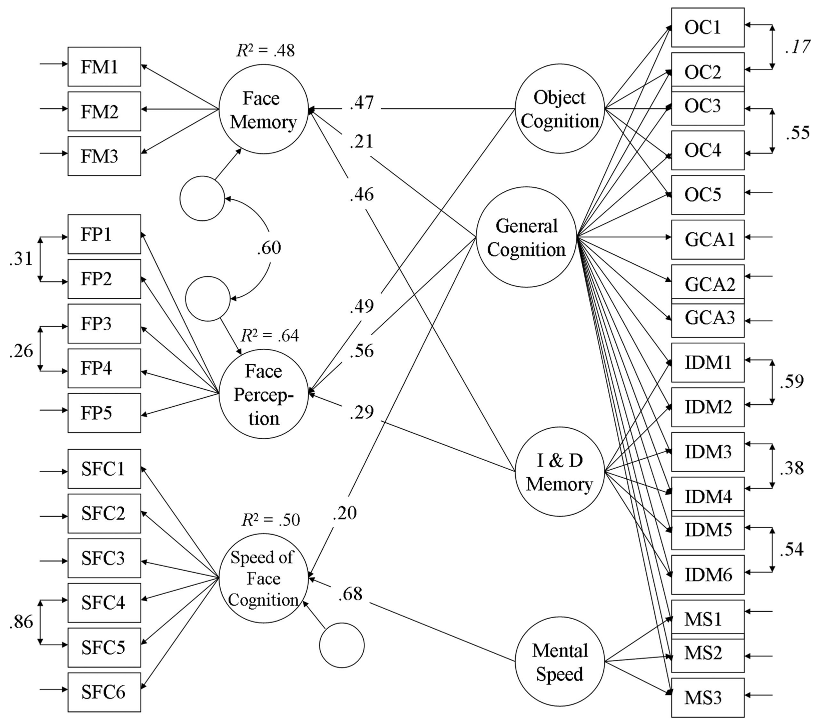

Figure 4. Schematic diagram for the structural model in Experiment 2, $\chi^2(403, N = 209) = 572$, RMSEA = .045, CFI = .940. Coefficients that did not reach statistical significance at $\alpha = .05$ are italicized. Regression weights between factors are standardized regression coefficients. Empty circles on the face-cognition side represent variance not accounted for by the predictors. FM = face memory; FP = face perception; SFC = speed of face cognition; R^2 = amount of explained variance; OC = object cognition; GCA = general cognitive ability; I & D Memory and IDM = immediate and delayed memory; MS = mental speed; RMSEA = root-mean-square error of approximation; CFI = comparative fit index.

tasks. With single tasks it is necessarily difficult or impossible to convincingly show that task specificities are irrelevant for the conclusions drawn from specific results. It is at least partly possible to abstract from task specificities by varying construct-irrelevant features of tasks and by focusing on the communalities of groups of tasks. To the degree that individual tasks fail to adequately assess the construct they were designed to test, latent variable modeling allows detecting such misspecifications.

Internal consistency estimates were disappointingly small for some measures. The main reason for this effect was the high guessing probability for many tasks. A more appropriate estimate of the reliability is the loading as presented in Figure 2. The magnitude of these fully standardized loadings is more promising. The most adequate estimate of the reliability of the abilities we propose is omega. Omega is acceptable—although not impressive—for all three factors in both studies. Other things being equal, omega would be higher if the operational differences between the tasks within a factor were smaller. However, then the nomothetic span of the latent factors would be narrower. Given the divergence of tasks used, we deem omega to be acceptable.

A few last methodological points we want to address concern the specificity of tasks, participants, and stimuli. In both experiments we used a broad spectrum of tasks, all of which are frequently used in experimental and neurocognitive research on face cognition. Although it is ultimately an empirical question, we can see no reason why different results should emerge with a different task selection—as long as the quality criteria we specified are met. It is obvious that this last statement must be made with less confidence if only a single task is used rather than a compilation of tasks sharing measurement intention. With respect to participants and stimulus specificity, the present data are obviously restricted to Caucasian participants, and so are the stimuli we used. It would be interesting to see the results with more diverse participants and stimuli.

