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Parallel Processing in Face Perception

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The authors examined face perception models with regard to the functional and temporal organization of facial identity and expression analysis. Participants performed a manual 2-choice go/no-go task to classify faces, where response hand depended on facial familiarity (famous vs. unfamiliar) and response execution depended on facial expression (happy vs. angry). Behavioral and electrophysiological markers of information processing—in particular, the lateralized readiness potential (LRP)—were recorded to assess the time course of facial identity and expression processing. The duration of facial identity and expression processes was manipulated in separate experiments, which allowed testing the differential predictions of alternative face perception models. Together, the reaction time and LRP findings indicate a parallel architecture of facial identity and expression analysis in which the analysis of facial expression relies on information about identity.

Keywords: face perception, facial expression, facial identity, mental architecture, parallel processing

Faces are undoubtedly stimuli that are extremely important for social cognition and interaction. Thus, it is clear that a face can reveal an enormous range of socially relevant information. For example, from the face an observer may derive a person's identity, gender, age, emotional state, or his or her current focus of attention. Prominent models of face recognition have assumed that these different types of perceptual analyses for faces are mediated by functionally independent components that operate in parallel. In particular, parallel processing and functional independence have been asserted between modules that mediate the recognition of facial identity and facial expression (e.g., Bruce & Young, 1986; Young, Newcombe, de Haan, Small, & Hay, 1993; for a review, see Calder & Young, 2005). Yet, the temporal organization of facial identity and expression processing is not fully understood. One reason for this situation appears to be the difficulties of inferring the organization of covert mental processes and their online time course from reaction time (RT) measures alone (cf. Osman, 1998). In the past decade, however, researchers have developed electrophysiological methods to attack this inferential problem. The major aim of the present research, therefore, was to reveal the functional organization of basic mechanisms of face perception using a psychophysiological approach that, although established in mental chronometry (cf. Coles, Smid, Scheffers, & Otten, 1995), has not yet been applied to the perception of facial identity and expression.

The principal model of face recognition assumes parallel processing within functionally independent face processing components. Thus, Bruce and Young's (1986) model of face recognition postulates that faces are initially processed in a common stage of structural encoding. Subsequently, different aspects of the face, such as identity, expression, or facial speech, are analyzed within mutually independent processing routes. More specifically, it has been assumed that facial identification is achieved via viewpoint- and expression-independent descriptions of faces that are stored in so-called face recognition units (FRUs), which contain the structural codes of familiar faces. By contrast, facial expression is analyzed in a parallel but functionally independent pathway. More recently, Haxby, Hoffmann, and Gobbini (2000) suggested a neuroscientific model of face recognition in which the idea of parallel processing routes for facial identity and expression analysis is preserved while the assumption of functional independence is relaxed. This model assumes that two separate streams depart from inferior occipital cortex. One stream departs to the face-responsive region within the inferotemporal cortex (including the fusiform face area or FFA) that is thought to represent invariant facial features involved in facial identification. A second stream that departs to the face-responsive region within the superior temporal sulcus (STS) appears critical for the recognition of facial expression and is assumed to mediate mainly the processing of changeable facial aspects. Although the two processing streams are considered to operate in parallel, they may interact to some degree such that facial identity processing in the FFA supports the analysis of facial expression in the STS, for example, when individuals have distinctive expressions.

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The assumption that functionally independent pathways mediate different aspects of face perception (e.g., Bruce & Young, 1986; Young et al., 1993) has received support from different lines of research. For instance, dissociations and selective impairments of facial identity or facial expression recognition have been observed in humans suffering from selective brain injuries (Bornstein, 1963; Damasio, Damasio, & Van Hoesen, 1982; Kurucz & Feldmar, 1979; Tranel, Damasio, & Damasio, 1988; Young et al., 1993). Moreover, single unit recordings in monkey temporal cortex have suggested that different cortical cell populations are sensitive to facial identity and facial expression (Hasselmo, Rolls, & Baylis, 1989), a finding that has been confirmed in human studies using positron emission tomography (PET; e.g., Sergent, Ohta, MacDonald, & Zuck, 1994) and functional magnetic resonance imaging (fMRI; e.g., Haxby et al., 2000). Finally, in RT studies, it has been found that facial identity processing is facilitated by the repetition of familiar faces because of the reactivation of FRUs, whereas speeded performance in expression tasks does not show such a face repetition benefit (e.g., Young, McWeeny, Hay, & Ellis, 1986; Ellis, Young, & Flude, 1990). This RT dissociation is again consistent with the idea of functionally independent facial identification and expression processes.

However, more recent face perception studies have challenged this independency assumption on the basis of behavioral, computational, and neuroimaging evidence (e.g., Ellamil, Susskind, & Anderson, 2008; Fox & Barton, 2007; Ganel & Goshen-Gottstein, 2004; Ganel, Valyear, Goshen-Gottstein, & Goodale, 2005; Schweinberger & Soukup, 1998; Vuilleumier & Poutois, 2007; Winston, Henson, Fine-Goulden, & Dolan, 2004; for a review, see Calder & Young, 2005). First, Calder and Young (2005) suggested that facial identity and expression may be initially coded in a single multidimensional representation system and only later analyzed by more specialized higher level identity and expression processes. Within the facial representation system, as demonstrated in a computational study of face recognition using principal component analysis (Calder, Burton, Miller, Young, & Akamatsu, 2001), the coding of facial identity and expression is not completely independent as some principal components code both facial dimensions. Second, on the basis of results obtained in face adaptation studies, Fox and colleagues (Fox & Barton, 2007; Fox, Oruc, & Barton, 2008) proposed expression-invariant representations of identity but identity dependent in addition to identity-invariant representations of expression, in line with findings of an fMRI adaptation experiment (Winston et al., 2004). Clearly, the principal component analysis and adaptation results suggest that the independence of facial identity and expression processing is relative rather than absolute. This notion is indeed supported by studies using the Garner interference paradigm, in which it was found that participants are unable to ignore irrelevant variations in the identity or gender of faces when processing facial expression, whereas they could ignore facial expression when facial identity or gender was task-relevant (Atkinson, Tipples, Burt, & Young, 2005; Baudouin, Martin, Tiberghien, Verlut, & Franck, 2002; Schweinberger & Soukup, 1998; for recent corroborating evidence from face adaptation studies, cf. Fox et al., 2008). Schweinberger, Burton, and Kelly (1999; see also Atkinson et al., 2005) further examined whether differences in task difficulty are responsible for the asymmetric Garner interference effect. Thus, it is conceivable that the faster-to-process facial dimension (e.g., identity) interferes more with the slower-to-process dimension (e.g., expression) than vice versa. To examine this hypothesis, Schweinberger et al. manipulated the time demands for facial identity and expression analysis by using faces that were morphed along the dimensions happy–sad and familiar–unfamiliar. It is important to note that they found that even for stimulus conditions in which the classification of facial identity was more time consuming than those of facial expression, performance in the expression classification task was still impeded by irrelevant variations in facial identity. By contrast, irrelevant variations in facial expression did not interfere with identity judgments. To explain these findings, Schweinberger et al. suggested a parallel-contingent processing model in which facial expression analysis depends on identity analysis, yet processing of identity and expression temporally overlaps.

The assumption of an asymmetric effect from facial identity to expression processing, however, has not remained uncontested. Thus, when facial expression was made easier to discriminate than facial identity, Ganel and Goshen-Gottstein (2004) found interference both from identity-to-expression and from expression-to-identity processing, suggesting that the two processing pathways interact in both directions.[1] They further argued that the asymmetric effect reported by Schweinberger and colleagues (1999) may have been due to differences in the relative discriminability of facial identity and expression. Although this is logically possible, because the stimuli used for identity and expression classification were nonidentical in their study, it may not be very likely given that RTs in the two tasks did not differ overall. It may also be noted that event-related brain potential (ERP) studies provided evidence in line with the one-directional processing contingency as suggested by Schweinberger et al. Thus, Potter and Parker (1997) and Münte et al. (1998) found the earliest same–different ERP effects in an identity matching task to occur at around 200 ms. By contrast, the earliest ERP effects in expression matching occurred only at around 450 ms, suggesting that identity processing precedes expression analysis (but see Bobes, Martin, Olivares, & Valdes-Sosa, 2000). This conclusion has to be treated with caution, however, as some ERP studies showed influences of facial expression on the ERP before the N170 component (e.g., Eger, Jedynak, Iwaki, & Skrandies, 2003; Eimer & Holmes, 2002). As the N170 is taken to reflect the structural encoding of faces (Eimer, 2000b), this latter series of studies suggests that the time course of cortical expression analysis may be more rapid than the one of structural encoding for faces.

Whereas the studies reviewed above may suggest an asymmetric relationship between identity and expression processing, it appears that our knowledge about the temporal organization of facial identity and expression analysis is limited for several reasons. First, the Garner paradigm does not provide information about the

[1] In the study of Ganel and Goshen-Gottstein (2004; see also Ganel et al., 2005), participants performed both identity and expression categorizations, whereas in Garner studies reporting asymmetric Garner interference effects, separate participant groups performed the identity task and the expression task (e.g., Atkinson et al., 2005; Schweinberger et al., 1999; Schweinberger & Soukop, 1998). Therefore, it is possible that transfer effects contributed to the results by Ganel and colleagues (Ganel & Goshen-Gottstein, 2004; Ganel et al., 2005). For instance, prolonged performance on an expression task may have made expression of the same faces harder to ignore in a subsequent identity task.

exact time course of identity and expression processing or about the specific locus within information processing where the interaction between these two stimulus dimensions takes place. Thus, it is possible that the interference effect happens at a stage that follows the processing of facial identity and expression (cf. Atkinson et al., 2005). Second, although consistent with a parallel processing architecture, PET and fMRI findings are limited because the temporal resolution of signal changes is too low to allow the meaningful study of rapid cognitive processes in real time. Third, a limitation of previous ERP studies comparing the time course of facial identity and expression processing is that they have focused on relative timing differences between different face categorization tasks. Moreover, ERP studies indicating rapid expression analysis examined only schematic faces (Eger et al., 2003) or unfamiliar faces displaying fearful and neutral expressions (Eimer & Holmes, 2002) rather than the integrated processing of facial identity and expression. Thus, at least to our knowledge, the combined processing of identity and expression has not been examined so far using ERPs. Finally, alternative processing models of face perception have not been elaborated with respect to the functional organization of the different component processes by means of chronometric methods.

The main issue in the debate about face processing models indeed is whether facial identity and expression processes are fully independent from each other, as assumed by Bruce and Young's (1986) model, or whether these processes interact in one way or another. Thus, a parallel-dependent model still assumes parallel facial identity and expression analysis while allowing for some dependency between these two processing routes, for example, by incorporating identity-dependent expression representations (e.g., Ellamil et al., 2008; Fox & Barton, 2007) or common representation dimensions (Calder et al., 2001). Another possibility is that identity information is fed into expression analysis, as suggested by the parallel-contingent model of face recognition (Schweinberger et al., 1999).

The Present Study

The present study's main goal was to provide an in-depth look at the functional organization of facial identity and expression processing in an attempt to discriminate between alternative face recognition models. To this end, we used advanced mental-chronometric techniques that supplement the RT method with the recording of electrophysiological time markers. Thus, ERPs provide access to neural activity that is triggered during sensory, cognitive, and motor processing with extremely high (millisecond-to-millisecond) time resolution. We took advantage of a paradigm that uses the lateralized readiness potential (LRP) as a particularly useful measure to trace response-specific preparation to distinguish between different models of information processing (cf. Coles, 1989; De Jong, Wierda, Mulder, & Mulder, 1988; Eimer, 1998; Miller & Hackley, 1992; Osman, Bashore, Coles, Donchin, & Mayer, 1992). The LRP is a continuous online measure of selective motor activation, with a clear neuroanatomical origin within the primary motor cortex (cf. Leuthold & Jentzsch, 2002). Basically, it is assumed that the LRP begins to deviate from baseline as soon as information about the response hand is available (cf. Kutas & Donchin, 1980; Eimer, 1998).

