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From face processing to face recognition: Comparing three different processing levels

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ABSTRACT

Verifying that a face is from a target person (e.g. finding someone in the crowd) is a critical ability of the human face processing system. Yet how fast this can be performed is unknown. The 'entry-level shift due to expertise' hypothesis suggests that - since humans are face experts - processing faces should be as fast – or even faster – at the individual than at superordinate levels. In contrast, the 'superordinate advantage' hypothesis suggests that faces are processed from coarse to fine, so that the opposite pattern should be observed. To clarify this debate, three different face processing levels were compared: (1) a superordinate face categorization level (i.e. detecting human faces among animal faces), (2) a face familiarity level (i.e. recognizing famous faces among unfamiliar ones) and (3) verifying that a face is from a target person, our condition of interest. The minimal speed at which faces can be categorized (~260 ms) or recognized as familiar (~360 ms) has largely been documented in previous studies, and thus provides boundaries to compare our condition of interest to. Twenty-seven participants were included. The recent Speed and Accuracy Boosting procedure paradigm (SAB) was used since it constrains participants to use their fastest strategy. Stimuli were presented either upright or inverted. Results revealed that verifying that a face is from a target person (minimal RT at ~260 ms) was remarkably fast but longer than the face categorization level (~240 ms) and was more sensitive to face inversion. In contrast, it was much faster than recognizing a face as familiar (~380 ms), a level severely affected by face inversion. Face recognition corresponding to finding a specific person in a crowd thus appears achievable in only a quarter of a second. In favor of the 'superordinate advantage' hypothesis or coarse-to-fine account of the face visual hierarchy, these results suggest a graded engagement of the face processing system across processing levels as reflected by the face inversion effects. Furthermore, they underline how verifying that a face is from a target person and detecting a face as familiar – both often referred to as "Face Recognition" – in fact differs.

1. Introduction

Individuals are mostly recognized by their faces. Something we do daily for example is *verifying that a face is from a target person* (e.g. finding someone in the crowd). Classically, it is investigated in experimental tasks by proposing a verbal label to participants (e.g. "Brad Pitt") and asking them whether subsequently presented faces match or not with the label.

Objects are usually categorized faster at the basic-level (e.g. bird vs. other animals) than at the superordinate (e.g. animal vs. vehicle) or subordinate-level (e.g. Indigo Bunting vs. other birds)

Abbreviations: RT, Reaction Time; minRT, minimal RT; HFC, Human Face Categorization; IFR, Individual Face Recognition; FFR, Familiar Face Recognition; SAB, Speed and Accuracy Boosting procedure.

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(Rosch et al., 1976). The basic level is thus thought to be the entry level at which people first process objects (Anaki & Bentin, 2009; Johnson & Mervis, 1997; Jolicoeur, Gluck, & Kosslyn, 1984; Rosch et al., 1976; Tanaka, 2001; Tanaka & Taylor, 1991; Wong & Gauthier, 2007). However, this entry level may shift to the subordinate level with atypicality (e.g. penguins categorized faster than as birds; Jolicoeur et al., 1984) or with expertise (e.g. Indigo Bunting categorized as fast as birds by expert bird watchers; Johnson & Mervis, 1997; Tanaka & Taylor, 1991). Humans are usually considered to be face experts (Carey & Diamond, 1977; Carey, Schonen, & Ellis, 1992; Tanaka & Gauthier, 1997). Consistent with this idea, it has been shown that faces are categorized as fast - or even faster (see Anaki & Bentin, 2009) - at the individual level (e.g., as Brad Pitt) than at a superordinate level (e.g., as a human face) (Anaki & Bentin, 2009; Tanaka, 2001).

However, at odds with such interpretation, neurophysiological or neuroimaging studies have suggested that superordinate, coarse, information is processed before the more detailed information required for higher-level categorization (Large, Kiss, & McMullen, 2004; Löw et al., 2003; Martinovic, Gruber, & Müller, 2008; Sugase, Yamane, Ueno, & Kawano, 1999; for faces, see Goffaux et al., 2011). Interestingly, behavioral tasks also argue in favor of such a *coarse-to-fine access* to perceptual representations (Fabre-Thorpe, 2011; Hochstein & Ahissar, 2002), when studying *minimal reaction times* (minRT) - i.e. the minimal processing time necessary to give reliable responses (Rousselet, Macé, & Fabre-Thorpe, 2003). Aforementioned behavioral studies indeed classically studied mean or median RTs without speed constraints. However, these RTs could reflect processes which are not strictly necessary, such as verification or access to lexical information. For example, access to basic words could be shorter than access to superordinate words since they are more frequently used. Using the minRT approach, Macé, Joubert, Nespoulous, and Fabre-Thorpe (2009) showed a *superordinate advantage* compared to the basic level when animals had to be categorized, a finding further confirmed in other studies (Kadar & Ben-Shahar, 2012; Loschky & Larson, 2010; Praβ, Grimsen, König, & Fahle, 2013; Vanmarcke & Wagemans, 2015; Vanmarcke et al., 2016). Such superordinate-level advantage was shown to be independent of stimuli duration or target and distractor diversity (Poncet & Fabre-Thorpe, 2014).

The prediction of the superordinate advantage level hypothesis for faces would be that faces would be categorized faster at the superordinate than at the individual level, despite the expertise advantage. To date, only one study compared different levels of face categorization using minimal RTs. In this study, participants had to perform a 'human face vs. animal face' superordinate categorization task, which was contrasted with a 'familiar face vs. unfamiliar face' subordinate recognition task. Results were clear as the superordinate task was performed much faster (minRT: ~250 ms) than the subordinate (~440 ms) (Barragan-Jason, Lachat, & Barbeau, 2012). Although particularly strong, such an effect was expected since the superordinate categorization task can rely on the detection of low-level features (Crouzet, Kirchner, & Thorpe, 2010; Rossion & Caharel, 2011; Rossion & Jacques, 2011) and hence be very fast (about 260 ms, reviewed in Fabre-Thorpe, 2011). In contrast, participants had to recognize famous faces among unknown ones in the subordinate (i.e. familiarity) task. They did not know in advance which famous faces would be presented. Each face thus had to be processed up to the individual level in a bottom-up fashion before a familiarity signal could be triggered. Such level of processing thus refers to a particular kind of face recognition task, for which no clue is available before the face is processed, and more akin to unexpectedly meeting an acquaintance in the street (Fig. 1A). Several studies have now reported that such face recognition task can be performed at about 360 ms at the fastest (Barragan-Jason, Besson, Ceccaldi, & Barbeau, 2013; Barragan-Jason et al., 2012; Besson, Ceccaldi, Didic, & Barbeau, 2012), a quite long delay compared to face categorization tasks.

What about verifying that a face is from a target person, the other face processing level aforementioned (Fig. 1A)? Such task has never been studied using a minimal RT approach. Under the entry level shift due to expertise hypothesis, such task should be performed faster – or at least as fast – than a superordinate level task (Anaki & Bentin, 2009; Tanaka, 2001). Under the superordinate advantage level hypothesis in contrast, such task should need more processing time than a superordinate task. In fact, some studies have reported strikingly fast RTs (about 250 ms) in similar tasks, suggesting it is worth investigating this issue in detail (Lewis & Ellis, 2000).