Implications for Experimental and Neurocognitive Work on Face Cognition

Deriving relevant distinctions between facets of face cognition and adapting the experimental paradigms profited greatly from prior experimental and neurocognitive research on face cognition. We are convinced that the reverse of this knowledge transfer is also possible. The results from Experiments 1 and 2 are consistent with experimental, clinical, and neuroimaging evidence (e.g., Bruce & Young, 1986; Burton et al., 1990; Calder & Young, 2005; Gobbini & Haxby, 2007) but substantially go beyond these findings in three ways.

First, we provided evidence that essential aspects of established functional and neuroanatomical models of face cognition, such as the distinction between processes of face perception and face memory, also hold at an individual-differences level. Second, the results also exceed the assumptions of these models by being the first to show that speed and accuracy of face cognition draw on different aspects of the mind. Most established models of face recognition, especially the model by Bruce and Young (1986), were derived primarily from reaction time data. Still, they make no explicit statement concerning whether processes of face accuracy should be distinguished from processes of face speed. The majority of the previous studies in face cognition followed this example. The present findings are potentially challenging for this line of research because the choice between performance measures based on either speed or accuracy is likely to have a strong impact on the results and conclusions drawn from such experimental studies.

Finally, Experiment 2 shows that individual differences in face cognition are not strongly dependent on individual differences in general memory and object cognition. In the long-standing controversy about whether faces are just another instance of object cognition (e.g., Kanwisher, 2000; Tarr & Gauthier, 2000), our results can thus be seen as further evidence that faces are indeed special. Rather than embedding face memory under a general memory factor, assuming that faces are just one of many stimulus types, the current results endorse and support the view that faces are distinct from other materials and that face cognition functions according to specific principles. Indicators of object cognition herein used houses as stimuli but were procedurally identical to four indicators of face perception and to one indicator of face memory. Therefore, this test of face specificity in individual differences is particularly strong. Nevertheless a replication of this conclusion with a variation on the stimuli and stimulus types would be intriguing. It would be particularly important to show that face-cognition abilities can be distinguished from corresponding factors with a different stimulus type for which participants show high perceptual expertise. Future research will have to show whether the distinction between individual differences in face and object cognition also holds for tasks that draw more on object memory or on the speed of object cognition.

Identifying distinct face-cognition abilities allows for estimating the contribution of specific neurocognitive subprocesses to the new abilities (Herzmann, Kunina, Sommer, & Wilhelm, 2009). Neurocognitive subprocesses were measured as components in the event-related potential. Face perception and face memory were moderately related to neurocognitive indicators of structural face encoding (latency of the N170 component) and the access to structural representations of faces and to person-related knowledge—reflected in both latencies and amplitudes of the early and late repetition effect, respectively. The speed of face cognition was moderately related to the amplitudes of early and late repetition effects. These findings show that individual differences in face cognition partly depend on the speed of structurally encoding faces and on the efficiency and speed of accessing face memory.

Intrinsically Social Abilities

We consider the research presented here to be but a start into a psychometrically rigorous approach toward exploring individual differences in face-related abilities and social cognition. As outlined in the introduction, many intrinsically social processes rely on information delivered by the face. At first glance, these other aspects may appear to be even more interesting than those aspects emphasized here, most of all emotion recognition and emotion expression. However, we considered it important to start at the beginning, that is, with face perception and memory. Such a starting point provides a solid basis for future work tapping into other aspects of social cognition centered on the face or body. Nevertheless, we believe that the present work will find ready application in applied settings where the ability to quickly and reliably perceive and recognize other individuals is at stake.