To infer the locus of experimental effects within information processing, a first important characteristic of the LRP is its onset in waveforms time-locked to the onset of either the stimulus or the overt response (cf. Leuthold, Sommer, & Ulrich, 1996; Osman & Moore, 1993). The interval from stimulus onset to stimulus-locked LRP onset (S-LRP interval) indicates the duration of those processes occurring before the start of the LRP. The interval between response-locked LRP onset and the overt response (LRP-R interval) indicates the duration of those processes of stimulus evaluation that occur after LRP onset. In other words, the S-LRP and the LRP-R intervals serve as chronometric markers for the duration of premotoric and motoric processing, respectively. Another important characteristic of the LRP is its independence from the execution of an overt response. Thus, an LRP is also observed when participants covertly prepare a forthcoming response on the basis of partial stimulus information, and another stimulus attribute—perhaps one that takes more time to process—determines whether or not to execute the preactivated response (e.g., Miller & Hackley, 1992; Osman et al., 1992). Hence, it is evident that an LRP is present not only in go trials but also in no-go trials, that is, when participants first covertly activate a response that is subsequently withheld.

To reveal the cognitive architecture underlying the information processing systems, the use of a hybrid-choice RT go/no-go task in combination with the recording of the LRP has turned out to be particularly successful (e.g., Abdel Rahman, Sommer, & Schweinberger, 2002; Miller & Hackley, 1992; Osman et al., 1992; Smid, Mulder, Mulder, & Brands, 1992; van Turennout, Hagoort, & Brown, 1997, 1999). This is nicely illustrated by the study of Abdel Rahman and colleagues (2002), who aimed to distinguish between serial and parallel access to semantic and name information in face identification. They employed a choice RT go/no-go task in which the stimulus had to be classified along two separate information dimensions of portrayals of familiar politicians. The semantic classification, which was manipulated in difficulty (easy = nationality vs. difficult = political party), determined response hand (left vs. right), whereas the presumably slower phonological name decision determined response execution (go vs. no go). Abdel Rahman et al. hypothesized that according to both a serial model and a parallel model with partial output of semantic information to response activation, the stimulus-locked LRP onset should reflect the time demands of semantic information retrieval. Most important, however, the serial model predicts the LRP-R interval and the duration of hand activation in no-go trials, as measured by the no-go LRP, to be independent of semantic classification difficulty because phonological processing is contingent on the completion of semantic processing. By contrast, the parallel model critically assumes that increases in semantic processing time do not propagate to parallel phonological processing. Thus, when semantic categorizations are hard compared with easy, the interval between semantic-driven hand activation and phonology-driven response execution should become smaller. This effect should be reflected by a *shorter* LRP-R interval and a shorter or absent no-go LRP for difficult than for easy semantic decisions. The LRP findings of Abdel Rahman et al. clearly supported the parallel processing model of semantic and name information retrieval in face identification because the LRP-R interval decreased with increasing semantic difficulty, whereas the no-go LRP was present only for easy but not for difficult semantic decisions.

In the present experiments, we used the LRP in combination with the choice RT go/no-go paradigm to provide a test of alternative views about facial identity and expression processing. As illustrated by the study of Abdel Rahman et al. (2002), selectively manipulating the time demands of cognitive processes is a powerful way to strengthen the inferential logic of this RT paradigm. Therefore, in a behavioral experiment, we first validated a face stimulus set with respect to the time demands of facial familiarity and expression decisions. In two further experiments, we employed the choice RT go/no-go paradigm in combination with the recording of electrophysiological markers of information processing to test alternative face processing models. The specific predictions are outlined in detail in the context of these experiments.

Experiment 1

To vary the time demands of identity and expression processing, we used *morphing*, an image manipulation method to attenuate or exaggerate characteristics of real faces (e.g., Beale & Keil, 1995; Benson & Perrett, 1991; Young et al., 1997). Schweinberger et al. (1999) demonstrated that morphing can be used to manipulate the perceptual salience of identity or expression information in faces quite selectively. Compared with that study, we used a larger stimulus pool to discourage picture-based strategies. Also, to assess the processing demands of the facial stimulus set that would be used in the later ERP experiments, we asked participants to perform speeded familiarity decisions to familiar and unfamiliar faces and expression decisions to happy and angry faces.

However, inferences from the present familiar–unfamiliar morphing study might be problematic given that the distinction between expression is assumed to be categorical (Calder, 1996), whereas the one between familiar and unfamiliar faces presumably is not because unfamiliar faces may be similar to faces that we know (but see Levin & Beale, 2000; Campanella, Quinet, Bruyer, Crommelinck, & Guerit, 2002).[2] In addition, morphing of familiar and unfamiliar faces is by definition asymmetric because familiar faces form a closed set and unfamiliar faces an open set. This asymmetry is likely to be reflected at the processing level, for example, in terms of an exhaustive memory search for unfamiliar faces but a self-terminating search for familiar faces. As a result, a combination of different levels of morphing on the familiarity continuum could be problematic. One might question, therefore, whether the duration of identity and expression processing can be selectively influenced by morphing separately across the familiarity and the expression continuum. With Experiment 1, we addressed the above concerns by testing whether discriminability effects obtained for faces morphed along the familiarity continuum were equivalent to those for famous faces morphed along a symmetric politician–actor dimension.

To this end, we created a second stimulus set for which photographs of famous politicians and actors, displaying happy and angry expression, were separately morphed on the identity and the expression dimensions. This approach allowed us to address the problem of asymmetric effects of morphing for the familiarity dimension because famous faces can be easily assigned to the respective category of actors versus politicians. All these measures together should be suitable for testing whether morphing faces is a valid method of selectively manipulating the duration of expression and identity analyses as required for the following ERP studies.

Method

Participants. Twenty-four participants between 18 and 36 years of age ($M = 24.95$ years) were recruited. Twelve performed the identity task, and 12 performed the expression task. All participants reported normal or corrected-to-normal vision and were paid for participation.

Stimuli acquisition and apparatus.

Familiar and unfamiliar face set. A set of 96 images of famous and unfamiliar faces displaying happy or angry expressions taken from video resources was edited using Adobe Photoshop (Version 7.0) to remove the background and convert them into 8-bit grayscale images adjusted to comparable levels of brightness and contrast. The horizontal and vertical resolution of each photographic frame was 170×216 pixels (72 pixels/in.).

In a separate questionnaire study, 10 students (five men) of the University of Glasgow rated the 96 stimuli with regard to the type of displayed expression (i.e., happy, angry, sad, surprised, disgusted, fearful, and neutral), intensity of expression on a scale from 0 (*low*) to 5 (*high*), and familiarity on a scale from 0 (*unfamiliar*) to 5 (*highly familiar*). In addition, participants were asked to provide semantic information (e.g., name, movie) in the case they recognized a face as familiar. On the basis of this questionnaire study, images of 10 famous persons and 10 unfamiliar persons, each displaying happy and angry expressions, were selected. Separate t tests were performed to test for differences between the intensity ratings for happy and angry expressions and between ratings for famous and unfamiliar faces. Famous faces were rated more familiar ($M = 4.46$) than unfamiliar faces ($M = 0.28$), $t(9) = 40.7$, $p < .001$, and angry facial expressions were rated ($M = 3.95$) as more intense than happy facial expressions ($M = 3.57$), $t(9) = 2.1$, $p < .05$. Intensity of angry expression ($M = 3.96$ vs. 3.93), $t < 1$, and intensity of happy expression did not differ between famous and unfamiliar faces ($M = 3.68$ vs. 3.46), $t < 1$.

To independently manipulate the salience of expression as well as the familiarity of the face, we morphed each photograph using Sierra Morph (Version 2.5) software. Each happy face was paired with the angry face of the same person and each famous face was paired with an unfamiliar face of similar age, head orientation, and expression. Morphing for each pair was performed separately for famous and unfamiliar faces from happy to angry (expression morph) and separately for faces displaying angry and happy expression from familiar to unfamiliar (identity morph). For each pair, eight images were created by blending two faces in the following proportions of Face 1 relative to Face 2: 100:0, 85.7:14.3, 71.4:28.6, 57.1:42.9, 42.9:57.1, 28.6:71.4, 14.3:85.7, and 0:100. As a result, there were 80 famous and 80 unfamiliar faces for the facial expression morph continuum as well as 80 faces displaying happy expression and 80 faces displaying angry expression for the facial identity morph continuum (see Figure 1 for example stimuli).

[2] We thank an anonymous reviewer for making these points.

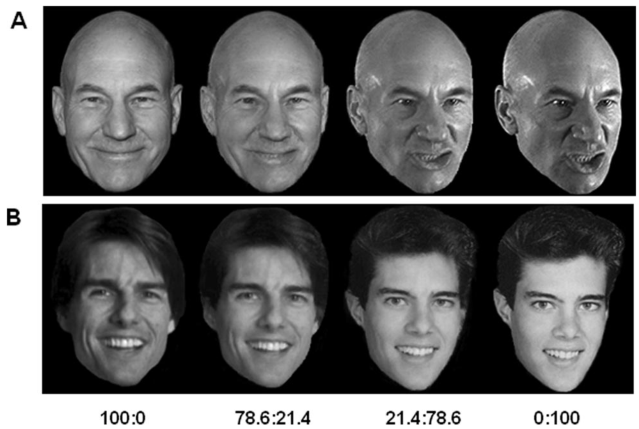

Figure 1. Examples of the test stimuli used: (A) expression morph from happy to angry for one person, and (B) identity morph from familiar to unfamiliar for one expression. The proportion of Face 1 relative to Face 2 (morph level 1 = 100:0 and 0:100, morph level 3 = 71.4:28.6 and 28.6:71.4) is indicated below the stimuli.

This stimulus set was tested in a pilot RT experiment. Here, preliminary data analysis for individual faces revealed inappropriate performance for a few photographs (two famous, two unfamiliar) as reflected by high RT variability ($SD > 380$ ms) and low accuracy (<70% correct) even at morph level 1 (i.e., proportion of Face 1 relative to Face 2: 100:0 and 0:100). These face stimuli were excluded from data analysis of the pilot study. For the remaining stimulus set, we found that RT increased and accuracy decreased with increasing morph level in both the identity and expression judgments. Although the face stimuli yielded the expected results, we considered faces at morph level 4 (i.e., proportion of 57.1:42.9 and 42.9:57) to be unsuitable for presentation in the subsequent choice RT tasks because performance accuracy was considerably lower and more variable compared with morph level 3 in the identity task ($M = 84.5$ vs. 92.4%, $SD = 16.4$ vs. 10.1) and the expression task ($M = 81.5$ vs. 90.4%, $SD = 20.2$ vs. 12.6). Moreover, to guarantee a reasonably large difficulty effect for familiarity and expression discriminations, we also excluded faces at morph level 2. As a result, the actual familiar–unfamiliar face set used in the following experiments consisted of faces at morph levels 1 and 3.

Actor and politician face set. A second face set of 48 images of actors and politicians displaying happy or angry expression was created. To this end, the photographs of eight famous actors and eight well-known politicians each displaying happy and angry expressions were edited like the pictures of the familiar–unfamiliar face set. Each happy face was paired with the angry face of the same person, and each face of an actor was paired with a face of a politician of similar age, head orientation, and expression. Morphing for each pair was performed separately for faces of actors and politicians from happy to angry (expression morph) and separately for faces displaying angry and happy expressions from actor to politician (identity morph). For each pair, eight images were created by blending two faces in the following proportions of Face 1 relative to Face 2: 100:0, 85.7:14.3, 71.4:28.6, 57.1:42.9, 42.9:57.1, 28.6:71.4, 14.3:85.7, and 0:100. As a result, there were 32 actor and 32 politician faces for the facial expression morph continuum as well as 32 faces displaying happy expression and 32 faces displaying angry expression for the facial identity morph continuum. Following pilot testing, we excluded faces at morph levels 85.7:14.3, 57.1:42.9, 42.9:57.1, and 14.3:85.7 for the same reasons as for the familiar–unfamiliar face set. As a result, in the following RT experiment, the two stimulus sets consisted of faces at morph levels 1 and 3.

The stimuli were displayed on a 19-inch monitor with a viewing distance of 80 cm, which was assured by a fixed chin rest. Accordingly, the visual angle of the stimuli was $3.6 \times 4.3°$. Stimulus presentation and response recording were controlled by the Experimental Runtime Software (ERTS), Version 3.32 (BeriSoft Cooporation 2000).

Procedure. The experiment was split into two parts. In the first part, faces of actors and politicians were presented. One half of participants had to decide first whether a presented face was an actor or a politician (identity task), whereas the other half of participants judged the same stimuli with regard to the expression displayed, that is, happy versus angry (expression task). In the second part, the familiar and unfamiliar happy and angry faces of the main stimulus set were displayed. Half of the participants had to decide whether a presented face was famous or unfamiliar (identity task), whereas the other half of participants judged the same stimuli with regard to the displayed expression, that is, happy versus angry (expression task).