How fast verifying that a face is from a target person would be relatively to detecting a face as familiar when no clue is available also remains unclear. In fact, the numerous terms used to refer to the verification that a face is from a target person ('category-verification task', Tanaka, 2001; 'individual-level verification task', Anaki & Bentin, 2009; or 'face-identification task', e.g. Delorme & Thorpe, 2001; Reddy, Reddy, & Koch, 2006) highlights how much its underlying mechanisms remain poorly understood. Specifically, does such a task need to rely on a *person identity-level* - a higher, amodal and semantic level of representation, which would follow visual processes (Bruce & Young, 1986)? If so, verifying a face identity would be best described as a 'face-identification task' and would be rather long, for instance close to familiarity tasks (Valentine, 2001). In contrast, verifying a face identity could rely on facial diagnostic clues (e.g. specific facial features characteristic of a face) that could help preparing and optimizing visual processing through top-down strategies, such as preactivation and attentional selection (e.g. Eimer, 2014). In this case, it could be quite fast, and close to categorization tasks, which rely on similar mechanisms.

In this study, we compared performance speed in an Individual Face Recognition task (i.e. verifying that a face is from a target person) to a Human Face Categorization task and to a Familiar Face Recognition task. The difference between these conditions is visually schematized in Fig. 1A. Interestingly, the distinction between Individual Face Recognition and Familiar Face Recognition conditions is not always clear in the literature whereas they may rely on different processes and hence yield different RTs.

As already presented, the speed at which faces can be processed is largely known for either Human Face Categorization (minRT: ~260 ms) or Familiar Face Recognition (minRT: ~360 ms). The aim of this study is to assess the speed of Individual Face Recognition compared to these boundaries (Fig. 1B), and thus to determine what temporal hierarchy, if any, there is between these three levels of face processing. To test the entry level shift related to expertise or the superordinate level hypotheses, we will compare minimal RTs in the Individual Face Recognition condition to the Human Face Categorization and Familiar Face Recognition conditions (Fig. 1C). For such comparisons to make sense, it is necessary to constrain participants to use their fastest strategy in each condition (Barragan-Jason et al., 2013). We thus used the Speed and Accuracy Boosting procedure (SAB), a recent procedure based on a go/no-go paradigm with a response deadline (Besson et al., 2012) in which responses must be provided before a constraining time limit, set in this study at 600 ms (Fig. 1D). Last, since face inversion is known to disrupt holistic processing and access to face configuration, we investigated the effect of face inversion on these different conditions, by also running all three with inverted stimuli (Farah, Wilson, Drain, & Tanaka, 1998; Maurer, Grand, & Mondloch, 2002; Rossion, 2008; Yin, 1969).

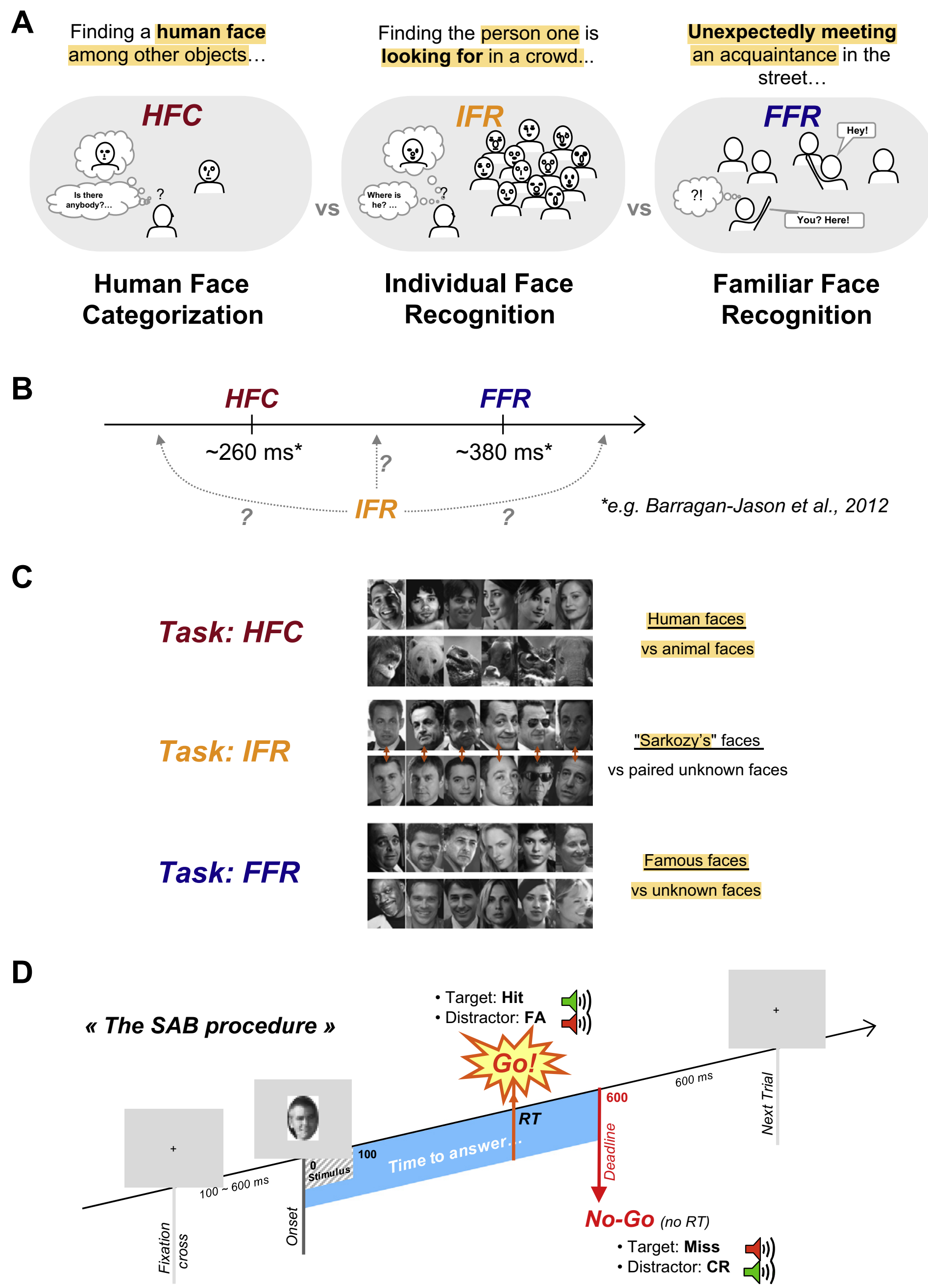

Fig. 1. Experimental design. (A) Schema depicting different levels of face processing: Human Face Categorization (HFC), Individual Face Recognition (IFR), Familiar Face Recognition (FFR). (B) If the minimal processing time needed for Human Face Categorization and Familiar Face Recognition can be predicted from previous studies, different hypotheses are possible regarding the minimal processing time needed for Individual Face Recognition. (C) Samples of the stimuli used in each of the three tasks. (D) SAB procedure. See Section 2.4 for details.