Abilities of face cognition supposedly represent facets of social and emotional intelligence. However, social and emotional intelligence, as broad and general construct labels, currently cannot yet count as well-established and sound ability constructs. Given that there are not yet widely accepted measurement instruments available for these general abilities, we suggest that the relation between face cognition and social or emotional intelligence should be investigated once such measurement instruments are developed and evaluated. As argued earlier, we think that four attributes are critical prerequisites for sound measures of interpersonal abilities: They should (a) unequivocally tap into a circumscribed interpersonal ability, (b) be derived from well-supported experimental and neurocognitive research, (c) be important or predictive of aspects relevant in real life, and (d) compare participants' responses with an objective response standard. This set of requirements is not met by most interpersonal ability constructs.

Emotion recognition as a facet of emotional intelligence (Matthews et al., 2004, 2007; Mayer, Salovey, Caruso, & Sitarenios, 2003) is certainly closest to meeting the previously stated requirements. It will be interesting to see in the future how strongly the three face-cognition abilities are related to measures of emotion recognition. Conceptually it would make sense to think about face perception or some aspects thereof as necessary but not sufficient for emotion recognition. Obviously, it would be an interesting research question to explore whether emotion recognition can be conceived of as a function of the three face-cognition factors or whether it is at least partially independent.

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(*Appendices follow*)

Appendix A

Classification of All Indicators According to Basic Task Attributes

Table A1

Indicator	Name of indicator	Speed/ accuracy	Serial position (Experiment 1)	Serial position (Experiment 2)	Duration (in min)	No. of trials	No. of stimuli
FP1 and FP2	Sequential matching of part–whole faces	Accuracy	6	18	5.8	60	30
FP3 and FP4	Simultaneous matching of spatially manipulated faces	Accuracy	8	24	12.3	60	30
FP5	Facial resemblance	Accuracy	2	5	9.2	48	32
FM1	Acquisition curve	Accuracy	1	1	18.5	150	180
FM2	Decay rate of learned faces	Accuracy	9	16	2.4	30	60[a]
FM3	Eyewitness testimony	Accuracy	4	10	3.2	30/46[b]	60/92[b,c]
SFC1	Recognition speed of learned faces	Speed	7[b]	17[b]	20.0	32	32
SFC2	Delayed nonmatching to sample	Speed	3	9	4.3	30/46[b]	60/92[b]
SFC3	Simultaneous matching of faces from different viewpoints	Speed	5	12	2.8	30	60
SFC4 and SFC5	Simultaneous matching of upper face halves	Speed	10	4	5.2	60	30
SFC6	Simultaneous matching of morphs	Speed	11	22	2.3	30	30
GCA1	Raven's APM test	Accuracy	7[d]	17[d]		16	16
GCA2	Memory updating	Accuracy		11	18	18	18
GCA3	Rotation span	Accuracy		20	15	12	12
IDM1 and IDM2	Visual memory	Accuracy		6/26[e]	4.5/1.5[e]	24/8[e]	24/8[e]
IDM3 and IDM4	Verbal memory	Accuracy		2/19[e]	4.5/1.5[e]	24/8[e]	24/8[e]
IDM5 and IDM6	Name memory	Accuracy		14/21[e]	6/2.5[e]	24/8[e]	24/8[e]
OC1 and OC2	Sequential matching of part–whole houses	Accuracy		3	5.8	60	60
OC3 and OC4	Simultaneous matching of spatially manipulated houses	Accuracy		8	12.3	60	60
OC5	Eyewitness testimony of houses	Accuracy		23	3.2	46	46
MS1	Finding *A*s	Speed		15	1.5	80	80
MS2	Symbol substitution	Speed		7	1.8	80	80
MS3	Number comparison	Speed		25	3.5	80	80

Note. Speed/accuracy: predominant source of performance variability. FP = face perception; FM = face memory; SFC = speed of face cognition; GCA = general cognitive ability; APM = Advanced Progressive Matrices section of Raven's Progressive Matrices and Vocabulary Scales (Raven, Court, & Raven, 1979); IDM = immediate and delayed memory; OC = object cognition; MS = mental speed.
[a] Familiar faces used from acquisition curve. [b] The first number refers to Experiment 1, and the second to Experiment 2. [c] Familiar faces used from delayed nonmatching to sample. [d] Indicators SFC1 and GCA1 were accomplished together. [e] The first number refers to the immediate recall, and the second to the delayed recall.