Each trial started with the display of a fixation cross for 500 ms, which was replaced by the target face, presented for 2,000 ms and followed by a blank screen for 500 ms to ensure a sufficiently long intertrial interval. Participants indicated their decision by pressing the appropriate *left* or *right* response key of the ERTS key panel with their left or right index finger, respectively. The key assignment was balanced across participants.

Each participant started with one block of 16 practice trials for which actors and politicians were shown, followed by 16 practice trials of familiar and unfamiliar faces. Face stimuli were randomly drawn from the respective stimulus set that was used for test trials. Feedback was provided after each trial. Subsequently, 192 test trials displaying in random order actors and politicians were followed by 384 test trials of familiar and unfamiliar faces. In contrast to the practice trials, feedback was no longer provided. There was a break after a block of 64 trials.

Data analysis. Correct responses within the time window of 150 to 2,000 ms were taken into data analysis. Mean RT and mean accuracy for the identity and expression tasks were submitted to separate analyses of variance (ANOVAs), respectively, for the two stimulus sets as well as the identity task and the expression task, with repeated measures on the variables morph type (identity vs. expression morph), identity (actor vs. politician and famous vs. unfamiliar, respectively), expression (happy vs. angry), and morph level (1 vs. 3).

Results

Familiar and unfamiliar face set. Because of too slow responses or misses ($RT > 2{,}000$ ms) in the identity task and expression task, respectively, 0.69% and 0.23% of the trials were excluded from data analysis. Mean RT and mean accuracy are depicted in Figure 2.

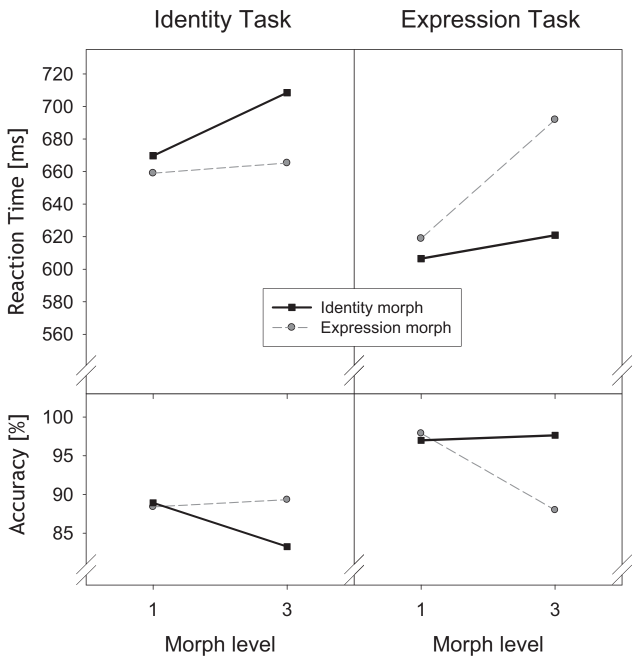

Figure 2. Reaction time and accuracy data in Experiment 1 for the familiar/unfamiliar face sets in the identity task (left) and the expression task (right) as a function of morph levels 1 versus 3 (easy vs. hard) and morph type (identity vs. expression morph).

Analysis of mean RT data for familiar and unfamiliar faces indicated in the identity task faster responses for familiar than unfamiliar faces ($M = 622$ vs. 729 ms), $F(1, 11) = 12.4$, $p < .01$, for expression than identity morphs ($M = 662$ vs. 689 ms), $F(1, 11) = 15.3$, $p < .01$, and for morph level 1 than morph level 3 ($M = 664$ vs. 687 ms), $F(1, 11) = 22.5$, $p < .001$. The familiarity effect in RT was larger for faces displaying happy than angry expressions (131 vs. 84 ms), $F(1, 11) = 12.6$, $p < .01$. The Morph Type × Morph Level interaction was significant, $F(1, 11) = 5.4$, $p < .05$. As can be seen in Figure 2, RT was influenced only by the morph-related manipulation of facial identity ($M = 670$ vs. 708 ms), $F(1, 11) = 15.0$, $p < .01$, but not by that of facial expression ($M = 659$ vs. 665 ms), $F < 1$. These RT effects were also reflected in the analysis of response accuracy, which also revealed a significant Morph Type × Morph Level interaction, $F(1, 11) = 14.6$, $p < .01$. Response accuracy was lower at morph level 3 than 1 for facial identity morphs but not for facial expression morphs (see Figure 2).

In the expression task, responses were faster for expression than identity morphs ($M = 614$ vs. 655 ms), $F(1, 11) = 28.6$, $p < .001$, and for morph level 1 than morph level 3 ($M = 613$ vs. 656 ms), $F(1, 11) = 42.2$, $p < .001$. For familiar but not for unfamiliar faces were responses faster to faces with happy than angry expression ($M = 606$ vs. 655 ms), resulting in an Identity × Expression interaction, $F(1, 11) = 7.3$, $p < .05$. An important finding was that the Morph Type × Morph Level interaction was significant, $F(1, 11) = 15.3$, $p < .01$. As can be seen in Figure 2, RT was influenced by the morph-related manipulation of facial expression ($M = 619$ vs. 692 ms), $F(1, 11) = 45.9$, $p < .01$, but not by that of facial identity ($M = 607$ vs. 621 ms), $F(1, 11) = 2.4$, $p > .10$. The analysis of response accuracy also showed a Morph Type × Morph Level interaction, $F(1, 11) = 52.7$, $p < .001$, due to lower accuracy at morph level 3 than 1 for facial expression morphs but not for identity morphs (see Figure 2).

Actor and politician face set. Because of too-slow responses or misses (RT > 2,000 ms), 0.72% and 0.59% of the trials were excluded from data analysis in the identity task and the expression task, respectively. Mean RT and mean accuracy are depicted in Figure 3.

For the actor–politician face set, in the identity task responses were faster for expression than for identity morphs ($M = 644$ vs. 669 ms), $F(1, 11) = 13.4$, $p < .01$, and for morph level 1 than morph level 3 ($M = 647$ vs. 666 ms), $F(1, 11) = 5.9$, $p < .05$. Responses were faster to faces of actors displaying happy than angry expression ($M = 651$ vs. 674 ms), whereas no such expression effect was present in politicians ($M = 652$ vs. 650 ms), $F(1, 11) = 6.0$, $p < .05$. There was a significant Morph Type × Morph Level interaction, $F(1, 11) = 8.8$, $p < .05$. As can be seen in Figure 3, RT was influenced only by the morph-related manipulation of facial identity ($M = 646$ vs. 692 ms), $F(1, 11) = 11.5$, $p < .01$, but not by that of facial expression ($M = 648$ vs. 641 ms), $F < 1$. The analysis of response accuracy also revealed a significant Morph Type × Morph Level interaction, $F(1, 11) = 6.5$, $p < .05$, due to lower accuracy for facial identity morphs at morph level 3 (see Figure 3).

In the expression task, responses were faster for actors than politicians ($M = 626$ vs. 652 ms), $F(1, 11) = 8.9$, $p < .05$, for happy than angry expressions ($M = 615$ vs. 663 ms), $F(1, 11) = 7.5$, $p < .05$, identity than expression morphs ($M = 620$ vs. 657 ms), $F(1, 11) = 25.3$, $p < .001$, and for morph level 1 than morph

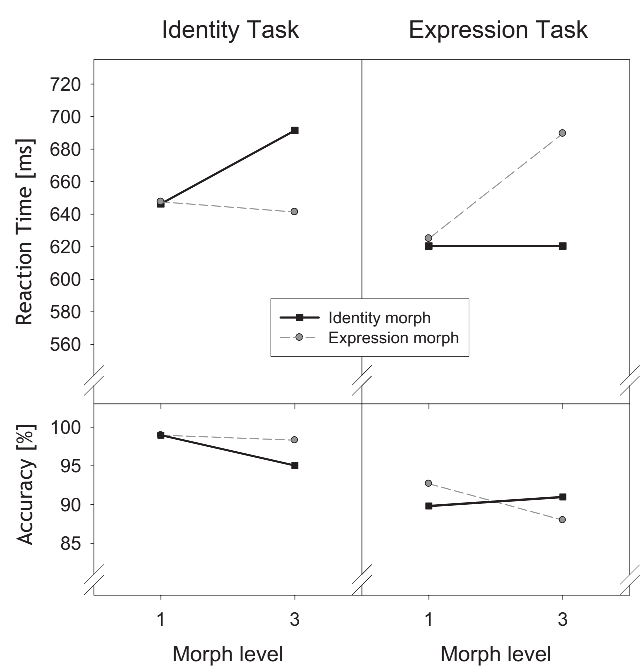

Figure 3. Reaction time and accuracy data in Experiment 1 for the actor–politician face set in the identity task (left) and the expression task (right) as a function of morph levels 1 versus 3 (easy vs. hard) and morph type (identity vs. expression morph).

level 3 (M = 623 vs. 655 ms), $F(1, 11) = 7.7$, $p < .05$. The significant Morph Type × Identity × Expression interaction, $F(1, 11) = 7.4$, $p < .05$, was due to an increased expression effect for faces of actors when expression but not identity was morphed. An important finding was that the Morph Type × Morph Level interaction was significant, $F(1, 11) = 14.5$, $p < .01$, as RT was influenced only by the morph-related manipulation of facial expression (M = 625 vs. 690 ms), $F(1, 11) = 15.7$, $p < .01$, but not by that of facial identity (M = 620 vs. 621 ms), $F < 1$ (see Figure 3). The analysis of response accuracy revealed a corresponding interaction effect, $F(1, 11) = 6.3$, $p < .05$, due to lower accuracy at morph level 3 than 1 for facial expression but not for identity morphs (see Figure 3). Moreover, the significant Morph Type × Morph Level × Occupation interaction, $F(1, 11) = 6.9$, $p < .05$, indicated that this morphing effect was stronger for politicians than actors.

Discussion

The familiar–unfamiliar face set, which was used in the following ERP experiments, included well-known and clearly unfamiliar faces that displayed noticeable angry and happy expressions, as indicated by the questionnaire results. Angry expressions were rated more intense than happy expressions, but this effect was not modulated by familiarity and, therefore, was considered irrelevant for subsequent ERP experiments. Most important, choice RT results of Experiment 1 confirmed the effectiveness of the discriminability manipulation of facial expression and identity for the stimulus set consisting of faces of morph level 1 (original faces) and morph level 3 (71:29 and 29:71). That is, decreasing the discriminability of the task-relevant facial dimension using morphing considerably prolonged RT in both tasks (>38 ms). In addition, manipulating the discriminability of the task-irrelevant dimension did not influence RT or response accuracy in the task-relevant facial dimension, indicating that changes in this facial identity dimension did not affect expression processing and vice versa. Most important, choice RT results demonstrated that the discriminability manipulation of task-relevant facial expression and identity produced equivalent effects for both face sets. Thus, it appears unlikely that potentially asymmetric morphing effects for familiar and unfamiliar faces differentially biased the duration of face-related processing stages.

It is further worth mentioning that RT was shorter for familiar faces than for unfamiliar faces, consistent with other previous reports of such a familiarity effect on RT (e.g., Schweinberger & Sommer, 1991). In contrast to Bruce and Young's (1986) independent processing assumption, in the expression categorization task, responses to familiar faces were faster for happy than angry expressions, whereas in the identity categorization task, faces of actors were responded to faster if they displayed a happy rather than an angry expression. These findings suggest that facial representations are stored with preserved information of the facial expression with which the face is mainly experienced (e.g., Baudouin, Gilbert, Sansone, & Tiberghien, 2000; Kaufmann & Schweinberger, 2004; Lander & Metcalfe, 2007), implying some form of interaction between identity and expression analysis (see also Ganel & Goshen-Gottstein, 2004). It is important to note, however, that these interaction effects were independent from those induced by the morphing of facial identity or expression.

In summary, Experiment 1 assured us in our choice of a stimulus set of familiar and unfamiliar faces, which produced the desired selective effects of discrimination difficulty on the duration of facial identity and expression while being sufficiently large to reduce purely image-based processing strategies. Such an effect might have been present in previous studies that employed much smaller stimulus sets to investigate the functional architecture of identity and expression processing (e.g., Baudouin et al., 2002; Ganel & Goshen-Gottstein, 2004; Schweinberger et al., 1999; Schweinberger & Soukop, 1998).