2. Material and methods

2.1. Participants

27 participants (15 women) were included in this study (median age: 24 [21–27], 2 left-handed). All participants signed informed consent and had normal or corrected-to-normal vision.

2.2. Experiment

The experiment included 3 tasks: (1) a Familiar Face Recognition task, (2) an Individual Face Recognition task and (3) a Human Face Categorization task. Each task was made of 2 consecutive blocks of 140 stimuli: one using upright stimuli, the other using inverted stimuli. No stimulus was repeated, even inverted. The order of the three tasks was pseudo-randomized and counterbalanced across participants, as well as the order of upright and inverted conditions.

2.3. Tasks

In the Familiar Face Recognition task, targets were famous faces of different persons (persons were never repeated) and distractors unknown faces. In the Individual Face Recognition task, targets were different picture of the same famous person and had to be recognized among matched unknown faces (distractors). One block (the upright or the inverted one) consisted in recognizing faces of Nicolas Sarkozy (NS), President of France during the period the experiment was run; the other block consisted in recognizing faces of Johnny Hallyday (JH), a highly famous French rock singer. Hence, the upright block was performed with one of the famous person target, whereas the inverted one was performed with the other famous person target, a choice that was pseudo-randomized and balanced across participants. In the Human Face Categorization task, targets were human faces and distractors animals faces all presented randomly. Each block was made of 70 targets intermixed with 70 distractors.

2.4. Procedure

Each block was run using the Speed and Accuracy Boosting procedure (SAB) with a response deadline set at 600 ms from stimulus onset, a deadline inferred from previous studies (Besson et al., 2012; Besson et al., 2015). Inspired by different approaches (the Speed-Accuracy Trade-off procedure, e.g. Dosher, 1976; response-deadline procedures, e.g. Reed, 1973 or more recently Bowles et al., 2007; minimal reaction times, e.g. Rousselet et al., 2003), the SAB procedure specifically aims at studying the reaction times distribution while constraining subjects to use their fastest strategy (for a discussion, see Besson et al., 2012). Briefly, it is based on a classical Go/No-Go task, constrains participants to answer before a response deadline (to boost speed), and provides an audio-feedback - positive if the item was a target (hit), negative if the item was a distractor (false-alarm) - at the response (to boost accuracy). If no response is made before the response deadline, the response is considered as a No-Go-response and, at the response deadline, an audio-feedback is played - positive if the item was a distractor (correct rejection), negative if the item was a target (miss) (Fig. 1D). Before each item presentation, a fixation cross is displayed for a pseudo-random time between 300 and 600 ms. Items are presented, one by one, in the center of a grey screen, for 100 ms (comprised in the response deadline). The SAB is highly demanding and training is necessary. Each block was preceded by a training block (20 targets to be recognized among 20 distractors), which could be repeated if needed following participants' request. Training stimuli were not re-used in any experimental block. A self-paced pause was proposed each 20 trials.

2.5. Stimuli

Sample stimuli for each task are presented in Fig. 1C. Famous faces in the Familiar Face Recognition task were selected as the best recognized famous faces of a large database used in previous experiments with participants of the same age as in this study (Barragan-Jason et al., 2013). Distractors for famous faces were unknown faces randomly selected from the same study. Unknown faces were chosen so that they "looked like" they could be famous.

Pictures for the Individual Face Recognition task were selected from the web. All original pictures presented a face area of at least 200 × 200 pixels. No blurry picture was included. We avoided as much as possible pictures with lots of details in the background and with any objects hiding the face (e.g. hand, microphone, other person, etc.). All pictures were chosen relatively close to one prototype face (e.g. in the same period of life, color of hair, etc.), but we avoided choosing pictures too similar (e.g. from the same photo shooting, etc.). The distractor sets were made by matching one-by-one an unknown face picture with each target picture (Fig. 1C). Pictures were as much as possible matched on the types of clothes, type and color of hair (and beard), color of eyes, age, paraphernalia or hiding object if needed, head orientation, face expression (e.g. smiling, laughing, neutral, talking, etc.).

Unknown human faces and animals faces of the Human Face Categorization task were randomly chosen from a previous similar experiment (Barragan-Jason et al., 2012).

All pictures for the three experiments were in grayscale (256 levels). Each picture was framed manually around the face following the same procedure (i.e. a rectangle delimited at the bottom by the chin, on the side by the point between the face itself and the ear or, when the ear was masked in three-quarter profiles, the farthest point between the eyebrow arch and the cheekbone, and at the top by the midpoint of the front hairline, extrapolated if necessary). Pictures could then be resized so that each face had the same size and could be cropped all identically around the face, using a homemade script on Matlab. Thus, all pictures were similar close-up grayscale pictures of centered faces of the same size (208 × 279 pixels, visual angle: ~4.7 × 6.3°). Lastly, all stimuli were equalized to the same luminance (mean grey-level: 108.7) and contrast (computed as the standard error of pixels luminance: 54) across conditions.

2.6. Set-up

Participants sat in a dimly lit room, at 90 cm from a computer screen piloted by a PC. Image presentation and behavioral responses recordings were carried out using the E-prime v2. Participants responded to the stimuli by raising their fingers from a custom-made infrared response pad.

2.7. Minimal reaction times

To obtain an estimation of the minimal processing time required to recognize targets, the minimal behavioral reaction time (minRT) was computed by determining the latency at which correct go-responses (hits) started to significantly outnumber incorrect go-responses (false-alarms) (Rousselet et al., 2003). For each task, analyses were performed both across trials (by pooling together all trials from all participants for a given condition) and across participants. Across trials analyses have been used in previous studies (Barragan-Jason et al., 2012; Besson et al., 2012; Rousselet et al., 2003) and are like building a "meta-participant", reflecting the performance over all the population. MinRTs across trials were computed using 10 ms time bins and determined as the middle of the first bin that was significant, χ^2-test, $p < 0.05$, followed by at least three significant consecutive bins. Across participants, in order to accommodate for the lower statistical power than across trials data since there were fewer trials, we used 40 ms time bins and a Fisher's exact test ($p < 0.05$). A minRT can't be computed if the distribution of hits and false alarms are too close. Thus some participants don't have a minRT, in particular when d' are low (details reported in Section 3).

2.8. Statistical analyses

Performance (accuracy) and bias were computed using d' and C based on the signal detection theory (corrected according to Snodgrass & Corwin, 1988). Participants' success on a task was determined statistically (χ^2-test between hits and false alarms (FA) among targets and distractors, $p < 0.05$). As parametrical conditions were largely met (normality checked with Lilliefors test, $p < 0.05$; variance equality tested with Brown & Forsythe test, $p < 0.05$), statistical comparisons were computed using ANOVAs. For RTs, mean and standard deviation were computed based on formula defined for lognormal distribution.

