Normative data for accuracy and response times at the computerized Benton Facial Recognition Test (BFRT-c)

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RUNNING HEAD: Computerized Benton Facial Recognition Test

Abstract

We report normative data from a large (N=307) sample of young adult participants tested with a computerized version of the long form of the classical Benton Facial Recognition Test (BFRT; Benton & Van Allen, 1968). The BFRT-*c* requires to match a target face photograph to one or three of 6 face photographs simultaneously presented. Percent accuracy at the BFRT-*c* (81%-83%) is below ceiling yet well above chance level, with little interindividual variance in this typical population sample, as expected from a sensitive clinical test. While split-half reliability on accuracy rates is relatively low due to the large variability in difficulty across items, correct response times (RTs) measured in this version – completed in 3 minutes on average - provide a reliable and critical complementary measure of performance at individual unfamiliar face matching. In line with previous observations from other measures, females outperform male participants at the BFRT-*c*, especially for female faces. In general, performance is also lower following lighting changes than head rotations, in line with previous studies emphasizing limited ability at matching pictures of unfamiliar faces with important variations in lighting direction. Overall, this normative data set supports the validity of the BFRT-*c* as a key component of a battery of tests identifying clinical impairments at individual face recognition such as observed in acquired prosopagnosia. However, beyond global indexes of performance based on accuracy rates only, this analysis strongly recommends full consideration of the time taken to match individual faces as well as the variability in performance across items.

KEY WORDS: face matching, Benton test, response times, lighting direction, unfamiliar faces

The Benton Facial Recognition Test (BFRT, first described and used by Benton & Van Allen, 1968; see Benton, Sivan, Hamsher, Varney, & Spreen, 1983 for the official reference of the test) is one of the oldest tests measuring human face processing ability, probably still the most widely used in clinical neuropsychological evaluations. This behavioral test was developed by the late Arthur Benton in the context of clinical and experimental studies of acquired prosopagnosia, i.e. individual face recognition impairment following brain damage (Bodamer, 1947; Quaglino & Borelli, 1867; see Busigny & Rossion, 2013 for a review), and of impairments at unfamiliar face matching in groups of patients with posterior brain damage (Benton & Van Allen, 1968; 1972; De Renzi, Faglioni & Spinnler, 1968; Tzavaras, Le Bras & Hecaen, 1970; see also Milner, 1968). The BFRT consists in the matching of grayscale photographs of individual (Caucasian) faces, first with one target face appearing on a top panel to be found among six faces presented simultaneously on a bottom panel (6 items), and then with one target face to be found three times among six faces (16 items) (Figure 1), for a total score out of 54 (i.e., $(6 \times 1) + (16 \times 3)$). The two pictures to match are virtually identical in the first six items, which are relatively easy and can almost serve as practice trials. However, the remaining 16 items require matching across changes of either head orientation (8 items) or lighting conditions (8 items), and are much more difficult. Overall, the BFRT is a difficult test to perform, with no ceiling effect (e.g., Benton & Van Allen, 1972). The stimuli used are also well controlled since they do not have external features such as hair or obvious cues (facial hair, glasses, etc.) and yet the overall shape of the faces, which plays a key role in our expertise in unfamiliar face perception (Retter & Rossion, 2015) is well preserved.

A score above 40 out of 54 (76%) is considered as evidence for normal individual face matching ability, 39-40 as a borderline score, 37-38 as reflecting a moderate impairment, and a clear impairment is considered for people scoring below 37 out of 54 (i.e., below 68.5%) (Benton et al., 1983).

Figure 1. Examples of items used in the BFRT-c. In all items, a target face (unfamiliar face, frontal view) presented on the top of the screen has to be found, as accurately and as fast as possible, among six face photographs presented simultaneously on the bottom of the screen. In the first part of the test (A; 6 items), only one face photograph has to be selected, virtually identical (i.e., small change of size and contrast) to the target face photograph. In the second part of the test (16 items), the target face has to be found three times among the six face photographs, which vary either in terms of head orientation (B; 8 items) or in terms of lighting conditions (C; 8 items).

Despite the wide usage of the test, to our knowledge, normative data of the BFRT have not been updated since the original publication of the test, and the available normative data only concern accuracy rates. Here we provide original normative data at a computerized version of this test from a wide sample – about three hundreds - of young Caucasian participants, for both accuracy rates and response times. We believe that reporting such data is important for at least three reasons.