Experiment 2

Experiment 2 used the stimulus set of Experiment 1 consisting of eight famous and eight unfamiliar identities, each displaying happy and angry expressions at two difficulty levels of facial familiarity. In the hybrid-choice RT go/no-go task, facial identity (famous vs. unfamiliar) determined response hand and response execution depended on expression (happy vs. angry). For example, some participants were asked to press the *left* response key for a famous person and the *right* response key for an unknown person, but to respond overtly only if the face looked happy and to withhold a response if the face looked angry. That is, depending on the outcome of these two decisions, a response was given with either the left or right hand or not at all. Finally, the time demands of the identity decision were manipulated by presenting either original or morphed faces along the familiarity dimension.

Table 1 summarizes the main predictions concerning the effect of the facial familiarity manipulations on chronometric measures made by the different face recognition models. As indicated by the RT findings in the identity task of Experiment 1, processing is very likely to be of shorter duration for familiar than unfamiliar faces. Thus, consistent with all face processing models, we expected a familiarity effect in terms of shorter RT and earlier S-LRP onset for familiar than unfamiliar faces. Crucially, however, the different models make divergent predictions as to how facial familiarity and discriminability influence the relative time course of identity and expression processing.

Bruce and Young's (1986) parallel-independent model critically assumes that expression decisions are uninfluenced by identity processing. If one further assumes faster identity than expression analysis (e.g., Schweinberger et al., 1999), the relative completion times of identity and expression processes will become similar with increasing duration of identity processing (see Figure 4A and 4B). Thus, this model predicts that S-LRP onset is influenced only by the duration of identity processing, which should depend on familiarity (famous vs. unfamiliar faces) and the difficulty of familiarity discriminations as manipulated by morphing. Most critical, however, if familiar faces are indeed processed faster than unfamiliar faces while independent expression processing remains invariant in its duration, the relative completion times of identity and expression analysis will be more dissimilar for familiar than for unfamiliar faces. As a result, the LRP-R interval should be longer rather than shorter for easy compared with hard familiarity decisions. In addition, a no-go LRP should be present only when identity processing finishes earlier than expression processing. In brief, we expected a larger discriminability effect on the LRP-R interval and a longer no-go LRP for familiar than unfamiliar faces (see Table 1). What are the predictions of this model if expression

Table 1
Predictions of Alternative Face Processing Models Regarding the Influence of Familiarity Discriminability (Easy [E] vs. Hard [H]) in Experiment 2, Assuming Faster Processing of Both Famous Versus Unfamiliar Faces and Facial Identity Versus Expression Processing

	Parallel independent		Parallel dependent		Parallel contingent		Observed (in ms)	
Variable	Unfamiliar	Famous	Unfamiliar	Famous	Continuous	Discrete	Unfamiliar	Famous
RT	E < H	E < H	E < H	E < H	E < H	E < H	780 < 795	719 < 741
S-LRP	E < H	E < H	E < H	E < H	E < H	E < H	501 < 521	458 = 452
LRP-R	E ≥ H[a]	E > H	E > H	E ≥ H[a]	E < H	E = H	234 > 204	201 = 207
No go LRP	E = No[a]	E = Yes	E = Yes	E = No[a]	E = Yes	E = No	E = Yes	E = No
	H = No	H = Yes[a]	H = No[a]	H = No	H = Yes	H = No	H = No	H = No

Note. RT = reaction time; S-LRP = stimulus-locked lateralized readiness potential; LRP-R = response-locked lateralized readiness potential. Two versions of the parallel-contingent model are distinguished in terms of continuous versus discrete output from face perception to motor stages. Note that the parallel-contingent model predicts the same effects for the processing of famous and unfamiliar faces.
[a] Depending on relative completion time of identity and expression processing.

is analyzed faster than identity? As can be seen in Figure 4C, because in this case the go/no-go decision can be made earlier than the hand decision, there should be no experimental effects on the LRP-R interval and the no-go LRP should be absent. Only the S-LRP interval should reveal effects of familiarity and discriminability (see Table 1).

It is important to note that the predictions for the parallel-dependent model differ from those of the parallel-independent model regarding the relative time course of facial identity and expression analysis because expression analysis may rely on identity-dependent expression representations (e.g., Fox & Barton, 2007) or shared coding dimensions (e.g., Calder et al., 2001). That is, it is reasonable to assume that the relative completion times for facial identity and expression analysis are more similar, if not identical, for familiar faces but more dissimilar for unfamiliar faces. Thus, in contrast to the Bruce and Young (1986) model, unfamiliar rather than familiar faces would produce a larger discriminability effect on the LRP-R interval and a more pronounced

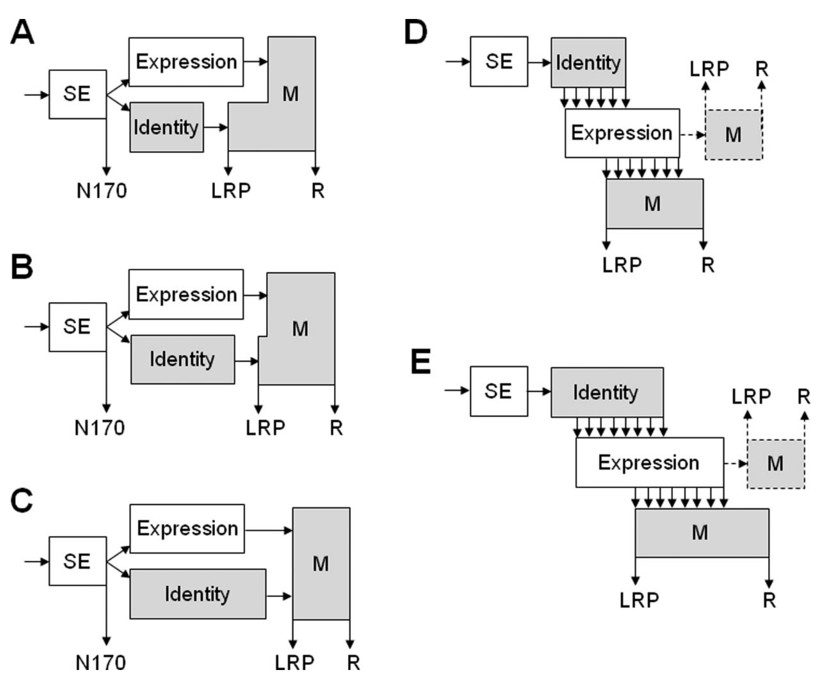

Figure 4. Schematic illustration of predicted effects of identity difficulty (easy vs. hard) on the lateralized readiness potential (LRP) in the two-choice go/no-go task for Bruce and Young's (1986) parallel-independent model (for familiar faces: A = easy vs. B = hard; for unfamiliar faces: B = easy vs. C = hard discrimination) and Schweinberger et al.'s (1999) parallel-contingent model of face processing (D = easy vs. E = hard discrimination). For the latter model, the motor stage depicted with solid lines refers to the continuous version, whereas the motor stage depicted with broken lines refers to the discrete version. SE = structural encoding; M = motor stage; R = overt response.

or longer no-go LRP. Of course, if expression decisions are made earlier than facial identity decisions irrespective of facial familiarity, predictions would match those for the parallel-independent model (see Table 1).

Finally, the parallel-contingent model assumes cascaded processing of facial identity and expression (Schweinberger et al., 1999). It is evident that the analysis of S-LRP and LRP-R intervals can also inform this model. As Schweinberger et al. (1999) did not specify the mode of information transmission from facial perception to motor processes, at least two model versions in terms of continuous versus discrete information transmission (cf. Meyer, Osman, Irwin, & Yantis, 1988; Miller, 1988) are conceivable. The *continuous model* version is characterized by partial information transmission from perceptual to even late motor stages. According to such a continuous model, the rate of activation growth in a late motor stage depends on the activation rate in earlier stages (cf. McClelland, 1979). If the familiarity decision is made more difficult, and hence information is accrued at a slower rate in the identity stage, this effect would propagate to both the expression and motor stages (see Figure 4D and 4E). As a result, this model predicts not only a prolonged S-LRP interval but also an increased LRP-R interval for more difficult identity discriminations. In addition, a no-go LRP should be obtained as the motor stage is activated while expression analysis is still going on. In contrast to the parallel-independent and parallel-dependent models, however, the no-go LRP is unlikely to differ for easy and difficult familiarity conditions as the difficulty effect propagates to the other stages. In the *discrete model* version, output from face perception to motor stages occurs only once face (expression) processing has completed, resulting in serially arranged perceptual and motor stages that do not overlap in time (e.g., Sanders, 1980; Sternberg, 1969). In this situation (see Figure 4D and E), the parallel-contingent model predicts an effect of familiarity and discrimination difficulty on the S-LRP but not on the LRP-R interval, and the no-go LRP should be absent.

To further test the locus of experimental effects on stages before motor processing, we also analyzed the N170 and P300 components of the ERP. The N170 specifically relates to the structural encoding of faces (e.g., Eimer, 2000b), whereas the P300 reflects an electrophysiological marker of the time demands for perceptual and cognitive processing stages but not motor stages (Leuthold & Sommer, 1998; McCarthy & Donchin, 1981; for reviews, see Verleger, 1997; Donchin & Coles, 1988).

Method

Participants. Twenty-two participants were tested and paid for participation (£5/hr). One participant was excluded from data analysis because the LRP was absent, and another one was excluded because of excessive error rates (>25%). The 20 participants (11 men) contributing data to this study were between 18 and 26 years of age ($M = 21.5$ years). All participants were right-handed and reported normal or corrected-to-normal vision.

Stimuli and apparatus. The stimulus set of 64 images consisted of eight happy and eight angry familiar faces as well as eight happy and eight angry unfamiliar faces, with each face being displayed at two levels of familiarity difficulty (morph levels 1 and 3). Facial expressions were those of the original image (expression morph level 1). All other aspects regarding stimulation and response recording were identical to those of Experiment 1.

Procedure. Participants performed a two-choice go/no-go task. Facial identity determined response hand and expression determined response execution. Half of the participants indicated by a *left* or *right* button press whether a presented face was famous or unfamiliar if it showed a happy expression but were asked to withhold their response for angry expressions. The other half of the participants received the reverse expression to go/no-go mapping. Go trials occurred with probability $p = .75$ to encourage hand preparation as in previous studies using the hybrid-choice RT go/no-go paradigm (e.g., Abdel Rahman et al., 2002; Miller & Hackley, 1992).

A trial started with the presentation of a fixation cross at the center of the screen for 500 ms. Subsequently, the target was displayed for 1,500 ms. The next trial commenced with the presentation of the fixation cross 700 ms later. In total, 1,280 experimental trials (960 go trials and 320 no-go trials) were presented. The experiment started with a block of 39 practice trials, for which face stimuli were randomly drawn from the stimulus set that was used during experimental trials. Thus, practice trials were identical to experimental trials except that additional feedback was provided after each trial. Subsequently, 10 experimental blocks followed consisting of 64 trials each. Half of participants initially responded to familiar faces with a left-hand response and to unfamiliar faces with a right-hand response, whereas the familiarity-to-key assignment was reversed for the other half of participants. After 640 trials, the key assignment was exchanged. Thus, participants responding to the first 10 blocks with their left index finger to famous faces now used the right index finger. Another practice block of 39 trials was presented, followed by another 10 experimental blocks of 64 trials each. Familiarity, difficulty of familiarity discrimination, and facial expression varied randomly.

Electrophysiological recording. The electroencephalogram (EEG) was recorded with sintered Ag/AgCl electrodes mounted in an electrode cap (Easy-Cap) at scalp positions Fz, Cz, Pz, Iz, Fp1, Fp2, F3, F4, C3′, C4′, P3, P4, O1, O2, F7, F8, T7, T8, P7, P8, FT9, FT10, P9, P10, PO9, PO10, F9′, F10′, TP9, and TP10. Note that the T7, T8, P7, and P8 locations are equivalent to T3, T4, T5, and T6 in the nomenclature proposed by Pivik and colleagues (1993). C3′ and C4′ electrodes were placed above left and right motor areas. The F9′ electrode was positioned 2 cm anterior to F9 at the outer canthus of the left eye, and the F10′ electrode was positioned 2 cm anterior to F10 at the outer canthus of the right eye. The positions TP9 and TP10 refer to inferior temporal locations over the left and right mastoids, respectively. The TP10 (right upper mastoid) electrode served as initial common reference, and a forehead electrode (AFz) served as ground. All impedances were typically below 5 kΩ. The horizontal electrooculogram (EOG) was recorded from F9′ and F10′ at the outer canthi of both eyes. The vertical EOG was monitored from an electrode above the right eye against an electrode below the right eye. All signals were recorded with a band-pass of 0.05–40.00 Hz (−6 dB attenuation, 12 dB/octave) and sampled at a rate of 250 Hz.