3. Results

3.1. Across participants accuracy

A repeated measures two-way ANOVA on accuracy with task and orientation as factors revealed a clear main effect of the task ($F(2,22) = 784.6$; $p < 0.0005$) and of the orientation ($F(1,23) = 402.3$; $p < 0.0005$), as well as a significant interaction between them ($F(2,22) = 60.2$; $p < 0.0005$). Accuracy was smaller in the Familiar Face Recognition condition than in the Individual Face Recognition, which itself was smaller than in the Human Face Categorization (see Fig. 2A). The Familiar Face Recognition was much more difficult than the Individual Face Recognition and Human Face Categorization and not every participant succeeded on the task. In the upright condition, three participants did not succeed on the Familiar Face Recognition and were thus discarded from the study, while in the inverted condition only a few succeeded at this condition (see Table 1). Furthermore, the effect of inversion was computed (i.e. the difference between inverted face accuracy and upright faces accuracy divided by the upright faces accuracy; e.g. Russell, Duchaine, & Nakayama, 2009) and showed a significant difference between the three task ($F(2,22) = 151.4$; $p < 0.0005$).

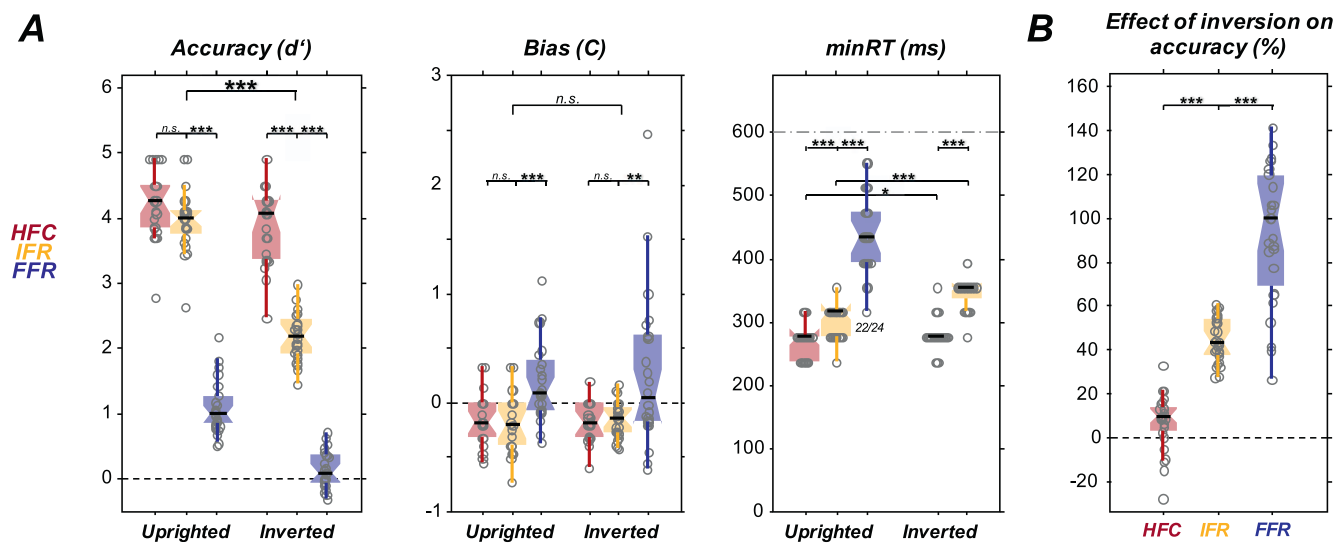

Fig. 2. Across participants analyses. (A) Comparison of performances, bias and minRTs computed across participant in each task. The main condition of interest, the Individual Face Recognition, is depicted in yellow. (B) Comparison of the effects of inversion on accuracy between tasks. * p < 0.05, *** p < 0.001, n.s.: p > 0.05. (minRTs: p-values were corrected with Bonferroni correction for multiple comparisons). Each circle is a participant. FFR = Familiar Face Recognition, HFC = Human Face Categorization, IFR = Individual Face Recognition. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Performance on the three tasks for upright and inverted faces (N = 27). FFR = Familiar Face Recognition, HFC = Human Face Categorization, IFR = Individual Face Recognition, N = number of participants, RT = Reaction Time, SD = standard deviation.

		Upright FFR task	Inverted FFR task	Upright IFR task	Inverted IFR task	Upright HFC task	Inverted HFC task
Accuracy (d')	Mean	1.06	0.13	3.96	2.18	4.20	3.85
	SD	0.41	0.28	0.47	0.37	0.52	0.56
	Range	[0.50; 2.16]	[−0.32; 0.71]	[2.64; 4.91]	[1.44; 2.98]	[2.78; 4.91]	[2.47; 4.91]
	Across trials	1.00	0.12	3.98	2.17	4.25	3.84
Bias (C)	Mean	0.19	0.26	−0.19	−0.16	−0.14	−0.18
	SD	0.37	0.70	0.27	0.17	0.23	0.18
	Range	[−0.37; 1.13]	[−0.62; 2.46]	[−0.73; 0.32]	[−0.42; 0.16]	[−0.56; 0.32]	[−0.60; 0.19]
	Across trials	0.18	0.18	−0.26	−0.18	−0.19	−0.18
Hits (%)	Mean	63	45	99	90	99	98
	SD	16	20	1	3	2	3
	Range	[27; 84]	[0; 73]	[94; 100]	[83; 94]	[90; 100]	[86; 100]
	Across trials	63	45	99	90	99	98
FAs (%)	Mean	25	41	4	18	3	4
	SD	12	22	4	8	2	3
	Range	[4; 49]	[0; 74]	[0; 16]	[4; 34]	[0; 9]	[0; 10]
	Across trials	63	45	99	90	99	98
Hits median RTs	Mean	452.9	426.0	352.5	389.8	323.7	336.1
	SD	31.7	95.1	25.5	20.4	26.8	27.7
	Range	[392; 548]	[221; 544.5]	[318; 418]	[355.5; 427]	[289.5; 396]	[295; 397.5]
	Across trials	449	423.5	351	388	320	334
Obtained a minRT/succeeded the task	N (%)	22/24 (91.67%)	2/4 (50.00%)	24/24	24/24	24/24	24/24
Minimal RTs	Mean	443.9	441.8	301.7	351.7	273.4	283.4
	SD	66.0	57.2	26.8	27.3	25.6	25.6
	Range	[320; 560]	[400; 480]	[240; 360]	[280; 400]	[240; 320]	[240; 360]
	Across trials	380	–	260	290	240	240

Post-hoc analyses showed that this effect was larger in the Familiar Face Recognition than in the Individual Face Recognition (Familiar Face Recognition: 88.1%, $SD = 29.6\%$; Individual Face Recognition: 44.5%, $SD = 9.9\%$; $p < 0.0005$), which itself was larger than in the Human Face Categorization (8.1%, $SD = 10.7\%$; $p < 0.0005$; Fig. 2B).

