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BRIEF REPORT

Face and Object Cognition Across Adult Age

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We investigated the specificity of face compared with object cognition from an individual differences and aging perspective by determining the amount of overlap between these abilities at the level of latent constructs across age. Confirmatory factor analytic models tested the specificity of speed and accuracy measures for face and object cognition ($N = 448$; 18 to 88 years). Accuracy measures were distinguishable and slightly dedifferentiated across age, which was not due to loss of visual acuity and contrast sensitivity. There was no face specificity for speed measures. These results support the specificity of face cognition from differential and developmental perspective only for performance accuracy.

Keywords: face cognition, object cognition, individual differences, age differences

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Face processing has been considered a basic component within the broader concept of social cognition (e.g., Beauchamp & Anderson, 2010; Herzmann, Danthiir, Wilhelm, Sommer, & Schacht, 2007; Wilhelm et al., 2010). This conceptualization rests on the assumption that faces are intrinsically social stimuli and that there are fundamental processing differences between faces and nonsocial stimuli. Attempts have been made to distinguish social and emotional intelligence, which are partly measured with tasks that use faces as stimuli (Hunt, 1928; Matthews, Zeidner, & Roberts, 2002; Weis & Süß, 2007), from established, academic abilities, which are measured with tasks that use words, numbers, and schematic figures. So far, a systematic comparison of individual differences across age of face cognition abilities with accuracy- and speed-related measures of perceiving and memorizing other complex visual stimuli, and are different from words and numbers, is missing. Such evidence is pivotal to draw conclusions about the specificity and validity of social and face cognition abilities.

Experimental, neuropsychological, and neuroimaging research have provided evidence for processing differences of faces and complex, visual objects. Experimental studies have shown that different processing characteristics underlie face and object cognition: holistic and relational processing for faces and feature-based processing for other objects (Bruce & Humphreys, 1994; Farah, Wilson, Drain, & Tanaka, 1998). Neurological data from patients with lesions have shown double dissociations between face and object cognition (Henke, Schweinberger, Grigo, Klos, & Sommer, 1998; Moscovitch, Winocur, & Behrmann, 1997; see Farah, 2004, for review). Finally, neuroimaging studies have identified brain areas in the ventral visual cortex differently activated by faces, buildings, and letters (Haxby et al., 2001; Ishai, Ungerleider, Martin, Schouten, & Haxby, 1999). Although these studies provided evidence for processing differences between faces and complex objects and suggest the existence of distinguishable mental abilities, none of them investigated the specificity of face cognition at the level of latent constructs (abilities). The present study provides such evidence. First, it will establish construct measures of face and object cognition based on individual differences and test whether face and object cognition constitute two separable mental abilities or a single, domain-general ability. Second, it will investigate the change of the covariance

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structure between face and object cognition across adult age because, even if construct specificity holds for face cognition in young adults, it remains to be seen whether dedifferentiation (Balinsky, 1941), and thus a reduction in specificity, occurs with increasing age (Hildebrandt, Wilhelm, Schmiedek, Herzmann, & Sommer, 2011).

Selecting the appropriate control stimulus category is important when contrasting face versus object cognition. Visual objects should be matched to faces for interest, social and biological relevance, complexity, and visual experience (cf. Kanwisher & Moscovitch, 2000). Farah et al. (1998) suggested a continuum between holistic (faces) and feature-based (written words) representations, with houses holding an intermediate position. Houses are suggested to be sufficiently similar to faces and are frequently used in neuroimaging studies. In these studies, face processing has been localized in the occipitotemporal (OTA) and fusiform face areas (FFA), whereas house processing was found to activate the parahippocampal place area (PPA). However, Haxby and colleagues (2001) suggested that the FFA and PPA—although maximally responsive to faces and houses, respectively—show considerable overlap.