A first reason is to provide information about humans' behavioral ability to match pictures of unfamiliar faces, which is the main type of stimulus used in the field of face processing. While most experimental studies report high performance levels at simultaneous matching pictures of unfamiliar faces (e.g., Busigny & Rossion, 2010; Estudillo & Bindemann, 2014; Herzmann, Danthiir, Schacht, Sommer, & Wilhelm, 2008; Sergent, 1984), some studies have reported significantly lower performance (i.e., below 80%, Bruce, Henderson, Greenwood, Hancock, Burton, & Miller, 1999; Bruce, Henderson, Newman, & Burton, 2001; Megreya & Burton, 2006; 2008), claiming that *people are "poor" or "highly inaccurate" at matching images of unfamiliar faces*". To be fair, this claim of "poor performance" is based on a comparison with the ceiling performance obtained in the same tasks for highly familiar (i.e., famous) faces (e.g., Bruce et al., 2001). Moreover, these latter studies have used difficult tasks in which the number of targets to find in a large array of faces is undetermined and/or unknown by the participant, or same/different tasks, increasing the contribution of decisional responses biases to performance. Moreover, distractor faces are selected to be highly similar perceptually to target faces in all these studies (from Bruce et al., 1999). Finally, these studies have generally used pictures of individual faces varying greatly in lighting conditions – often taken with different cameras. In this context, it seems important to provide updated normative data at a difficult and widely used face matching test such as the BFRT which,

having been developed in a clinical context, uses a forced-choice procedure with the number of target faces being constant and known by the participant (i.e., avoiding decisional response biases), and where only a subset of items which can be analyzed separately also require to match faces across lighting variations.

Second, there is a relatively recent and growing interest in interindividual variability of face processing abilities, which is generally claimed to be much wider than initially thought (e.g., Bowles, McKone, Dawel, Duchaine, Palermo, Schmalzl, Rivolta, Wilson, & Yovel, 2009; Herzmann et al., 2008; Megreya & Burton, 2006; Palermo, Rossion, Rhodes et al., 2017; Wilmer, Germine, Chabris, Chatterjee, Williams, Loken, Nakayama, & Duchaine, 2010; Wilmer, Germine, Chabris, Chatterjee, Gerbasi, & Nakayama, 2012). Estimates of this (high) variability has been mainly based so far on explicit memory encoding of unfamiliar faces, followed by delayed recognition (e.g., Woodhead & Baddeley, 1981), such as in the widely used Cambridge Face Memory Test (CFMT, Duchaine & Nakayama, 2006). A “perceptual” version of this test, the Cambridge Face Perception Test (CFPT, Duchaine, Germine & Nakayama, 2007), much less widely used, is also associated with a large interindividual variability in performance (Bowles et al., 2009; Duchaine et al., 2007; Garrido, Duchaine, & Nakayama, 2008). However, the CFPT is not based on matching of different individual faces, but rather involves *similarity judgments* on morphed faces (see also Logan, Wilkinson, Wilson, Gordon, & Loffler, 2016), i.e. a task which is also likely to be highly influenced by higher-level cognitive processes. Other tests associated with high interindividual variability in unfamiliar face matching performance rely again on ambiguous tasks in which the number of targets to find in a large array of faces is unknown by the participant (Bruce et al., 1999; Jenkins, White, Van Montfort, & Burton, 2011; Megreya & Burton, 2006) or same/different tasks that are particularly prone to decisional biases (e.g., The Glasgow Face Matching Test, Burton,

White, & McNeill, 2010). In comparison to these tasks, the BFRT, developed in a clinical context and validated by the testing of various neurological populations (Benton & Van Allen, 1968, 1972), is much simpler in its instructions, with the number of target faces fixed and known by the participant. As for the face stimuli, they are not known for being selected based on perceptual similarity criteria. Hence, there are reasons to believe that interindividual variability at unfamiliar face matching – a critical component of the ability to recognize individual faces - may be more accurately estimated from the BFRT than other tests used in laboratory settings.