3.2. Across participants minRTs

MinRTs could not be calculated for all participants in the Familiar Face Recognition, in particular in the inverted condition. Hence, the 2×3 repeated measures two-way ANOVA design with task and orientation as factors were not carried out. Nevertheless, an unbalanced one-way ANOVA across upright conditions on log-transformed minRTs first revealed a significant effect of the task on minRTs ($F(2,69) = 115.2$; $p < 0.0005$). Indeed, in the upright condition, minRTs were longer in the Familiar Face Recognition than in the Individual Face Recognition (difference across participants: 142 ms, $SD = 67$ ms), itself longer than Human Face Categorization (28 ms, $SD = 32$) (see also Fig. 2A, Table 1). Second, a repeated measures two-way ANOVA with task and orientation as factors across Individual Face Recognition and Human Face Categorization tasks revealed a main effect of the task ($F(1,23) = 82.4$; $p < 0.0005$) and of the orientation ($F(1,23) = 56.1$; $p < 0.0005$), and a significant interaction between them could be observed ($F(1,23) = 28.8$; $p < 0.0005$) (see also Fig. 2A, Table 1).

3.3. Across trials analyses

Because minRTs by nature is sensitive to the lack of statistical power, analyses across trials were conducted (Fig. 3) using both

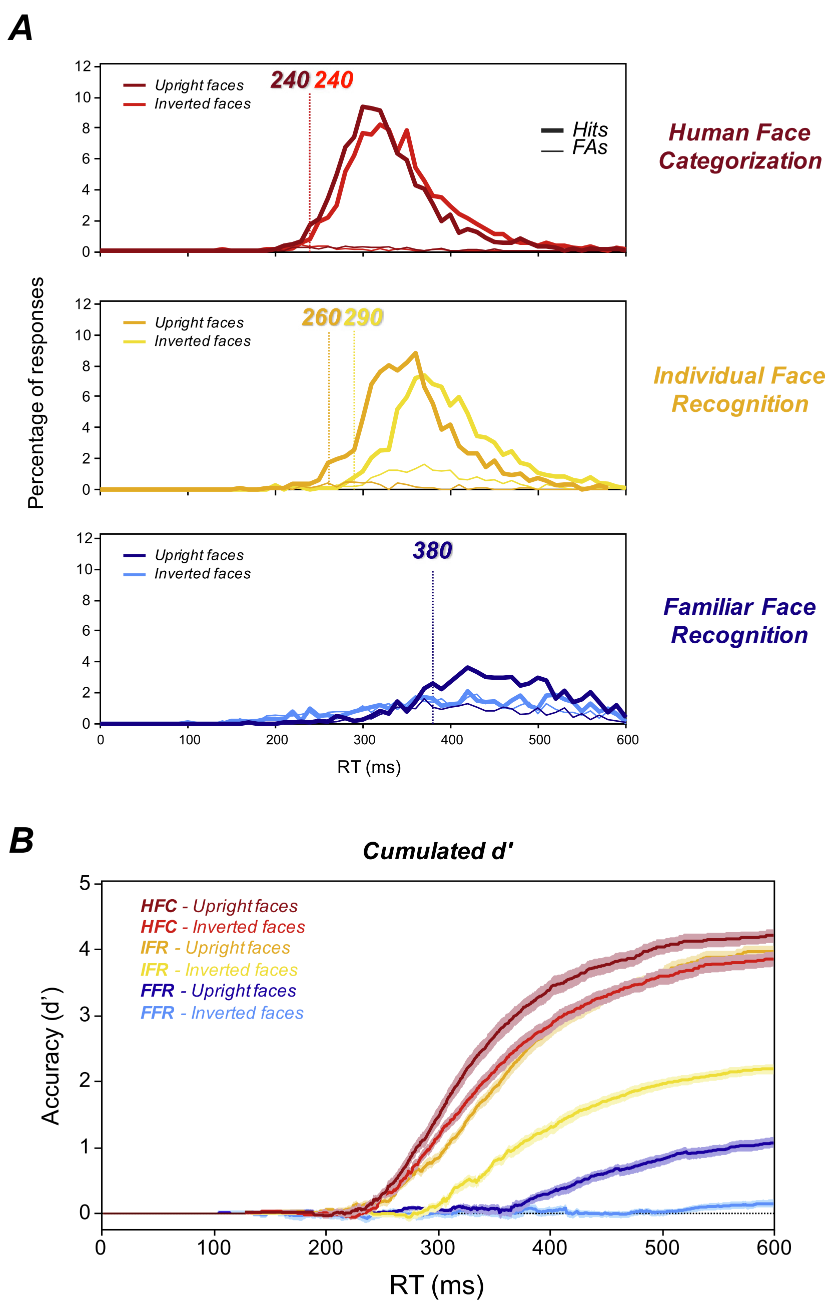

Fig. 3. Performances across time. (A) Performances obtained on each of the three tasks. Across trials distributions of RTs obtained in each task in the upright or inverted condition. Vertical bars and numbers correspond to across trials minRTs obtained in each task. (B) Cumulated d' for the three tasks with standard error of the mean computed for each 1-ms time step. FFR = Familiar Face Recognition, HFC = Human Face Categorization, IFR = Individual Face Recognition.

distributions of RTs and cumulated d-prime. Such analyses are similar to the results of a meta-participant and provide a summary of the results.

3.4. Bias

A repeated measures two-way ANOVA on bias with task and orientation as factors revealed a clear main effect of the task ($F(2,22) = 8.2$; $p = 0.002$), but not of the orientation ($F(1,23) = 0.2$; $p = 0.68$), and no interaction between them ($F(2,22) = 0.69$; $p = 0.51$). For upright, as for inverted stimuli, a conservative bias was observed in the Familiar Face Recognition condition, contrasting with a liberal and identical bias observed in the Individual Face Recognition and Human Face Categorization (Fig. 2A, Table 1).

3.5. Across-targets analyses

In order to investigate any effect of individual stimulus, for each target, a detection rate (i.e. percentage of go-responses) and a median RT were computed (Fig. 4). Unbalanced one-way ANOVAs across upright conditions, revealed a main effect of the task for both variables (detection rate, $F(2417) = 463$; $p < 0.0005$; median RT, $F(2417) = 669$; $p < 0.0005$). When focusing on *very well detected targets* across the three conditions (i.e. targets detected between 90% and 95% of time, i.e. very well detected targets excluding those at ceiling, and with detection rates not different among conditions, $F(2,38) = 0.75$; $p = 0.5$), a main effect on median RTs still remained

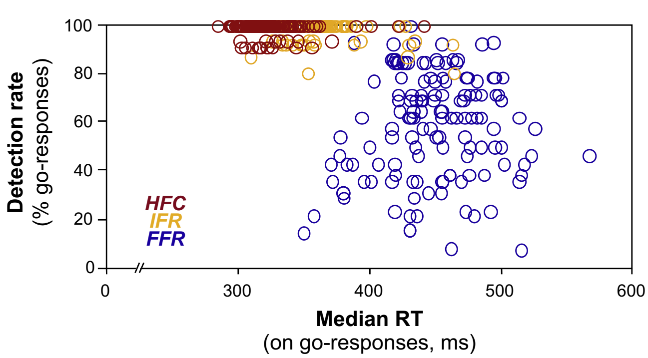

Fig. 4. Across-targets analysis of detection rate as a function of median RT on targets. Each circle is a target.