Using a latent variable approach in samples of young adults, we have provided strong evidence that face cognition can be differentiated into three processing domains: face perception, face memory, and the speed of face cognition (Wilhelm et al., 2010). We define *face perception* as the ability to accurately process facial features, their configuration, and the face as a whole. We measure it with two widely used paradigms: the part versus whole (e.g., Tanaka & Farah, 1993) and the face inversion paradigm (Yin, 1969). The first paradigm captures sequential matching performance, which is only minimally affected by immediate memory because of a short retention interval and low memory load. It is thus plausible that perceptual processes are the main cause of individual differences in performance. The inversion paradigm is a pure measure of perception. Because the latent variable face perception accounts for the common variance of both paradigms, it is sound to interpret face perception performance that is captured by this latent variable as limited by perceptual processes. *Face memory* is the ability to accurately encode, store, and retrieve faces from long-term memory. The *speed of face cognition* is the ability to quickly perceive and recognize faces. These three face cognition factors were shown to be related to, but clearly distinguishable from, a general factor of object cognition accuracy in young adults (Wilhelm et al., 2010). In the study by Wilhelm et al. (2010), *object cognition* was measured with five indicators (four indicators for perception, one for memory) that were procedurally identical to the face indicators but used houses as stimuli. The *speed of object cognition* has not been considered in that previous study, and we thus investigated it here.

In a subsequent aging study, we have shown that the three-factorial structure of face cognition abilities is age-invariant (Hildebrandt, Sommer, Herzmann, & Wilhelm, 2010); and that face perception and face memory remain specific mental abilities across adult age when compared with general cognitive functioning, which was assessed as working memory, immediate and delayed memory, figural reasoning, and mental speed (Hildebrandt et al., 2011). In the present study, we investigated the specificity of face cognition compared with object cognition (accuracy and speed) across age, because face specificity compared with academic cognitive abilities might be due to stimulus complexity.

The specificity of face cognition may also depend on the participants' age. The age dedifferentiation hypothesis (Balinsky, 1941) postulates stronger relationships between cognitive abilities in older compared with younger adulthood. No study thus far has addressed the question of age-related individual differences in face cognition compared with object cognition using a latent variable approach. This approach is essential for examining ability dedifferentiation because, in contrast to single-task approaches, method specificity and measurement error can be accounted for when multiple tasks are used. Latent variables can be interpreted as abstractions from specific tasks and they control for a variety of method artifacts.

With advancing age, correlations of sensory functions and cognitive abilities may increase (e.g., Baltes & Lindenberger, 1997). Hence, we tested whether age-related decrease of visual acuity and contrast sensitivity may account for dedifferentiation of face cognition abilities, if it occurs.

Summarizing, the present study had two aims. First, we tested the specificity of face cognition abilities from object cognition abilities. We extend our previous results by including both accuracy and speed measures for face and house perception. Thus, a two factorial model of object cognition (object cognition accuracy and speed of object cognition) was tested for its factorial specificity compared with the three factors of face cognition. Following our previous work with younger adults (Wilhelm et al., 2010), we expected face specificity on the level of accuracy. No clear predictions could be made for the speed of face cognition because no related findings exist. We have, however, recently shown that the speed of face cognition and the speed of recognizing facially expressed emotions are perfectly correlated but that both factors are distinct from clerical speed, as measured in tasks with letters, numbers, and symbols (Hildebrandt, Schacht, Sommer, & Wilhelm, 2012). It might thus be predicted that the speed of face cognition is not distinguishable from the speed of object cognition, because houses are more similar in complexity to faces with emotional expressions than to letters, numbers, and symbols. Furthermore, clerical speed tasks that captured a distinguishable ability in that previous study did not share substantial method variance with the speed tasks of face cognition and emotion recognition. Whereas face tasks were two choice reaction time (RT) tasks, clerical speed tasks were based on multiple comparisons.

Second, we investigated the change of the relationship between face and object cognition, in both speed and accuracy indicators, across adult age. If dedifferentiation occurs (e.g., Balinsky, 1941), face specificity should decrease in older adults and might depend more strongly on sensory functions (Baltes & Lindenberger, 1997). Both aims were pursued with hitherto unreported data from a cross-sectional aging study (see Hildebrandt et al., 2010, for more details).

Method

Participants

Participants were 448 individuals (50% females): 149 young (M_{age} = 24, SD = 5), 148 middle-aged (M_{age} = 49, SD = 8), and 151 older adults (M_{age} = 72, SD = 5). Mean age of the whole sample was 49 years (*SD* = 20). Educational background was heterogeneous, including participants with low school degree (qualifying for occupational education), high school degrees, and academic degrees. The older group was slightly positively selected. None of the older participants performed below the commonly used cutoff score of 24 on the Mini-Mental State Examination test (Folstein, Folstein, & McHugh, 1975), taken to indicate risk for dementia.