Third, and importantly, there are currently no normative data for the *time* taken to perform the BFRT, which is generally administered as a paper-and-pencil test. The lack of response times (RTs) data is a critical issue: without time-constraints, a simultaneous face matching task, even across changes of views and lighting, can probably always be performed at a high level of accuracy (see Özbek & Bindemann, 2011). This issue was noted early on by Benton himself, who mentioned that some patients with prosopagnosia could reach normal performance at his test (Benton, 1980, 1990; Benton & Van Allen, 1972; see e.g., Delvenne, Seron, Coyette, & Rossion, 2004; De Renzi, Faglioni, Grossi, & Nichelli, 1991; McNeil & Warrington, 1991; and the review of Gainotti, 2013). For this reason, Benton always stated that low performance at the BFRT was not diagnostic of (acquired) prosopagnosia (Benton, 1980). Duchaine and Nakayama (2004; 2006b) reached the same conclusion for people diagnosed with a long-life impairment in individual face recognition, i.e. developmental prosopagnosia, showing that 73% of their group of participants could perform at normal accuracy levels at the BFRT. However, it has long been noticed that RTs of patients with acquired prosopagnosia are unusually prolonged at the BFRT or other face matching tasks, and thus that an analysis of RTs clearly reveal their disorder at individual face recognition (e.g., Bukach, Bub, Gauthier, &

Tarr, 2006; Busigny & Rossion, 2010; Davidoff & Landis, 1990; Delvenne et al., 2004; Farah, 1990). For instance, the patient PS, a case of severe prosopagnosia following brain damage whose case has been documented in many studies (e.g., Caldara, Schyns, Mayer, Smith, Gosselin, & Rossion, 2005; Rossion, Caldara, Seghier, Schuller, Lazeyras, & Mayer, 2003), achieved a score of 39/54 (72.2%, “borderline score”) at the BFRT as tested in 2006 (reported by Busigny & Rossion, 2010). However, PS took more than 30 minutes to perform the test, while age-matched participants in that study performed the test with an average accuracy rate of 84.7%, in 6–8 minutes. Another case of acquired prosopagnosia, NS, also had a borderline score (40/54) at the BFRT, but took about 20 minutes to perform the test (Delvenne et al., 2004; see also Bukach et al., 2006 for another case; and Young, Newcombe, de Haan, Small, & Hay, 1993 for slow RTs at the BFRT in right posterior brain damaged patients). In the same vein, Duchaine and Weidenfeld (2003) found that normal participants could achieve reasonably high scores at the BFRT even when a large portion of the face was masked, leaving only the eyebrows and hairlines as matching cues. However, even though these authors did not provide RTs in their study, they acknowledged that participants provided with the eyebrows and hairline only were particularly slow at performing the test. More generally, it is becoming increasingly clear that speed of processing is critical in evaluating individual face recognition: faces are thought to be individually recognized or discriminated within one or two gaze fixations (Hsiao & Cottrell, 2008; Prieto, Van Belle, Liu, Norcia, & Rossion, 2013), successful behavioural matching of faces is typically performed in a few hundreds of milliseconds from stimulus onset to motor response (e.g., Jacques, d’Arripe, & Rossion, 2007; Sergent, 1984;), and electrophysiological studies indicate that the repetition of the same face picture is detected below 200 ms following stimulus onset, even across size and viewpoint changes (i.e., reduction of the N170 face-sensitive component; e.g.,

Caharel, d'Arripe, Ramon, Jacques, & Rossion, 2009; Jacques et al., 2007; see Rossion & Jacques, 2011 for review). Hence, it is important to provide updated norms of performance at the BFRT that include the time taken to perform this unfamiliar face matching test.

For all these reasons, we report here the detailed results of a large sample of participants (307;105 males) tested with a new electronic version of this test, the BFRT-*c*.

METHODS

Participants

307 Caucasian participants (mean age: 22.62 years, range 18.25 – 39.75 years), with 202 females (mean age: 22.66 years, range 18.25 – 39.75 years) and 105 males (mean age: 22.53 years, range 18.75 – 30.75 years) were tested on a computerized version of the BFRT between March 2013 and April 2016. They were tested before a longer unrelated experiment recording their electroencephalogram (EEG). They were part of a larger sample of participants, from which we excluded non-Caucasian participants, or participants older than the mean age + 3SD. All of them reported normal or corrected-to-normal vision and did not report difficulties at face identity recognition, as requested for the selection of the participants in the experiment. Participation was voluntary. Signed informed consent was given and monetary compensation was provided for the whole experimentation the participants took part in, including the BFRT.