(*Appendices continue*)

Appendix B

Sample Stimulus Sets for Indicators FP3 and OC3

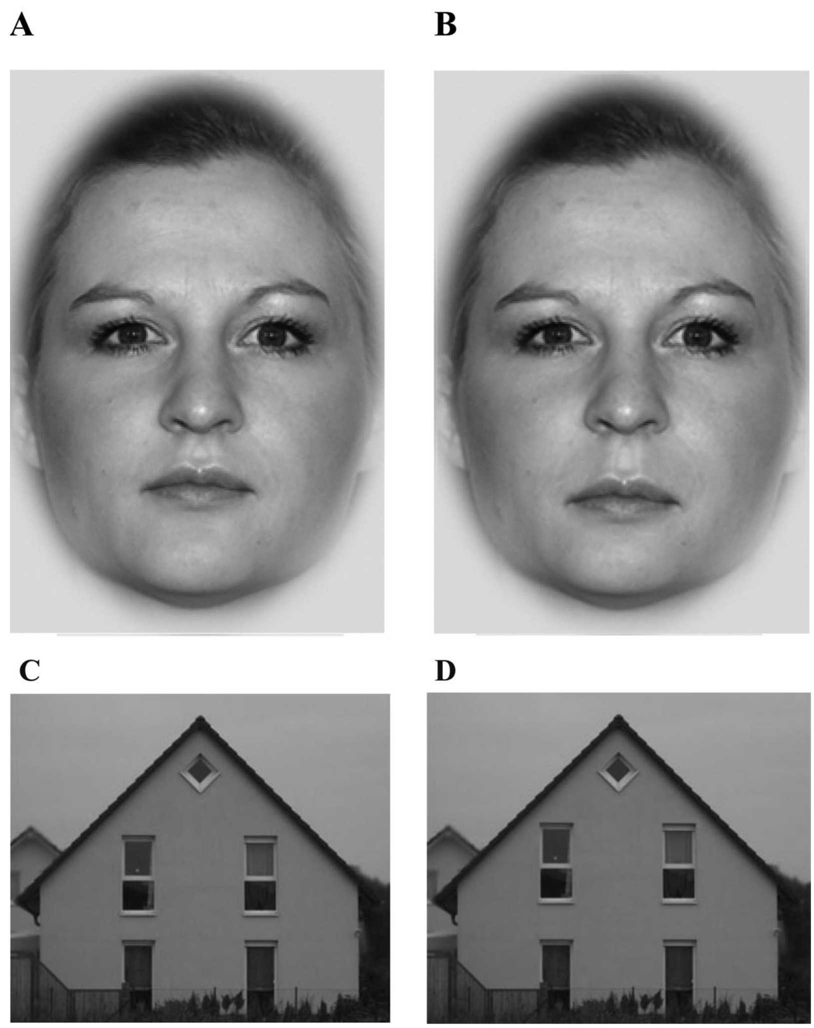

Figure B1. A: The original face for a given trial. B: The mouth–nose relation of this face was altered by moving the mouth down 11 pixels. C: The original picture of a house for a given trial. D: The window–roof relation of this house was altered by moving the windows up 9 pixels. FP3 = Face Perception 3 (simultaneous matching of spatially manipulated faces—upright); OC3 = Object Cognition 3 (simultaneous matching of spatially manipulated houses—upright).

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