Procedure and Stimuli

Tasks were programmed using Inquisit 2.0© and administrated on PCs with 17-in. color monitors, 85 Hz refresh rate, and 1280 × 1024 resolution. Face and house stimuli were converted to gray scale and edited in the same format. Faces were fitted into a vertical ellipse of 200 × 300 pixels, so that only internal features of a face were visible. More details on procedure and stimuli can be found in the online supplemental material and in Hildebrandt et al. (2010).

Measures

The study included two tasks of face perception (FP), each with two experimental conditions, yielding four performance indicators. Four tasks measured face memory (FM). Five tasks assessed the speed of face cognition (SFC). One SFC task was composed of two experimental conditions. Thus, two performance indicators were derived from this task. Consequently, six indicators for SFC were available. For the measurement of object cognition, we replaced face stimuli with houses in the two face perception tasks and in two of the speed tasks. Both object perception (OP) tasks included two different experimental conditions, yielding four indicators, similar to their face pendant. Analyses were based on four performance indicators for OP and three indicators for the speed of object cognition (SOC). Face and object perception tasks required participants to extract relevant facial or object features, to discern their relationships to one another, and to configurally process the whole stimulus. The face and house tasks based on the part-whole paradigm (indicators FP 1, FP 2, and OP 1, OP 2, respectively, see Appendix A of the online supplemental material) also capture visual short-term memory (STM). By modeling performance on these tasks in the same factor along with the paradigm of simultaneous matching of faces and houses, the face perception factor captures their common variance, that is, perceptual processing but not STM. Face memory tasks required encoding and recognizing unfamiliar faces. Speed tasks required perceptual processing, encoding, and recognition of faces and houses. Accuracy in speed tasks was at ceiling for all indicators. Task descriptions and descriptive statistics are provided in the online supplemental material.

The Freiburg Vision Test (FrACT; Bach, 2007) was used to measure visual acuity (VA) and contrast sensitivity (CS). VA and CS were taken with the best optical correction, where applicable. We analyzed visual acuity expressed in Snellen's fraction decimal units. Higher values express better vision. FrACT defines contrast sensitivity by considering the luminance of the bright and dark parts of correctly recognized optotypes. Lower values represent better sensitivity to contrast.

Scoring and Analytical Approach

Speed data were Winsorized (Barnett & Lewis, 1978) and parameterized as averages of inverted latencies (calculated: 1,000/RT in ms) across trials, representing the number of correct responses per second. Performance for perception and memory indicators was scored as proportion of correct responses across all trials of a given measure.

Analyses were conducted in Mplus 5.1 (L. K. Muthén & Muthén, 1998–2007). Traditionally, multiple-group mean and covariance structures (MGMCS; e.g., Little, Card, Slegers, & Ledford, 2007) are used to investigate possible changes of latent level relationships across different age groups. The MGMCS approach is the method of choice whenever analyses are conducted on extreme groups, like younger versus older adults. In the present study, however, observations were collected along a continuous age variable. In order to exhaust the information of the age variable, age-weighted (locally weighted) structural equation modeling (LSEM; described in detail by Hildebrandt, Wilhelm, & Robitzsch, 2009) was used alongside MGMCS analyses. This approach combines SEM with the method of locally weighted averaging, used in nonparametric regression (Fox, 2008) and nonparametric mixed effects models (Wu & Zhang, 2006). We calculated weights for observations at every focal age, defined in 1-year steps from 20 to 80 years, using a normal kernel function of weighting. Weights were highest for observations at the focal age, falling off symmetrically with increasing distance of an observation from the focal value. Based on the calculated sample weights, a series of 61 SEM models were fitted for all possible focal ages between 20 and 80 years. Parameter estimates with corresponding standard errors from these model series will be plotted across age in order to describe their changes in form of age gradients.

We scaled latent factors by fixing the loadings for each latent variable to an average of one and the sum of the indicator intercepts to zero (Little et al., 2007), which has the advantage that all loadings and factor variances can be freely estimated. Model fit was assessed with the comparative fit index (CFI) and the root mean square error of approximation (RMSEA).