Offline, trials containing blinks were corrected using a dipole approach (BESA 5.1.6), and EEG activity was rereferenced to an average mastoid reference. Trials with any EEG artifacts (>100 μV) and trials with incorrect behavioral responses were removed from analysis. The analysis epoch of stimulus-synchronized ERP waveforms started 200 ms before target onset and lasted for a total duration of 1,200 ms. For response-locked ERPs, the 1,200-ms epoch started 1,000 ms before the response. EEG and EOG activity were averaged time-locked to either stimulus or response onset.

In addition, for each participant and experimental condition, the LRP was calculated by subtracting the activity over the primary motor cortex ipsilateral to the response hand from the ERP at homologous contralateral recording sites using the C3′ and C4′ electrodes. The resulting difference waveforms were averaged across hands to eliminate any ERP activity unrelated to hand-specific motor activation (cf. Coles, 1989; Eimer, 1998), resulting in the LRP.

Data analysis. Correct responses within the time window of 150 to 1,500 ms after target onset were taken into data analysis. For the N170 and P300 deflections, we measured peak latencies at electrodes P10 and Pz, respectively. N170 peak amplitudes were determined at electrodes P9 and P10 and P300 peak amplitudes at midline electrode sites Fz, Cz, and Pz. LRP onsets were measured in low-pass filtered (5 Hz, 6 dB/octave) waveforms and analyzed by applying the jackknife-based procedure suggested by Miller, Patterson, and Ulrich (1998) and Ulrich and Miller (2001). That is, 20 different grand-average LRPs for each of the experimental conditions were computed, each containing data from 19 participants, by omitting from each grand average the data of a different participant. LRP onsets were determined in the waveform of each grand average. The stimulus-synchronized LRP waveform (S-LRP) was aligned to a 200-ms baseline before stimulus onset, whereas the response-synchronized LRP waveform (LRP-R) was referred to a 200-ms baseline starting 900 ms before response onset, as in Abdel Rahman et al. (2002). As recommended by Miller et al., the S-LRP onset was determined at the time when LRP amplitude reached 50% of maximal LRP amplitude in that specific condition, whereas onsets in the LRP-R waveforms were obtained using a relative LRP amplitude criterion of 30%.

LRP onset latency measures were submitted to ANOVAs with F values corrected as follows: $F_C = F/(n - 1)^2$, where F_C denotes the corrected F value and n the number of participants (cf. Ulrich & Miller, 2001). The presence of the no-go LRP was assessed by measuring mean S-LRP amplitude in no-go trials in successive 50-ms time intervals starting 300 ms after stimulus onset. For each time window, a two-tailed t test was performed against zero, and the no-go LRP was considered to be present if the t test was significant ($p < .05$).

Results

Behavioral performance. Behavioral data for go trials and for no-go trials were submitted to separate ANOVAs with repeated measures on the variables familiarity (familiar vs. unfamiliar) and difficulty of familiarity discrimination (easy vs. hard). The ANOVA revealed faster responses to famous than to unfamiliar faces (M = 730 vs. 787 ms), $F(1, 19) = 35.7$, $p < .001$, and for easy compared with hard familiarity decisions (M = 749 vs. 768 ms), $F(1, 19) = 64.2$, $p < .001$. The interaction between familiarity and difficulty was not significant, $F(1, 19) = 1.7$, $p > .2$.

An analogous analysis of accuracy data in go trials revealed more accurate responses for famous than unfamiliar faces (M = 97.4 vs. 93.5%), $F(1, 19) = 6.4$, $p < .02$, and for easy than difficult familiarity discriminations (M = 97.0 vs. 94.0%), $F(1, 19) = 25.8$, $p < .001$. For no-go trials, a main effect of familiarity occurred, $F(1, 19) = 40.2$, $p < .001$, because of higher accuracy for familiar than for unfamiliar faces (M = 97.7 vs. 94.4%).

Electrophysiological measures.

LRP. LRP onset measures were submitted to an ANOVA with repeated measures on the variables familiarity (familiar vs. unfamiliar) and difficulty of familiarity discrimination (easy vs. hard). Figure 5 depicts the LRP waveforms for the different experimental conditions on go trials. The ANOVA of the S-LRP interval revealed a main effect of familiarity, $F_C(1, 19) = 25.1$, $p < .001$. The S-LRP onset occurred earlier for famous faces than for unfamiliar faces (M = 455 vs. 511 ms). The main effect of discrimination difficulty was not significant ($F_C < 1$). The Difficulty × Familiarity interaction was marginally significant, $F_C(1, 19) = 3.5$, $p < .08$. Separate t tests indicated a reliable difficulty effect for unfamiliar faces (M = 501 vs. 521 ms), $t(19) = 1.9$, $p < .05$ (one-tailed), whereas it was absent for familiar faces (M = 458 vs. 452 ms), $t = -0.6$.

The analysis of response-locked LRP onsets revealed no reliable effects of familiarity and difficulty (F_Cs < 1). The interaction between familiarity and difficulty of familiarity was not significant, $F_C(1, 19) = 2.4$, $p = .14$. However, separate t tests revealed a longer LRP-R interval for easy than hard familiarity decisions for unfamiliar faces (M = 234 vs. 204 ms), $t(19) = 1.8$, $p < .05$ (one-tailed), but not for familiar faces (M = 201 vs. 207 ms), t = 0.5 (see Figure 6).

As can be seen in Figure 7, a no-go LRP was present only in the condition in which identity discrimination for unfamiliar faces was easy. Two-tailed t tests indicated a reliable no-go LRP in the unfamiliar–easy condition between 400 and 450 ms, ts(19) $<$ –2.1, ps $< .05$, whereas for famous faces and easy discriminations, the no-go LRP did not reliably differ from baseline (ps $> .14$).

N170. The ERP waveform at electrode site P10 is depicted in Figure 8. N170 amplitude values were submitted to an ANOVA with repeated measures on the variables go/no-go (go vs. no-go trial), familiarity (familiar vs. unfamiliar), difficulty of familiarity discrimination (easy vs. hard), and electrode (P9 vs. P10). N170 peak amplitude was larger over the right than the left parietotemporal electrode (M = –5.6 vs. –7.1 μV), $F(1, 19) = 4.8$, $p < .05$,

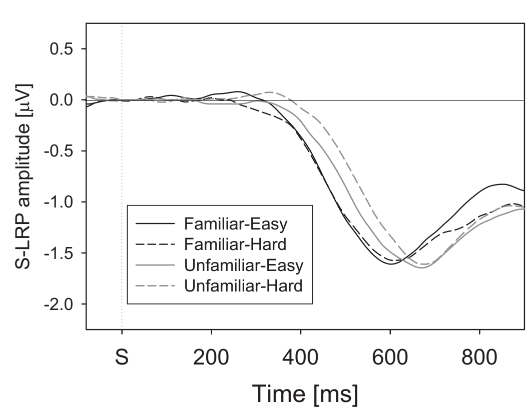

Figure 5. Grand-mean stimulus-locked lateralized readiness potential (S-LRP) in go trials in Experiment 2 as a function of facial familiarity (familiar vs. unfamiliar) and identification difficulty (easy vs. hard). S = stimulus onset.

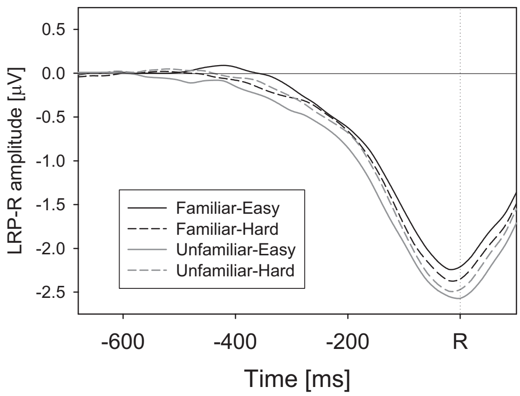

Figure 6. Grand-mean response-locked lateralized readiness potential (LRP-R) in Experiment 2 as a function of facial familiarity (familiar vs. unfamiliar) and identification difficulty (easy vs. hard). R = response onset.

and larger for famous than for unfamiliar faces ($M = -6.5$ vs. -6.2 µV), $F(1, 19) = 9.6$, $p < .01$. Difficulty did not affect N170 amplitude as a main effect, $F < 1$, but did in interaction with the go/no-go condition, $F(1, 19) = 5.5$, $p < .05$. The interaction was due to a reliable larger N170 amplitude for easy than difficult discriminations on no-go trials ($M = -6.6$ vs. -6.2 µV), $F(1, 19) = 8.2$, $p < .05$, but not on go trials ($M = -6.3$ vs. -6.3 µV), $F < 1$. N170 latency ($M = 185$ ms) was not influenced by experimental conditions (Fs < 1.9, ps $> .18$).

P300. The ERP waveform at the Pz electrode depicted in Figure 9 shows the effect of experimental variables on the P300 component. The analysis of P300 amplitudes with an identical ANOVA, except for the variable electrode (Fz, Cz, Pz), revealed a centroparietal distribution, $F(2, 30) = 105.3$, $p < .001$, which is typical for the classic P300 component (Johnson, 1988). P300 amplitude was larger for no-go than go trials ($M = 6.0$ vs. 5.0 µV),

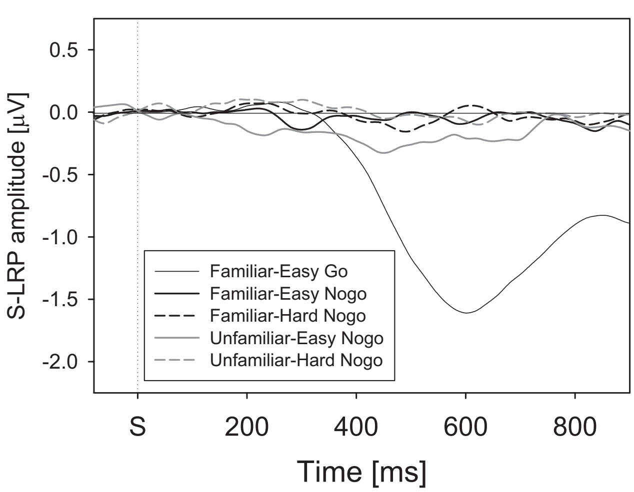

Figure 7. Grand-mean stimulus-locked lateralized readiness potential (S-LRP) in no-go trials in Experiment 2 as a function of facial familiarity (familiar vs. unfamiliar) and identification difficulty (easy vs. hard). The familiar–easy go condition (thin black line) is depicted for comparison. S = stimulus onset.

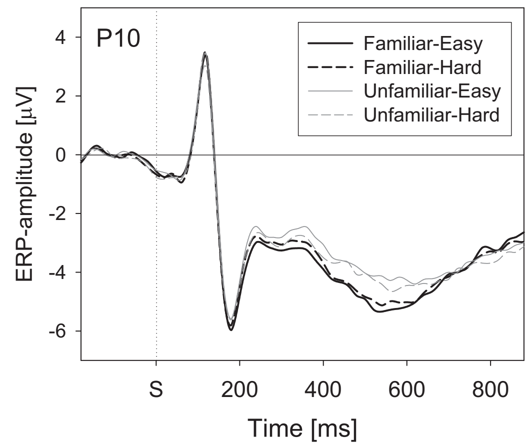

Figure 8. Grand-mean stimulus-locked event-related brain potential (ERP) waveforms at the P10 electrode in go trials of Experiment 2 as a function of facial familiarity (familiar vs. unfamiliar) and identification difficulty (easy vs. hard). S = stimulus onset.