BFRT, computerized version

In the computerized version of the BFRT, the 22 items (6 + 16) of the original BFRT (long form) are presented on a computer screen in the original fixed order, using Matlab

7.8.0 (R2009a). In each item, an unfamiliar target face (full-front view) has to be found among six probe faces presented simultaneously below it. All photographs are grayscale and depict (Caucasian) faces only, with the overall shape preserved but without the hair and without any clothing or other obvious cues (e.g., earring, moustache, beard, make up). All have a neutral expression. Unlike the original version of the test, the target and the six probe faces, which have been extracted from a scanned version of the original panels using Adobe Photoshop 7.0, are presented onto a single dark gray background panel (two different panels for target and probe faces in the original version of the test), subtending approximately $26.5^\circ \times 20^\circ$ of visual angle when viewed from 60 cm. As another difference with the original test, the target faces are displayed at a slightly larger size (133×200 pixels; $3.53^\circ \times 5.25^\circ$ of visual angle) than the probe faces (129×150 pixels; $3.34^\circ \times 4^\circ$ of visual angle) in order to further avoid the matching based on low-level, image-based visual cues. Finally, in the computerized version of the BFRT, instructions require to select the probe face(s) as accurately *and* as fast as possible.

In the first part of the test (6 items, half males), the target face has to be found only once among the six probe faces which are all full-front views. The face photograph to be selected is virtually identical to the target face photograph (see Figure 1A). In the second part of the test (16 items, half males), the target face has to be found 3 times (i.e., 3 different exemplars of the same identity) among the 6 probe faces, which vary either in terms of head orientation (8 items, half with female faces; see Figure 1B), or in terms of lighting conditions (8 items, half with female faces; see Figure 1C).

Face photographs have to be selected with the computer mouse, without any constraints regarding the order of selection for the items requiring 3 choices, and without any chance of correcting one's responses. The 6 face photographs remain on the computer screen until the participant's (completed) response (3 choices), or for a

maximum of 30 seconds. After each item, a black screen is presented until the participant presses a key to continue. As in the original BFRT, the first 6 items are scored 1 or 0 and the remaining 16 items are scored 3, 2, 1 or 0, depending on the number of faces correctly selected.

Procedure

Participants were tested individually at a distance of approximately 60 cm from the computer screen. After having completed an electronic demographic questionnaire, they were presented with the BFRT-computerized version (BFRT-c).

RESULTS

Global performance

Accuracy (total score max 54)

The average score at the BFRT-c was 44.81/54 ($\approx 83\%$), with a standard deviation of 3.44. Scores ranged from 35/54 to 52/54 with none of the participants performing at ceiling, and all participants scoring well above chance level (i.e., $>25/54$). The frequency distribution of total scores (Figure 2A) deviates from normality (Kolmogorov-Smirnov = 0.106, $df = 307$, $p < .001$; Shapiro-Wilk = 0.975, $df = 307$, $p < .001$). Based on this, we calculated the 5th percentile which falls between 40/54 and 39/54. Note that only 12 participants ($\approx 4\%$) present with a score equal to or below 2 SD of the mean (37.93 $\approx$ 38/54, or 70.2%), and none of the participants present with a score below 3SD (34.49/54, or 63.9%). Note also that the relatively poor performance in terms of accuracy rates of the 12 participants could not be attributed to generally poor cognitive abilities since

these participants all get at least their school leaving certificate and most of them already get a certificate for higher education.

Response times

Since the 6 first items of the test require only one response (i.e., one face photograph to select), and viewing conditions between the target face and the response face remain the same, RTs for these items are obviously shorter (about 3 sec. on average, see below) than for the remaining 16 items requiring three responses (i.e., three face photographs to select) and with a change of viewing conditions (head orientation or lighting) between the target face and the response faces (about 10 sec. on average, see below). Hence, we did not consider mean RT / item for the whole test but rather considered the *total time* needed by participants to complete the test. Across individuals, this measure ranges between 1.42 minutes (85.09 sec.) and 6.54 minutes (392.22 sec.), with an average of 3.01 minutes (180.85 sec.; SD: 59.87 sec. or 0.99 min). As shown in Figure 2B, the total time to perform the test is not normally distributed (Kolmogorov-Smirnov = 0.092, $df = 307$, $p < .001$; Shapiro-Wilk = 0.941, $df = 307$, $p < .001$). The 95th percentile is 300.57 sec.