($F(2,38) = 32.1$; $p < 0.0005$), implying that, in each condition, the speed did not depend upon detection rate alone. Post-hoc analyses on this selection of targets showed that median RTs were longer in the Familiar Face Recognition than in the Individual Face Recognition (Familiar Face Recognition: 446 ms, $SD = 41$ ms; Individual Face Recognition: 369 ms, $SD = 41$ ms; $p < 0.0005$), which themselves were longer than in the Human Face Categorization (326 ms, $SD = 18$ ms; $p < 0.0005$). Similar results were observed on distractors.

3.6. Supplementary analyses

3.6.1. Effect of target identity on Individual Face Recognition performance

Results of Individual Face Recognition tasks are presented in Table 2. Overall, no statistical difference was observed between the two targets (Nicolas Sarkozy, IFR-NS or Johnny Hallyday, IFR-JH) on any variable (accuracy, bias or minRT). Nonetheless, it should be noted that there was a trend towards an effect of the target in the two-way ANOVA on accuracy ($F(1,44) = 3.73$, $p = 0.06$), which could be explained by a main simple effect of the target in the inverted condition ($F(1,50) = 6.47$, $p = 0.015$).

3.6.2. Effect of Individual Face Recognition preparation on the first target

RTs of each participant were ordered by the rank of presentation of the targets, with no RT if no go-response was made on a particular target by a given participant (omission). We focused on the RTs of the first target (targets were different faces across participants as targets were presented randomly for each participant) (Fig. 5A). Importantly, the large difference observed between Familiar Face Recognition and Individual Face Recognition reported in earlier results across all targets was apparent right from the beginning, i.e. for the first target.

In a complementary analysis, we focused on the first go-responses (rather than on the first target as in the previous analysis). Each first go-response given either on a target or a distractor was thus correct (hit) or incorrect (false-alarm). Therefore, this allowed us to compute minRTs (Fig. 5B). Results were largely convergent with the previous analysis. No error was made on Human Face Categorization upright and only one on Individual Face Recognition upright. This contrasted with the Familiar Face Recognition for which results were much poorer.

Table 2
Performance on the two Individual Face Recognition (IFR) tasks. N = number of participants, RT = Reaction Time, SD = standard deviation.

		Upright IFR-NS	Inverted IFR-NS	Upright IFR-JH	Inverted IFR-JH
Underwent the task	N	12	15	15	12
Accuracy (d')	Mean	4.00	2.34	3.89	1.93
	SD	0.62	0.20	0.36	0.37
	Range	[2.64; 4.91]	[2.04; 2.75]	[2.98; 4.49]	[1.44; 2.98]
	Across trials	3.90	2.35	3.92	1.92
Bias (C)	Mean	−0.22	−0.13	−0.18	−0.18
	SD	0.31	0.19	0.26	0.19
	Range	[−0.73; 0.32]	[−0.42; 0.25]	[−0.52; 0.32]	[−0.41; 0.16]
	Across trials	−0.29	−0.14	−0.19	−0.20
Hits median RTs	Mean	347.2	392.0	356.8	389.3
	SD	20.7	23.5	27.2	14.8
	Range	[318; 400.5]	[355.5; 427]	[318; 418]	[364; 409]
	Across trials	347	390	354	388
Obtained a minRT/succeeded the task	N	12/12	15/15	15/15	12/12
Minimal RTs	Mean	290.1	346.8	309.4	356.7
	SD	25.3	30.0	23.8	20.8
	Range	[240; 320]	[280; 400]	[280; 360]	[320; 400]
	Across trials	260	300	260	330

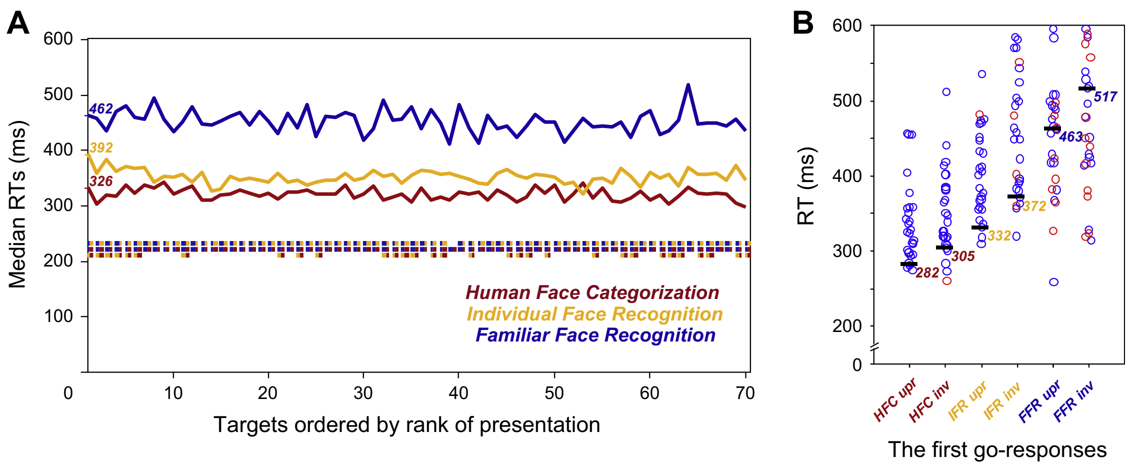

Fig. 5. Supplementary analyses. (A) Comparison of median RTs obtained on targets ordered by rank of presentation. Colored rectangles represent significance between conditions. (B) RTs obtained for the first go-responses, in each of task. Each dot represents an RT obtained by a participant either on a target (i.e. hit, in blue) or on a distractor (i.e. false alarm, in red). Horizontal lines indicate the minRT. No minRT could be computed for Familiar Face Recognition because of too many false-alarms. FFR = Familiar Face Recognition, HFC = Human Face Categorization, IFR = Individual Face Recognition, upr: Upright condition, inv = Inverted condition. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3.6.3. Effect of practice

We then focused on the RTs of the first target compared to the rest of the RTs in the same condition to investigate a possible role of practice or of fatigue. Statistical differences between each pair of rank of targets presented were computed. No repetition effect was observed (Fig. 5A).

4. Discussion

The aim of this study was to assess the difference between three different levels of face processing: (1) face categorization (i.e. detecting human faces among animal faces) (Human Face Categorization condition), (2) face familiarity (i.e. recognizing famous faces among unfamiliar ones) (Familiar Face Recognition condition) and (3) verifying that a face belongs to a target person (Individual Face Recognition condition, Fig. 1A). Familiar Face Recognition and Individual Face Recognition conditions are commonly referred to with the same name, i.e. "face recognition task", and one further goal of this study was to assess whether they were alike or whether they differentiated. Because the speed of processing Human Face Categorization (minRT: ~260 ms) and Familiar Face Recognition (minRT: ~360 ms) are largely documented, our main variable of interest was related to the Individual Face Recognition speed of processing and how it would compare to either Human Face Categorization or Familiar Face Recognition (Fig. 1B). Results revealed that Individual Face Recognition is much faster than Familiar Face Recognition, but, albeit longer than Human Face Categorization, still strikingly rapid: reliable responses can be given in a quarter of second only, strongly constraining models of Individual Face Recognition processing.