$F(1, 19) = 12.6$, $p < .01$, for easy than difficult familiarity conditions ($M = 5.8$ vs. 5.2 µV), $F(1, 19) = 10.9$, $p < .01$, and for familiar than unfamiliar faces ($M = 5.8$ vs. 5.3 µV), $F(1, 19) = 8.4$, $p < .01$.

The analysis of P300 peak latency revealed a Go/No Go × Familiarity interaction, $F(1, 19) = 21.5$, $p < .001$, indicating that P300 on go trials peaked earlier for famous than unfamiliar faces ($M = 547$ vs. 579 ms), whereas the reverse held true on no-go trials ($M = 573$ vs. 527 ms). The Go/No Go × Difficulty interaction, $F(1, 19) = 6.2$, $p < .05$, indicated shorter P300 latency to easy than difficult to discriminate faces on go trials ($M = 554$ vs. 570 ms), $F(1, 19) = 3.7$, $p = .07$, but again a reverse numeric trend on no-go trials ($M = 557$ vs. 543 ms), $F(1, 19) = 1.6$, $p = .22$.

Discussion

In Experiment 2, RT and electrophysiological indices revealed the influence of familiarity and familiarity discrimination diffi-

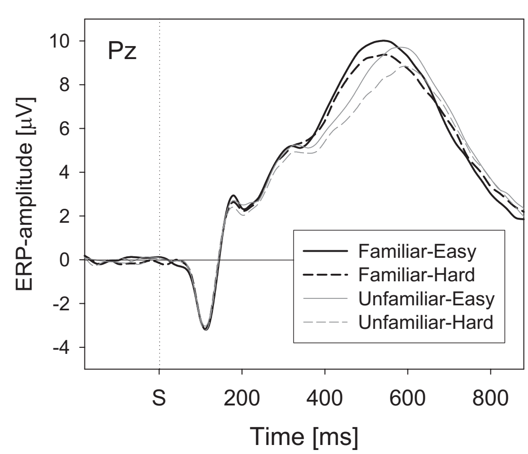

Figure 9. Grand-mean stimulus-locked event-related brain potential (ERP) waveforms at the Pz electrode in go trials of Experiment 2 as a function of facial familiarity (familiar vs. unfamiliar) and identification difficulty (easy vs. hard). S = stimulus onset.

culty on the duration of information processing. We obtained two main behavioral findings. Responses were faster to famous than unfamiliar faces and to easy than hard to discriminate facial identities. The familiarity effect accords with all face perception models and can be explained by assuming that the processing of unfamiliar faces (open face set) involves more time-consuming memory search processes than for familiar faces (closed face set). Looking at the results in our experiment, it is obvious that a higher level cognitive process is likely to contribute to the familiarity effect in RT given that P300 latency and S-LRP onset latency, but not N170 latency and LRP-R onset latency, were prolonged for unfamiliar compared with familiar faces. This account agrees with the finding that P300 latency to faces increases with memory set size, hence, sensitively reflecting the time demands of a memory search process (e.g., Schweinberger & Sommer, 1991). Of course, as indicated by the finding of larger N170 amplitude for familiar than unfamiliar faces, early perceptual processing stages might be influenced by familiarity too, yet not in their time demands (cf. Kloth et al., 2006, for similar findings in the neuromagnetic M170). We refer to possible implications of this result later in the General Discussion.

Also important for present purposes, RT indicated faster responses for easy than difficult familiarity decisions. Again, N170 latency was not affected, whereas the difficulty effect for familiarity on go trials was of similar magnitude in RT (19 ms) and in P300 peak latency (16 ms). Because P300 latency is usually taken to reflect perceptual and cognitive processing time (e.g., Leuthold & Sommer, 1998; McCarthy & Donchin, 1981; see Verleger, 1997, for a review), we assume that this manipulation indeed influenced a postsensory yet premotoric processing stage. Whereas these findings again accord with all face processing models, the analysis of LRP indices revealed an effect pattern that allowed us to discriminate between them.

Most important, the LRP findings indicated that the time course of facial identity and expression processing differs for famous and unfamiliar faces. Thus, it was only for unfamiliar faces that easy compared with hard familiarity decisions resulted in a shorter S-LRP, in a longer LRP-R interval, and in a significant no-go LRP. For familiar faces, experimental manipulations did not reliably influence chronometric LRP markers, and the no-go LRP was absent (see Table 1). The absence of an S-LRP difficulty effect for familiar faces in combination with its presence in RT and P300 latency might be due to random measurement error, as a result of which only the larger familiarity effect (57 ms) but not the difficulty effect (19 ms) could be detected in the S-LRP interval. Together, present LRP effects most closely follow the predictions made by the parallel-dependent model rather than those of the parallel-independent and the parallel-contingent models (see Table 1). More specifically, as concerns the parallel-contingent model, its continuous version predicted a general increase of the LRP-R interval and of the no-go LRP for easy than hard discriminations. On the other hand, the discrete version predicted the LRP-R interval to be uninfluenced by discriminability and the no-go LRP to be absent. These predictions were not or only partially supported; hence, we conclude that the parallel-contingent model does not provide a viable account of facial identity and expression processing in the present experiment.

The parallel-independent model fares better in explaining present LRP data, at least those for unfamiliar faces. That is, the assumption of asynchronous output from component face perception to motor stages accounts in a natural way for the longer LRP-R interval for easy compared with hard familiarity decisions. This is due to the fact that the time interval between familiarity-driven hand activation and expression-driven response execution is longer when familiarity decisions for unfamiliar faces are easy rather than hard (see Figure 4B and 4C). For the same reason, this model accounts for the presence of a no-go LRP in the easy familiarity condition, whereas the absence of the no-go LRP for the hard condition can be explained by assuming that familiarity processing for unfamiliar faces now finishes at about the same time as or later than the expression analysis. It is crucial to note that the parallel-independent model faces major problems in accounting for the null LRP effects observed for familiar faces. As this model assumes that facial identity and expression processing are independent, the shorter duration of the identity analysis for familiar than unfamiliar faces, as indicated by RT and the S-LRP interval, should give rise to a stronger and not weaker discriminability effect on the LRP-R interval and also a larger rather than an absent no-go LRP for familiar compared with unfamiliar faces (a scenario that is depicted in Figure 4A and 4B). Clearly, when LRP findings for unfamiliar and familiar are viewed in conjunction, they provide strong evidence against the parallel-independent model.

By contrast, the parallel-dependent face processing model assumes that expression processing differs for familiar and unfamiliar faces. Accordingly, this model can explain the discriminability effect on the LRP-R interval and the no-go LRP for unfamiliar faces as well as the respective zero effects on the LRP for familiar faces. That is, because of identity-dependent expression representations (e.g., Fox & Barton, 2007) or shared representations of identity and expression (e.g., Calder et al., 2001), it is quite likely that expression is processed faster for familiar than unfamiliar faces. As a result, relative completion times for facial identity and expression analysis are very similar, if not identical, for familiar faces and, therefore, LRP-R interval effects and the no-go LRP should be absent.

Of course, one might ask how the parallel-dependent model accounts for the effect of familiarity difficulty in RT for unfamiliar faces, because this effect could in principle be absorbed during the waiting time until the expression analysis finishes processing. However, other studies have clearly demonstrated that motoric preactivation shortens RT (cf. Leuthold et al., 1996; Miller & Hackley, 1992). Thus, when the duration of identity processing is increased for unfamiliar faces, the completion time of this process comes closer to that of the expression process. As a result, for easy compared with difficult familiarity decisions, more time is available to selectively activate the appropriate hand, and this more advanced preparatory state shortens RT. Therefore, we assume that the identity of unfamiliar faces is indeed processed in parallel and independent of the ongoing expression analysis.

Still, our interpretations regarding the processing of familiar faces in Experiment 2 rely on the interpretation of LRP null effects. Clearly, it is desirable to show systematic effects on the LRP-R interval and the no-go LRP also for famous faces, which the parallel-dependent model would predict, for example, when the duration of expression rather than facial identity processing is increased.

Experiment 3

As in Experiment 2, we employed a hybrid-choice RT go/no-go task, in which facial identity (famous vs. unfamiliar) determined response hand and response execution depended on facial expression (happy vs. angry). Manipulating the difficulty of the expression analysis rather than facial familiarity should help to temporally tease apart the facial identity and expression analysis and give facial identity processing a temporal advantage over expression processing. As a result, it should be possible to obtain more clear-cut evidence regarding the nature of parallel facial identity and expression processing of familiar faces on the basis of the no-go LRP.

Table 2 summarizes the predictions made by the different face recognition models. Both the parallel-independent model of Bruce and Young (1986) and the parallel-dependent model predict that the S-LRP onset is uninfluenced by the difficulty of expression processing. Moreover, given that Experiment 2 revealed no familiarity effect on the LRP-R interval when identity and expression were easy to discriminate, in Experiment 3, we expected that the LRP-R interval generally increases for hard than easy expression discriminations because, in the former case, hand activation is now more likely to start before the expression-based go/no-go decision (see Figure 10). It is important to note that the two parallel models of face recognition make contrasting predictions concerning the no-go LRP effects for familiar and unfamiliar faces. The parallel-dependent model assumes that the relative completion times of identity and expression analysis are more dissimilar for unfamiliar than for familiar faces, and this difference in completion times should further increase if expression processing is selectively delayed for hard discriminations (see Figure 10). By contrast, as outlined earlier, the parallel-independent model assumes relative completion times to be reversed for familiar and unfamiliar faces. Hence, only the parallel-dependent model predicts that the no-go LRP is more pronounced for unfamiliar than familiar faces. Specifically, we expected that for easy expression (and easy familiarity) discriminations, as in Experiment 2, a no-go LRP would be present only for unfamiliar faces, whereas for hard discriminations, a no-go LRP would be obtained also for familiar faces (see Figure 10 and Table 2).

Although the parallel-contingent model (Schweinberger et al., 1999) found little support in Experiment 2, for the sake of completeness, we briefly outline the predictions of this model as well (see Table 2). Thus, its continuous version predicts the S-LRP and the LRP-R interval to increase with facial expression difficulty, whereas a no-go LRP should be present irrespective of the difficulty of facial expression discriminations. The discrete version, by contrast, predicts facial expression difficulty only to influence the S-LRP but not the LRP-R interval and the no-go LRP to be generally absent.

Method

Participants. Sixteen participants (eight men) between 18 and 26 years of age ($M = 22.3$ years) were paid to contribute data to this study. One participant was left-handed, and everybody reported normal or corrected-to-normal vision.

Stimuli, apparatus, and procedure. These were identical to Experiment 2 except that facial expression was manipulated in its discriminability and determined response execution (go vs. no-go), whereas facial familiarity determined response hand and was always easy to perceive.

Electrophysiological recording and data analysis. Recording and data analysis methods were identical to those in Experiment 2.

Results

Behavioral performance. RT data for go trials were submitted to ANOVAs with repeated measures on the two-level variables familiarity (familiar vs. unfamiliar) and difficulty of expression discrimination (easy vs. hard). This analysis revealed faster responses for familiar than unfamiliar faces ($M = 727$ vs. 750 ms), $F(1, 15) = 5.9$, $p < .05$, and for easy than hard expression decisions ($M = 718$ vs. 759 ms), $F(1, 15) < 130.6$, $p < .001$. The interaction between the two factors was not significant ($F < 1$).

An analogous analysis of accuracy for go trials revealed no significant main effects or interactions of the variables familiarity and expression difficulty ($Fs < 3.3$, $ps > .09$). The analysis of no-go trial accuracy indicated better performance when expression discrimination was easy rather than difficult ($M = 98.3$ vs. 92.3%), $F(1, 15) = 25.5$, $p < .001$. This result rules out an explanation of the RT effects in terms of a speed–accuracy trade-off.

Electrophysiology.