Results

Nonseparable Speed Factors

A series of MGMCS models, defining correlated factors for FP, FM, and SFC, on the one side, and OP and SOC, on the other side, were estimated across the three age groups. The results support metric invariance in the MGMCS context (equal factor loadings across groups). The fit of the metric invariant model was $\chi^2(554) = 876.8$, $p < .001$, CFI = .931, RMSEA = .062, which suggested that the data fit the model well. Relative to competing models, the metric invariant model was the model of choice. Correlations among accuracy based latent factors were moderate to high in all age groups (.29 to .82). Correlations between speed and accuracy factors were low (.04 to .41). However, the two speed factors, SFC and SOC, were highly correlated, $r = .99$ in the younger, $r = .96$ in the middle-aged, and $r = .99$ in the older group. This strongly indicates that a single, domain-general speed factor would more appropriately capture the measured individual differences. Such a single speed factor that included all (face and object) speed indicators was specified. The fit of this model was comparable with the first: $\chi^2(568) = 895.2$, $p < .001$, CFI = .930, RMSEA = .062. The $\Delta\chi^2$ test (Bollen, 1989) of 18.4, with Δdf = 14, was not significant and showed that a factorial differentiation between SFC and SOC was unnecessary for all age groups. Speed measures of face cognition thus capture the same ability as speed measures for the processing of similarly complex visual stimuli.

Dedifferentiation Among Accuracy Measures

Given that a single speed factor for face and object cognition described individual differences in all three age samples best, the investigation of dedifferentiation between face and object cognition was restricted to accuracy-based measures. We report results on the factor correlations based on age-weighted SEMs. Please note that MGMCS results were completely accordant with those obtained by locally weighted models. However, the latter allow a more stringent and precise description of the shape of the parameters' trajectory across age.

First, a model was estimated with three correlated latent factors of FP, FM, and OP and two manifest variables of vision (VA and CS), which were allowed to correlate with each other and the latent variables. This model was repeatedly estimated at every focal age—as outlined in the Method. Absolute fit indices suggested that all locally estimated models fitted well: CFI ranged from .93 to .97, and RMSEA values were between .03 and .06. All factor loadings were significant at $p < .01$. Correlations of OP with FP and FM slightly increased across age, suggesting dedifferentiation. The correlation between FP and OP increased from $r = .66$ at age 20 to $r = .83$ at age 80 years. The correlation between FM and OP increased from $r = .33$ at age 20 to $r = .62$ at age 80 years. Age gradients of these correlations with corresponding confidence intervals (± 1 *SE*) are displayed in Panel A of Figure 1. Relative to young adults, the level of the correlations between OP and FP is substantial and notable at approximately age 65. OP was significantly closer related to FM beginning in middle adulthood. Importantly, face and object factors remained distinguishable until old age, although their relationship slightly increased. This suggests a weak form of dedifferentiation of face and object cognition, in contrast to a strong form in which latent factors would be perfectly or near perfectly correlated.

Second, to investigate the impact of VA and CS on the dedifferentiation of face and object cognition, we introduced regression paths from VA and CS to all latent factors (dependent variables; multiple indicators, multiple causes [MIMIC]model, with only direct effects as described by B. O. Muthén, 1989). VA and CS were included as correlated variables. In this model, vision-related variance of the latent factors was partialed out. Locally weighted models were reestimated after this modification. Age-gradients of correlation parameter for FP and OP, as well as FM and OP, are shown in Panels B1 and B2 of Figure 1. The estimated gradients from the previous model series, where vision was not partialed out, are also displayed in Panels B1 and B2. The correlations were somewhat lower after statistically controlling for VA and CS, but the shape of both gradients was independent from VA and CS. CS was barely related to face and object cognition in young age, but slightly more related in middle and old age. The correlations between VA and latent factors for face and object cognition did not exceed $r = .35$, and the correlation of CS with latent factors was