4.1. Differences between Individual Face Recognition and other face processing levels

Individual Face Recognition took ~20–30 ms longer than Human Face Categorization (across-participants mean minRTs: 302 ms vs. 273 ms; across-trials minRTs: 260 ms vs. 240 ms). Holding since the first response (66 or 50 ms difference depending on the analysis), this short difference is unlikely to be related to learning or repetition of similar stimuli. Importantly, Individual Face Recognition and Human Face Categorization appeared strongly similar, as evidenced by similar high accuracies, similar conservative bias, and similar RT distributions across trials (Fig. 3A). In contrast, Individual Face Recognition and Familiar Face Recognition appeared very different. Individual Face Recognition was ~120–140 ms faster than Familiar Face Recognition, with much higher accuracy and liberal vs conservative biases, suggesting that participants used different strategies. This difference in delays, as the difference in accuracy, held since the first response (Fig. 4) and was observed even considering comparably well-detected targets (Fig. 5). Hence, Individual Face Recognition appears highly similar to Human Face Categorization, widely regarded as a "fast" categorization task (Fabre-Thorpe, 2011), but sharply different from Familiar Face Recognition.

Since Familiar Face Recognition was tested under conditions that enforced reliance on familiarity rather than on identification (for discussion see Besson et al., 2012 and Barragan-Jason et al., 2013), it appears unlikely in Individual Face Recognition that a person identity-level (*amodal* and semantic level of representation) is reached in order to trigger such fast responses. In contrast, it is more plausible that Individual Face Recognition is of the same nature than Human Face Categorization, albeit delayed. Indeed, Individual Face Recognition may preactivate a diagnostic *visual* representation of the target face, as Human Face Categorization may preactivate a diagnostic *visual* representation of human faceness, that needs to be verified when the input stimulus is processed. Human Face Categorization is defined as a category-verification task. Likewise, Individual Face Recognition could be best described as a category-verification task at a subordinate-level of face processing (individual level). Such a description of Individual Face Recognition is not new (e.g. Tanaka, 2001; see also Mack & Palmeri, 2011; Palmeri & Gauthier, 2004) but not unanimous (e.g. Anaki & Bentin, 2009; Delorme & Thorpe, 2001; Reddy et al., 2006). We claim that the present findings, obtained using an assessment of minimal RTs, argue strongly in favor of such a description. Interestingly, evidence show that tasks at the same level than the Human Face Categorization or Individual Face Recognition are achievable in the near-absence of attention (Reddy et al., 2006; VanRullen, Reddy, & Koch, 2004), which argues again for a similar mechanisms behind both these levels.

4.2. Effects of face inversion

Different face inversion effects were observed on Individual Face Recognition and Human Face Categorization, as the effect of inversion was clearly stronger in Individual Face Recognition than in Human Face Categorization, both on accuracy (accuracy dropped by 44.5% for Individual Face Recognition vs. 8.1% for Human Face Categorization) and minRTs (Fig. 2). Thus face inversion partly disrupted Individual Face Recognition (while still allowing a fair level of performance). It also affected Human Face Categorization, but barely, consistently with a previous study that reported no inversion effect on d' or minRTs in a Human Face Categorization task (Rousselet et al., 2003; of note, inverted stimuli were intermixed with upright stimuli in this study). In contrast, face inversion completely impaired Familiar Face Recognition performance (accuracy dropped by 88.1%). Inversion is known to disrupt face recognition, disproportionally compared to non-face objects (Brown, Huey, & Findlay, 1997; Valentine, 1988; Valentine & Bruce, 1988; Yin, 1969). This face inversion effect – a marker of the holistic processing of faces (e.g. Farah et al., 1998; Maurer et al., 2002; Rossion, 2008) – is one of the critical characteristics of the face processing system. Importantly, these inversion effects appear highly consistent with the observed minRTs since Human Face Categorization appears to require minimal or no holistic processing and is the fastest, Individual Face Recognition appears to require partial holistic processing and takes slightly longer, while Familiar Face Recognition requires complete holistic processing and takes much longer (however other processes may also be involved in Familiar Face Recognition, e.g. bottom-up processing of the stimulus as a whole, etc.).

4.3. A hierarchy of face processing

Our results overall lend strong support in favor of the superordinate advantage hypothesis, which holds that the superordinate level is processed first (Human Face Categorization) before any other subordinate level (Individual Face Recognition or Familiar Face Recognition) (Macé et al., 2009). Even if Individual Face Recognition is fast and appears similar to Human Face Categorization in comparison to Familiar Face Recognition, it has special characteristics such as a sensitivity to face inversion that makes it slower. In this study, the hierarchy revealed between Human Face Categorization, Individual Face Recognition and Familiar Face Recognition regarding the minimal processing time and the face inversion effect may therefore reflect the different extent to which face-specific processes are engaged. More precisely, detecting human-faceness in Human Face Categorization may barely require any face specific processing; Individual Face Recognition may partly rely on some (relatively low-level) aspects of face configuration (for example on first-order relation, Maurer et al., 2002); Familiar Face Recognition would require the highest level of face configuration (for example holistic processing, Maurer et al., 2002; Rossion, 2008). Of note, this hierarchy may only apply to stimuli easily recognizable. In more ambiguous or noisy situations (e.g. cluttered or mooney faces), face categorization may not completely rely on the detection of diagnostic low-level features anymore (Crouzet et al., 2010; Rossion & Caharel, 2011; Rossion & Jacques, 2011), and may require more face-specific processes (e.g. holistic processing; e.g. Mack, Gauthier, Sadr, & Palmeri, 2008). Interestingly though, the face inversion effect we found in the Individual Face Recognition condition suggests that the face diagnostic visual representation preactivated by top-down preparation is not simply related to the preactivation of low-level visual features.

Expanding previous behavioral studies on animal categorization to face categorization, this result is consistent with the idea that a finer face representation is needed in order to categorize a face at the individual level than as "human". This appears in line with a coarse-to-fine access to face representations as has been posited (Large et al., 2004; Löw et al., 2003; Martinovic et al., 2008; Sugase et al., 1999; see also Fabre-Thorpe, 2011; Hochstein & Ahissar, 2002). Interestingly, more additional time was necessary from a superordinate to a basic level on animal categorization (e.g. Macé et al., 2009), than here on face categorization (respectively 40–65 ms vs. 20–30 ms), perhaps due to the expertise of humans for human faces.

Such a result is at odds with studies run without speed constraints (Anaki & Bentin, 2009; Tanaka, 2001). A plausible interpretation is that in studies with unconstrained time, processing may *spontaneously* proceed until the a priori most relevant or most natural entry-level, which in the case of faces is the identity level (Bruce & Young, 1986; Valentine, 2001). Along the way, coarser levels and categorization may be processed, however implicitly. This pattern suggests that once this spontaneous entry-level is reached, categorizing 'back' to a coarser level, involves further processing. Hence, in studies with unconstrained time, RTs may be as long – or even longer – at the superordinate level than at the basic or subordinate level (Anaki & Bentin, 2009; Tanaka, 2001). The inverse is observed in studies using time constraints as in the present study since participants are this time constrained to shift their natural entry-level to a more specific one. Our study show that participants can actually do it well, quickly and in a way that respects the visual hierarchy. This also suggests that experiments aiming at assessing the hierarchy of these levels should take care of the tendency of participants to spontaneously reach the natural entry-level.