LRP. LRP onset measures were submitted to an ANOVA with repeated measures on the variables familiarity (familiar vs. unfa-

Table 2
Predictions of Alternative Face Processing Models Regarding the Influence of Expression Discriminability (Easy [E] vs. Hard [H]) in Experiment 3, Assuming Faster Processing of Famous Versus Unfamiliar Faces

	Parallel independent		Parallel dependent		Parallel contingent		Observed (in ms)	
Variable	Unfamiliar	Famous	Unfamiliar	Famous	Continuous	Discrete	Unfamiliar	Famous
RT	E < H	E < H	E < H	E < H	E < H	E < H	732 < 769	704 < 750
S-LRP	E = H	E = H	E = H	E = H	E < H	E < H	476 = 468	442 = 444
LRP-R	E < H	E < H	E < H	E < H	E < H	E = H	184 < 210	191 < 217
No go LRP	E = No[a]	E = Yes	E = Yes	E = No	E = Yes	E = No	E = Yes	E = No
	H = Yes	H = Yes	H = Yes	H = Yes	H = Yes	H = No	H = Yes	H = Yes

Note. RT = reaction time; S-LRP = stimulus-locked lateralized readiness potential; LRP-R = response-locked lateralized readiness potential. Two versions of the parallel-contingent model are distinguished in terms of continuous versus discrete output from face perception to motor stages. Note that the parallel-contingent model predicts the same effects for the processing of famous and unfamiliar faces.
[a] Depending on relative completion time of identity and expression processing.

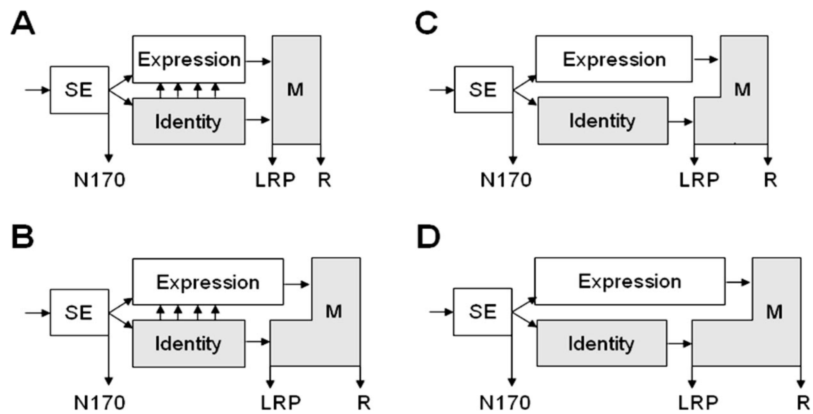

Figure 10. Schematic illustration of the parallel-dependent model's predicted effects of expression difficulty on the lateralized readiness potential (LRP) in the two-choice go/no-go task for famous faces (A = easy vs. B = hard discrimination) and for unfamiliar faces (C = easy vs. D = hard discrimination). SE = structural coding; M = motor stage; R = overt response.

miliar) and difficulty of expression discrimination (easy vs. difficult). The stimulus- and response-synchronized LRP waveforms are depicted in Figure 11 and Figure 12, respectively. As can be seen in the S-LRP waveforms (see Figure 11), the S-LRP interval was reliably shorter for famous compared with unfamiliar faces (M = 443 vs. 472 ms), $F_C(1, 15) = 5.2$, $p < .05$, but was not influenced by the difficulty of expression decisions ($F_C = 1$). The interaction between the two factors was not significant either ($F_C < 1$).

In the analysis of response-locked LRP grand-average waveforms (see Figure 12), the main effect of expression difficulty was significant, $F_C(1, 15) = 5.9$, $p < .05$, indicating a longer LRP-R interval for hard compared with easy to discriminate facial expressions (M = 213 vs. 187 ms). The main effects of familiarity and the Familiarity × Expression Difficulty interaction were not significant (F_Cs < 1).

As can be seen in Figure 13, the no-go LRP was absent for familiar faces when expression discrimination was easy but present in all other conditions. For the latter conditions, t tests indicated a reliable no-go LRP between 350 and 450 ms (ts $<$ –2.1, ps $< .05$). In later time intervals, the no-go LRP was present only for unfamiliar face stimuli.

N170. Figure 14 depicts stimulus-locked ERP waveforms at electrode P10, at which the N170 was most pronounced. N170 peak amplitudes were submitted to an ANOVA with repeated measures on the variables go/no-go, familiarity, difficulty of expression discrimination, and electrode. N170 peak amplitude was larger over the right than left parietotemporal electrode (M = –5.1 vs. –7.2 µV), $F(1, 15) = 4.4$, $p = .05$, larger to famous than to unfamiliar faces (M = –6.3 vs. –6.0 µV), $F(1, 15) = 5.6$, $p < .05$, and to easy than difficult to discriminate faces (M = –6.3 vs. –5.9 µV), $F(1, 15) = 10.6$, $p < .01$. No other effects were significant (Fs < 2.9, ps $> .11$). N170 latency (M = 191 ms) was not influenced by experimental variables (Fs < 1.9, ps $> .18$).

P300. The ERP waveform at the Pz electrode depicted in Figure 15 shows the effect of experimental variables on the P300 component. The analysis of P300 peak amplitude revealed a centroparietal distribution, $F(2, 30) = 88.2$, $\varepsilon = .85$, $p < .001$. Like N170 amplitude, P300 amplitude was larger for easy than difficult

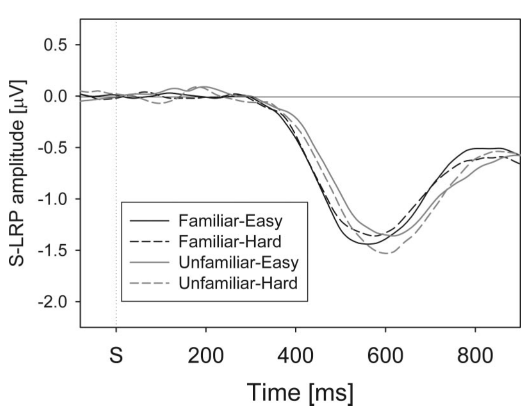

Figure 11. Grand-mean stimulus-locked lateralized readiness potential (S-LRP) in go trials in Experiment 3 as a function of facial familiarity (familiar vs. unfamiliar) and expression difficulty (easy vs. hard). S = stimulus onset.

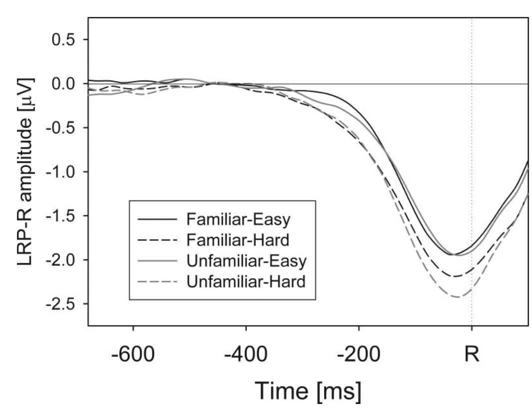

Figure 12. Grand-mean response-locked lateralized readiness potential (LRP-R) in Experiment 3 as a function of facial familiarity (familiar vs. unfamiliar) and expression difficulty (easy vs. hard). R = response onset.

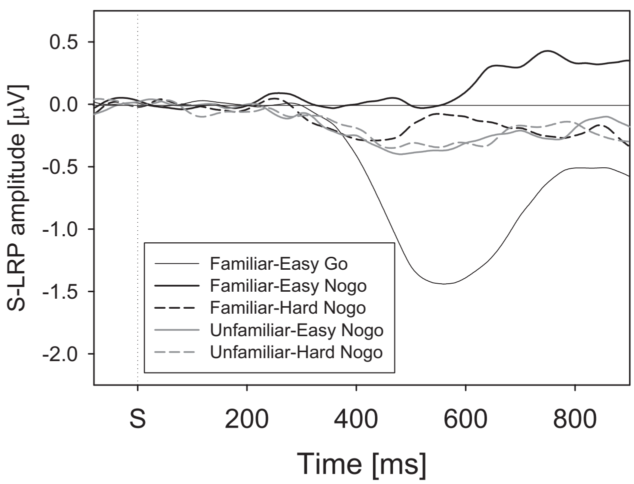

Figure 13. Grand-mean stimulus-locked lateralized readiness potential (S-LRP) in no-go trials of Experiment 3 as a function of facial familiarity (familiar vs. unfamiliar) and expression difficulty (easy vs. hard). The familiar–easy go condition (thin black line) is depicted for comparison. S = stimulus onset.

conditions (M = 5.4 vs. 4.8 μV), $F(1, 15)$ =18.8, $p < .001$, and for famous than unfamiliar faces (M = 5.3 vs. 4.9 μV), $F(1, 15)$ = 6.0, $p < .05$. P300 amplitude was not influenced by the go/no-go condition as a main effect (M = 5.0 vs. 5.2 μV), $F < 1$, but in interaction with electrode, $F(2, 30) = 14.8$, $\varepsilon = .70$, $p < .001$, indicating a stronger frontocentral positivity for no-go than go trials. Interaction effects were nonsignificant (Fs < 2.5, ps $> .10$). In the analysis of P300 latency, the Go/No Go × Familiarity interaction was significant, $F(1, 15) = 10.6$, $p < .01$, which was due to the fact that P300 peaked earlier for famous than unfamiliar faces in go trials (M = 534 vs. 576 ms), $F(1, 15) = 14.0$, $p < .01$, but not in no-go trials (M = 550 vs. 535 ms), $F = 1$.

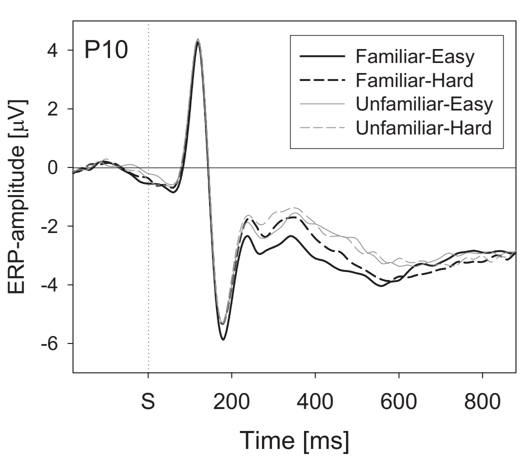

Figure 14. Grand-mean stimulus-locked event-related brain potential (ERP) waveforms at the P10 electrode in go trials in Experiment 3 as a function of facial familiarity (familiar vs. unfamiliar) and expression difficulty (easy vs. hard). S = stimulus onset.

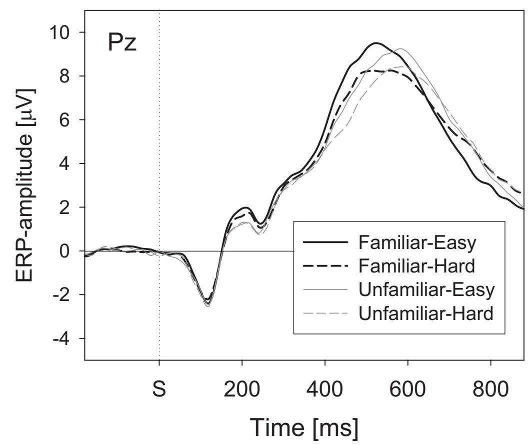

Figure 15. Grand-mean stimulus-locked event-related brain potential (ERP) waveforms at the Pz electrode in go trials as a function of facial familiarity (familiar vs. unfamiliar) and expression difficulty (easy vs. hard). S = stimulus onset.

Discussion

Experiment 3 replicated the findings of Experiment 2 concerning the influence of familiarity on information processing. RT, S-LRP onset, and P300 latency indicated faster processing of familiar than unfamiliar faces, whereas N170 latency was not influenced by familiarity. Together, these findings indicate, as in Experiment 2, that a higher level cognitive process, such as a memory-search process (cf. Schweinberger & Sommer, 1991), was speeded up for famous compared with unfamiliar faces. Also, N170 amplitude was again smaller for unfamiliar than familiar faces, suggesting an early effect of familiarity on the structural encoding stage (see also Kloth et al., 2006).

The main aim of Experiment 3, however, was to provide a further test of the parallel-dependent model of face processing. Consistent with this model, but also the parallel-independent model, the S-LRP onset was not affected by the difficulty of expression discrimination, despite the fact that this variable produced on average a considerable 41-ms effect in RT (see Table 2). In contrast to Experiment 2, it is unlikely that this zero effect was due to measurement error as the S-LRP onset sensitively revealed a familiarity RT effect on premotoric processing time, which was of clearly smaller magnitude than the RT effect produced by expression discriminability (23 vs. 41 ms). The zero S-LRP effect can be explained if one assumes that hand activation starts on completion of the identity analysis, and as identity processing was not experimentally manipulated in its duration, the S-LRP onset remained invariant. In line with this assumption, expression discriminability influenced late motor processing time as indicated by the longer LRP-R interval for hard versus easy expression discriminations. These findings accord with the assertion that facial identity and expression are processed in parallel and that partial information is used to activate the motor system (see Table 2).