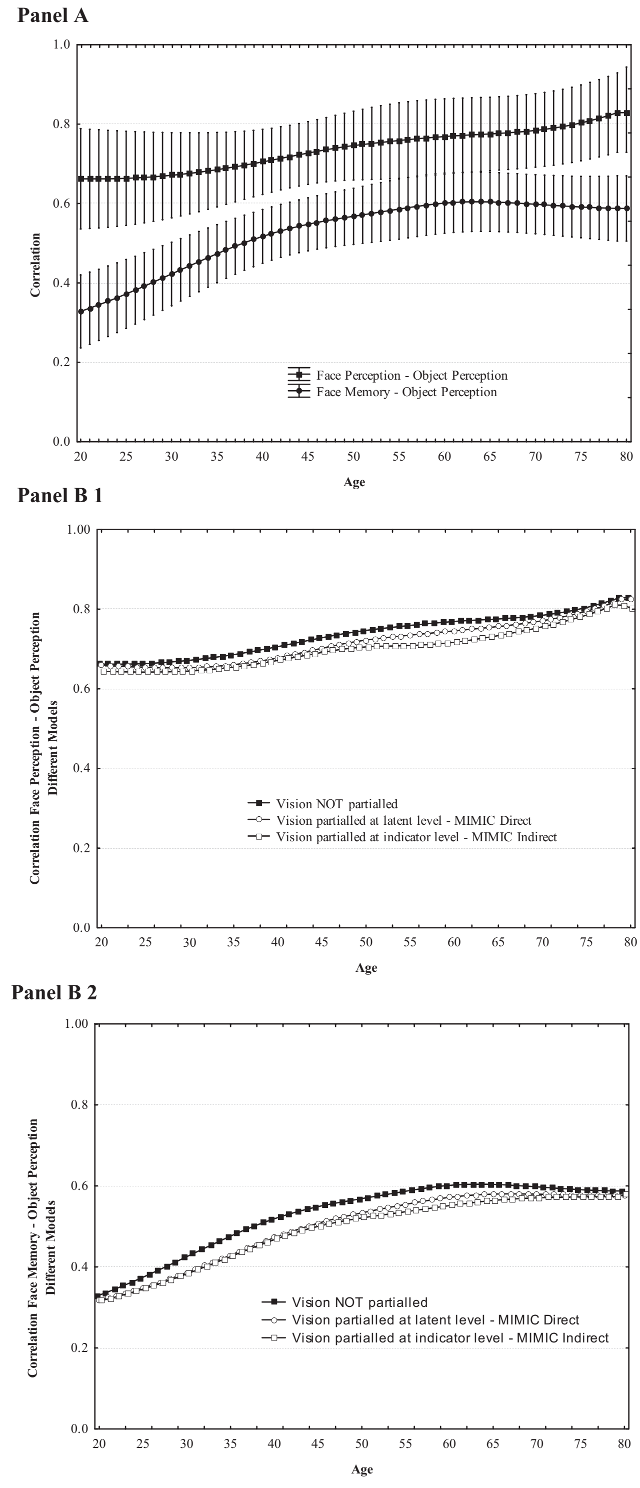

Figure 1. Age gradients of correlations. Panel A: Correlation between face cognition and object perception. Panel B1: Correlation between face perception and object perception, with contribution of vision partialed out (at the level of latent variables and at the level of indicators). Panel B2: The same gradients as Panel B1 for face memory.

not higher than $r = -.18$ (lower values representing better sensitivity to contrast).

Age-weighted SEMs were also estimated for MIMIC models with only indirect effects (B. O. Muthén, 1989; Figure 2) in a separate set of models. In these models, vision was partialed out at the level of the indicators. We investigated whether factor correlations showed less increase if vision was partialed out at the manifest level. Gradients of correlations from these model series are also displayed in Panels B1 and B2 of Figure 1. Again, correlations were slightly lower after statistically controlling for VA and CS at the manifest level than at the latent level, but the shape of both gradients was independent from VA and CS.

Discussion

Four conclusions can be drawn from the present results. First, the data unequivocally show that individual differences in the speed of face and object cognition cannot be distinguished from each other. Speed factors are completely overlapping in younger adulthood and across adult age. Second, individual differences in face and object perception are distinct throughout adult age, although their relationship is continuously increasing from a moderate level in young adulthood to substantially related abilities in old age. We interpret this result as indicating a weak form of dedifferentiation. This dedifferentiation is, however, not face-specific and operates more at a general cognitive level. In a previous report (Hildebrandt et al., 2010), we presented evidence for an essentially stable relationship between face perception and face memory across age. The correlation between both factors increased only slightly (about .10) across age. Therefore, in the case of face perception and memory, there is not much evidence for dedifferentiation. Third, individual differences in the accuracy of object perception and face memory are clearly less related than object perception and face perception. The correlation between object perception and face memory increased with age less continuously and showed an earlier onset of dedifferentiation. Fourth, VA and CS are only weakly related to face and object cognition and cannot account for the observed weak dedifferentiation.