4.4. The speed of Individual Face Recognition: implications

Assessing minimal processing time exerts strong constraints on the models of underlying neural mechanisms. Making a decision and a motor response would take ~110 ms (Kalaska & Crammond, 1992; VanRullen & Thorpe, 2001). Hence, brain signals triggering Human Face Categorization, Individual Face Recognition and Familiar Face Recognition responses could arise at post-stimulus onset latencies as short as ~130 ms ,~150 ms, and ~270 ms respectively (i.e. ~110 ms before the minimal time needed to perform the tasks, as reflected by across trials minRTs). Actually, the onset of Human Face Categorization brain signals (~130 ms) appears very similar with the ~130-ms latency at which EEG first changes following a (perceived) shift of faces (Jacques & Rossion, 2006) or with the ~125-ms latency at which EEG during a similar Human Face Categorization task started to correlate with RTs (based on a Multi-Variate Pattern Analysis; Cauchoix, Barragan-Jason, Serre, & Barbeau, 2014). Given how close Individual Face Recognition is to Human Face Categorization, it thus appears likely that brain signals triggering Individual Face Recognition should be seen around 150 ms or even a bit earlier. This would correspond to the onset of the N170, a face-sensitive component observed in evoked-related potentials, starting at ~130 ms and peaking around ~160–170 ms. The N170 is thought to index access to face representation and to reflect the engagement of a face-specific processing system independently of task demand (Rossion & Jacques, 2011). This seems all the more plausible since the Individual Face Recognition shows an inversion effect, to which the N170 is highly sensitive. Of note, the ~20–30 ms difference in speed between Human Face Categorization and Individual Face Recognition does not necessarily imply a serial stage from Human Face Categorization to Individual Face Recognition. Both Human Face Categorization and Individual Face Recognition may share similar processes, for example an obligatory face detection stage gating any face processing (e.g. Tsao & Livingstone, 2008), but since both may rely on the preactivation of a diagnostic visual representation through top-down mechanisms, processing at this level of representation of the input stimulus may be optimized differentially. Hence, it is possible that specific Individual Face Recognition processes start even before ~130 ms.

Thus, the prediction can be made that Individual Face Recognition relies on specific neural activity developing as early as 150 ms, or possibly earlier and consequently that the brain regions involved in this activity are those involved in early face processing, i.e. posterior areas of the visual ventral stream. Top-down factors, such as selective attention to diagnostic information (e.g. Palmeri & Gauthier, 2004) can influence how perceptual representations are instantiated (e.g. in IT, Folstein, Gauthier, & Palmeri, 2010). Numerous neuroimaging studies have shown that preparation to a particular target modulates activity in cortical regions selective to this target before perception (e.g. Esterman & Yantis, 2010; Gazzaley, Cooney, McEvoy, Knight, & D'esposito, 2005; Righart, Andersson, Schwartz, Mayer, & Vuilleumier, 2009), but also during its presentation (Esterman & Yantis, 2010; Harel, Kravitz, & Baker, 2014; Kok, Jehee, & de Lange, 2012). Thus, the activity of these posterior brain areas could be optimized to process target faces.

The large face inversion effect on Familiar Face Recognition suggests that, even more than Individual Face Recognition, Familiar Face Recognition needs face-specific processing. A possible explanation of such a difference is that detecting that a face is familiar is not possible using individual features only (e.g. an isolated nose is usually not sufficient to recognize someone as familiar), but requires an individual-level face representation. Familiar Face Recognition might therefore rely on longer face-specific processes in order to extract the full percept of an individual face (e.g. Rossion, 2008; Schiltz & Rossion, 2006).

Familiar Face Recognition and Individual Face Recognition also rely on very different expectations (i.e. a large number of possible targets on the one hand, one target on the other hand), which may affect decisional level of processing. Simultaneously, the level of familiarity may have been different in the two conditions (well-known targets in the Individual Face Recognition condition, targets with variable levels of familiarity, which were not controlled in this study, in the Familiar Face Recognition condition). Reducing the variability of the number of targets or increasing the level of familiarity could increase the signal-to-noise ratio during Familiar Face Recognition responses and thus increase the speed of RTs. For example, Ramon, Caharel, and Rossion (2011) used a go/no-go task with familiar faces that were all the classmates of the participants (this task may therefore be lying somewhere between our Familiar Face Recognition and Individual Face Recognition tasks), who consequently reached high accuracy. However, participants in our Familiar Face Recognition condition still responded largely faster (453 ± 32 ms) than in Ramon et al.'s study (578 ± 18 ms), probably because a response deadline was used. This emphasizes that a procedure such as the SAB can be helpful when assessing the face hierarchy. It would be interesting to run a task similar to the Ramon's et al.' study using the SAB.

Overall, the nature of these two conditions appears largely different regarding the preparation of the visual system, the level of face processing, familiarity and consequently the decisional level of processing. This may explain the large difference of RTs observed between them.

4.5. Limits of the study

The distinctiveness between targets and distractors was different between the Human Face Categorization, Individual Face Recognition and Familiar Face Recognition and may have impacted reaction times, despite controlling for low-level visual features (contrast and luminance, pictures cropped and centered around faces, distractors paired one-by-one with targets for the Individual Face Recognition conditions). These differences between conditions are inherent to the Human Face Categorization, Individual Face Recognition and Familiar Face Recognition conditions and hardly reducible. Nonetheless, different results suggest that our findings are unlikely to be contaminated by a simple effect of our stimuli. First, RTs across conditions were sensibly different even for targets with comparable level of detection (Fig. 4). In the same vein, no correlation of median RTs and accuracy was observed across targets in the Familiar Face Recognition, which would have been the case if RTs were directly related to stimulus difficulty. Second, and crucially, the fact that our findings hold since the first target presentation, appears to rule out a possible effect of the construction of the set. It also rules out a possible effect of learning (repetition of targets and/or a differential effect of adaptation to different tasks, Fig. 5).

Last, the use of a go/no-go paradigm with a response deadline prevents to determine whether no-go responses are voluntary or missed go-responses. This could have been captured using an old/new paradigm. However, this would have been irrelevant to our central aim, which was to assess minimal RT.

4.6. Conclusion

Face recognition corresponding to finding a specific person in a crowd appears achievable in only a quarter second. Despite this speed, a hierarchy from Human Face Categorization to Individual Face Recognition and to Familiar Face Recognition was evidenced, in favor of the superordinate level, or coarse to fine, hypotheses. This study emphasizes that Individual Face Recognition and Familiar Face Recognition are very distinct face recognition tasks and opens promising directions towards the investigation of how the visual system is recruited in each case.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2016.10.004.

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