Most important, (a) replicating the observations of Experiment 2, a no-go LRP was present for easy expression (and easy familiarity) discriminations with unfamiliar but not with familiar faces, whereas (b) a no-go LRP was generally observed when expression was hard to process (see Table 2), suggesting that also for familiar faces, hand activation started before the go/no-go decision was taken. The parallel-dependent model naturally accounts for these no-go LRP findings because of the assumption of identity-dependent expression representations (e.g., Fox & Barton, 2007) or shared representations of identity and expression (e.g., Calder et al., 2001). Thus, with faster identity processing for familiar than unfamiliar faces, as indicated by RT and S-LRP interval, the absence of the no-go LRP only for familiar faces indicates that relative completion times for facial identity and expression analyses are alike, whereas the presence of the no-go LRP when expression discriminations are hard suggests that expression processing is selectively prolonged. Together, we once again conclude that the parallel-dependent model supersedes the parallel-independent model as an account of face recognition, whereas the parallel-contingent model fails more generally.

General Discussion

The present study provides, at least to our knowledge, the first systematic test of alternative face perception models regarding the temporal organization of joint facial identity and expression processing. To more specifically investigate the cognitive architecture underlying face perception, we used a two-choice go/no-go task in which we selectively manipulated the duration of facial expression and identity processing in separate experiments. Critically, supplementing behavioral measures with electrophysiological markers of information processing, in particular the LRP, allowed us to assess more precisely the nature of facial identity and expression processing. Overall, Experiments 2 and 3 support two major conclusions regarding face recognition models: (a) Facial identity and expression are processed in parallel rather than in cascade, and (b) expression is more rapidly extracted for familiar than unfamiliar faces, suggesting that expression analysis of familiar faces is identity-dependent.

A first important finding of the present experiments as it relates to the discrimination among alternative face recognition models is the faster processing of famous than unfamiliar faces indicated by RT and S-LRP interval results. As pointed out earlier, we assumed that memory search through stored representations of faces is more time consuming for unfamiliar faces (open set) compared with familiar faces (closed set). For example, memory search may stop, and a “familiar” decision may be reached as soon as a match is detected between the perceived stimulus and the stored face representations. By contrast, an “unfamiliar” decision may require an exhaustive search through stored representations of faces, which on average will be more time consuming than the self-terminating search process for familiar faces. This explanation of the present familiarity effect in terms of a higher level cognitive process is supported by the absence of a familiarity effect in N170 latency together with its presence in P300 latency, which is known to sensitively reflect the time demands of memory search for faces (e.g., Schweinberger & Sommer, 1991). In addition, the present smaller P300 amplitude for unfamiliar than familiar faces also accords with the idea that memory search is more demanding for unfamiliar than familiar faces (Schweinberger & Sommer, 1991). We would like to note, however, that within the framework of Bruce and Young’s (1986) model, it is also conceivable that unfamiliar faces are not processed via the FRU route but may be strategically processed in a route of directed visual processing with selective attention on distinctive features, which are encoded and processed without the use of the FRUs. However, N170 findings speak against this possibility, because N170 amplitude was larger for familiar than unfamiliar faces. This finding suggests that, if anything, familiar and not unfamiliar faces received more attention, and that the allocation of additional attentional resources to the encoding of familiar faces increases N170 amplitude in line with similar proposals in the literature (cf. Eimer, 2000a). Certainly, although the present experiments provided strong chronometric evidence for a higher level cognitive mechanism to be responsible for the facial familiarity effect, more specific tests are required given that the mechanisms underlying the processing of unfamiliar faces have not been specified in such detail as those underlying the processing of familiar faces.

Evaluation of Face Recognition Models

Most important, present chronometric LRP data and the no-go LRP provided strong evidence for the assumption that (a) facial identity and expression are analyzed in parallel and (b) expression processing of familiar faces uses identity information. In the following, we summarize the main findings of Experiments 2 and 3 (see Tables 1 and 2) and then discuss their implications for alternative face recognition models. In Experiment 2, the duration of the facial identity process was lengthened using morphing along the unfamilar–familiar face dimension, thereby making the familiarity decision more difficult. This resulted for unfamiliar faces in an increase of RT and the S-LRP interval when the familiarity decision was hard rather than easy. Most crucial, however, the LRP-R interval was shortened rather than lengthened and the no-go LRP was abolished rather than elevated for hard compared with easy familiarity discriminations. For familiar faces, LRP indices did not show a reliable influence of familiarity difficulty in Experiment 2, indicating that information about expression is more readily available for familiar faces than unfamiliar faces. Actually, it was only when expression processing was considerably delayed by using morphed expressions in Experiment 3 that facial identity analysis gained a temporal advantage over expression processing, as indicated by the no-go LRP for familiar faces when identity was easy and expression was difficult to discriminate. Moreover, whereas RT was longer for hard than easy facial expression analysis in Experiment 3, the S-LRP interval was not influenced by the difficulty of expression discriminations.

The above findings are clearly at variance with the parallel-contingent model (Schweinberger et al., 1999), which assumes that the analysis of facial expression depends on partial information transmitted from the identity stage. Thus, both the continuous and the discrete model versions predicted that the S-LRP interval should be generally influenced by discriminability manipulations, which did not hold true for Experiment 3. Moreover, the continuous version predicted a general increase of the LRP-R interval and of the no-go LRP for easy than hard discriminations, whereas the discrete version predicted the LRP-R interval to be uninfluenced by discriminability and the no-go LRP to be generally absent. These predictions were not or only partially supported; hence, we conclude that the parallel-contingent model is not a feasible account of facial identity and expression processing.

The present results also do not accord with Bruce and Young’s (1986) assumption of independent processing of facial identity and expression. According to its independency assumption, it follows that familiarity with a face should not modulate the duration of expression processing. As familiar faces were found to be generally identified faster than unfamiliar faces, differences in relative completion times of facial identity and expression processing should be elevated for familiar faces. Thus, the parallel-independent model predicted stronger discriminability effects on the LRP-R interval and on the no-go LRP for familiar than unfamiliar faces (see Figure 4). However, in Experiment 2, the LRP-R interval was influenced only by discriminability for unfamiliar faces, and the no-go LRP observed in Experiments 2 and 3 was generally more pronounced for unfamiliar than familiar faces. These findings, indicating that facial expression is extracted more rapidly for familiar than unfamiliar faces, are at variance with one of the key assumptions of the parallel-independent model of face recognition, namely, that facial identity and expression are processed independently. Therefore, the parallel-independent model is also not a viable account of facial identity and expression processing in the present study.

In the end, chronometric and no-go LRP findings for familiar faces, together with those for unfamiliar faces, strongly support a parallel-dependent model of face recognition (see Figure 10). To reiterate, the crucial finding is that although we observed faster processing of familiar than unfamiliar faces, a temporal advantage for identity compared with expression processing was obtained only for unfamiliar faces when both facial dimensions were easy to process. This implies that information about expression has been much more readily available for familiar faces than for unfamiliar faces. Together, the LRP results of Experiments 2 and 3 provide strong evidence for the assumption that identity and expression analysis of familiar and unfamiliar faces occurs in parallel, yet expression processing relies on identity information.

In line with this view, results from face adaptation studies suggest that expression analysis relies on identity-dependent and identity-invariant representations of expression, whereas the analysis of facial identity uses only expression-invariant representations (cf. Fox & Barton, 2007; Fox et al., 2008; Winston et al., 2004). Furthermore, identity-dependent processing of facial expression also seems consistent with Calder and Young's (2005) assumption that facial identity and expression are initially represented in a single multidimensional system (cf. Calder et al., 2001) in which they share a limited degree of coding sets. This view accords with an influence of both familiarity and expression decision difficulty on N170 amplitude. This result, if not caused by single facial features but by the facial dimensions as a whole, may indicate that structural encoding at this stage has not yet bifurcated for identity and expression analysis, as implied by the assumption of a single multidimensional system (Calder et al., 2001; see also Burton, Bruce, & Hancock, 1999). Of course, this does not exclude a functional separation of both facial analysis processes. It is likely that identity and expression are analyzed separately subsequent to the structural encoding stage.

The present findings also agree with previous studies examining the functional independence of facial identity and expressions using the Garner task. Typically, it has been observed that participants are unable to ignore irrelevant variations in the identity or gender of faces when processing facial expression, whereas they are able to ignore facial expression when facial identity or gender is task-relevant (Atkinson et al., 2005; Baudouin et al., 2002; Schweinberger et al., 1999; Schweinberger & Soukup, 1998). This asymmetric interference effect in the Garner paradigm indicates that identity information influences the analysis of facial expression but not vice versa. To account for this pattern, Schweinberger et al. (1999) suggested their parallel-contingent processing model. Although this model found no support in the present work, it is evident that the parallel-dependent model, which assumes identity-dependent expression representations, is consistent with the finding of asymmetric Garner interference.

Possible Limitations of the Present Study

Although the present findings provide support for the parallel-dependent processing of facial identity and expression, it is fair to elaborate a few critical issues that may affect or limit our inferences. First, one could argue that differences in expression processing for unfamiliar compared with familiar faces are due to a stimulus artifact. According to this possibility, the expression analysis of unfamiliar faces might have been slower compared with that of familiar faces because facial expressions were generally less salient. However, we view this account as implausible given that unfamiliar and familiar expressions did not differ in their expression intensity ratings and that RT for expression discriminations were uninfluenced by facial identity in Experiment 1. Rather, it appears more likely that facial identity and expression analyses require a similar amount of time for familiar faces because facial representations are not expression-independent but stored with preserved information of the facial expression with which the face is mainly experienced (e.g., Baudouin et al., 2002; Kaufmann & Schweinberger, 2004; Lander & Metcalfe, 2007).

Second, it is important to note that our inferences are certainly limited to "happy" and "angry" emotions, which are relatively distinct and easy to discriminate because of relatively few common features (Susskind, Littlewort, Bartlett, Movellan, & Anderson, 2007). Therefore, future work has to show whether our results generalize for the whole range of basic expressions.

Third, there may be a problem with LRP-based inferences because the LRP does not provide direct access to facial identity and emotion processes. One might argue, therefore, that the present LRP findings better reflect the nature of information processing at the level of response decisions rather than at the level of perceptual processing. Of course, it is not possible to completely rule out this possibility; however, it is evident that decisions about hand activation and response execution (go vs. no-go) depend on facial identity and expression information as provided by perceptual processes. In our view, therefore, it is plausible to assume that the LRP provides important chronometric information about the time course of separate perceptual processes. This assumption has received strong support in previous studies that used the LRP in combination with the two-choice go/no-go paradigm to examine the nature of perceptual and motor processing (cf. Miller & Hackley, 1992; Osman et al., 1992; Smid et al., 1992). Therefore, we believe that the LRP provides a more powerful tool than RT to discriminate among different information processing architectures as, for example, proposed in the domain of face recognition for the analysis of facial identity and expression.

Still, the fact that facial identity determined the hand decision and expression determined the go/no-go decision could have led participants to develop certain processing and response strategies.

For example, participants might have decided to process hand-related information prior to go/no-go–related information because go responses were more probable than no-go responses (75% vs. 25%). Therefore, we investigated in two separate experiments the effects of expression and familiarity difficulty for the reversed stimulus–response assignment, that is, facial expression determined response hand and facial identity determined response execution. We hypothesized that if participants would strategically adjust information processing, then facial expression information (i.e., response hand) should influence the motor system earlier than identity information (i.e., response execution). Most critical, and in contrast to the strategy hypothesis, the LRP-R interval was not reliably influenced by expression discrimination difficulty, and the no-go LRP was generally absent. These data will be published in more detail separately, but we would like to note that those LRP results are consistent with the interpretation offered here, ruling out a possible explanation of current findings purely in terms of processing or decision strategies.

Conclusions

In summary, we found evidence that supported a parallel architecture of facial identity and expression analysis. A temporal advantage for facial identity analysis compared with expression analysis was generally observed for unfamiliar faces but for familiar faces only when expression discrimination was difficult. The observed differences between familiar and unfamiliar faces indicate that facial expression processing relies on identity information, supporting a model that assumes parallel-dependent processing of face recognition. Future research should assess more directly the neural mechanisms mediating this type of interactive face processing (cf. Calder & Young, 2005; Haxby et al., 2000).

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