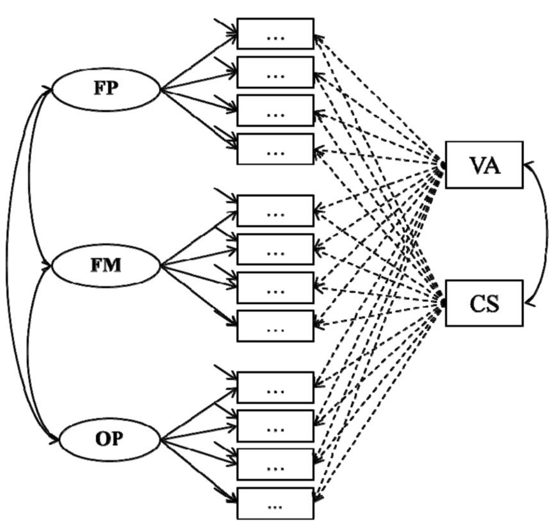

Figure 2. Multiple Indicators Multiple Cause Models (MIMIC) with indirect effects estimated as age-weighted structural equation models. CS = contrast sensitivity; FP = face perception; FM = face memory; OP = object perception; VA = visual acuity.

The result that the stimulus domain (faces vs. houses) does not differentially affect the speed of perception and recognition is a surprising and provocative finding. It implies that the same cognitive mechanism represents the source of individual differences in the speed of perceiving, learning, and recognizing faces and other complex objects like houses. In previous work, we could separate the speed of face cognition from mental speed, as assessed by clerical speed tasks with words, numbers, and symbols (Wilhelm et al., 2010). In addition, several studies suggested that cognitive or mental speed is a multidimensional construct that can distinguish between different modalities (e.g., Ackerman & Cianciolo, 2000; Danthiir, Wilhelm, Schulze, & Roberts, 2005; Kyllonen, 1985; Roberts & Stankov, 1999; see also Carroll, 1993). Speed tasks can be classified with respect to different criteria such as processing components, stimulus characteristics, or a combination of both. Kyllonen (1985) identified six dimensions of processing speed. He found four factors associated with the involved processing components (encoding, comparison, decision, and response execution) and two factors that were linked to the task's content, namely letters, primarily involving perceptual processes, and words, mainly based on semantic processes. Our previous and present results suggest a further distinguishable content—that of complex, visual objects—which is independent from the social or nonsocial nature of the stimulus. Similar abilities for the speed of face and object processing challenge the assumption of face specificity regarding processing speed (e.g., Bruce & Humphreys, 1994).

In contrast to the speed data, the accuracy data provided further evidence for the distinction between social and nonsocial abilities and confirm the idea of face specificity at the level of latent constructs. These findings should be extended in future studies that include additional stimulus classes and also control for prior expertise with nonface stimuli. We found weak factorial dedifferentiation between accuracy of face and object cognition. This corresponds to neuroimaging data and is in line with models postulating broader recruitment of resources in the aging brain (see Davis, Dennis, Daselaar, Fleck, & Cabeza, 2008). For old age, Payer et al. (2006) reported a loss of neural specificity within the ventral visual cortex for faces and houses, whereas face-specific activity in the FFA was partly maintained. Face specificity for accuracy measures is thus relatively stable until old age, despite a weak dedifferentiation that might be due to broader recruitment of cognitive resources in older age that leads to a loss of specialization at processing similar stimuli classes. Finally, dedifferentiation was not accounted for by the loss of visual acuity and contrast sensitivity across age, which might be the first candidate in the search for explanations of dedifferentiation between two vision-dependent abilities.

In conclusion, we provided evidence for the specificity of face cognition from an individual differences and aging perspective, but only for performance accuracy. This specificity is preserved across the adult age span despite a weak form of dedifferentiation. For performance speed, however, no specificity of face cognition abilities was found.

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