The total time to complete the test did not correlate with accuracy rates ($r = -0.086$, $p = .067$). In fact, among the 15 participants who needed more than 300.57 sec. (95th percentile) to complete the test, only two scored below normal range ($\leq 38/54$). Yet, participants who were slower than the 95th percentile (300.57 sec.) at the test, were generally *abnormally* slow, i.e., up to 392 seconds when considering all participants falling in the extreme 5% for response time (and up to 374 seconds when removing the two participants who scored below the 5th percentile).

A **B**

Figure 2. Frequency distribution of BFRT-c Total scores (A) and total time to complete the test (B).

Performance on the first part of the test (6 first items)

Accuracy (score max 6)

The overwhelming majority of participants (274 out of 307, 89.25%) performed at ceiling (i.e., scored 6/6) in the first part of the BFRT-*c* (i.e., 6 first items). Only three participants scored 4/6, the lowest score. The mean score is thus as high as 5.88/6 (98%), with a small standard deviation (0.35). Interestingly, all three participants who missed two items on the first part (4/6) scored below normal range in total (35/54 - 37/54), suggesting that failure on the first 6 items ($\leq 4/6$) of the BFRT-*c* already reveals difficulties at individual face matching. However, good performance at these items (which only require to match virtually identical face photographs) does not guarantee good performance at the remaining part of the test.

Response times

The mean response time for an item of the first part of the test (irrespective of accuracy) was 2.99 sec. on average, with a standard deviation of 1.54 seconds (range: 1.32 sec. – 17.40 sec.; distribution non normal in shape: Kolmogorov-Smirnov = 0.188, $df = 307$, $p < .001$; Shapiro-Wilk = 0.656, $df = 307$, $p < .001$; percentile 95 = 5.43 sec.). As for accuracy, normal performance in the first part of the BFRT-*c* does not necessarily predict normal performance on the whole test (and thus preserved individual face matching abilities). Indeed, among the 15 participants who were abnormally slow to complete the test (> 300.57 sec.), only eight were already abnormally slow on the first part of the test (> 5.43 sec.). Moreover, among the 15 participants who took more time than average to perform the 6 first items, only 8 were also too slow to complete the test (> 300.57 sec.).

Performance on the second part of the test (16 remaining items)

Accuracy (score max 48)

On the second part of the -BFRT-c, scores ranged from 30/48 to 46/48, with a mean of 38.92/48 ($\approx 81\%$) and a standard deviation of 3.34. The frequency distribution of scores significantly deviates from normality (Kolmogorov-Smirnov = 0.101, $df = 307$, $p < .001$; Shapiro-Wilk = 0.975, $df = 307$, $p < .001$; see Figure. 3A). The 5th percentile for this second part of the test fell between 33 and 34/48 (8 out of 307 or 2.6 % of participants scoring < 33 ; 23 out of 307 or 7.5% scoring < 34). Note that all the participants scoring below 33/48 still performed well above chance level.

Response times

The mean response time for an item of the second part of the test (irrespective of accuracy) was 10.17 sec. on average, with a standard deviation of 3.44 sec. (range: 4.55 – 20.35 sec.). Frequency distribution of mean response times also deviates from normality (Figure 3B; Kolmogorov-Smirnov = 0.096, $df = 307$, $p < .001$; Shapiro-Wilk = 0.952, $df = 307$, $p < .001$). The 95th percentile was 16.90 sec. Mean response time did not correlate with accuracy ($r = -0.056$, ns), and among the 15 participants who had a mean response time > 16.90 sec. (cut-off), only one also presented a score below normal range ($< 33/48$) on this part of the test. Again, participants who were slower than the 95th percentile (16.90 sec.), were generally *abnormally* slow, i.e., up to 20.35 seconds .

A **B**

Figure 3. Frequency distribution of scores (A) and average response time (B) at the second part of the BFRT-c.

Internal reliability

In order to evaluate the BFRT-*c*'s internal reliability, we measured how participants' performance on even items correlated with performance on odd items, considering only the second (i.e., the main) part of the test. Importantly, there are as many trials involving head rotation changes than changes in lighting direction (see below) in the odd and even samples of trials. Although the inter-item correlation was significant for accuracy rates (mean score even items = 19.66/24, SD = 1.73; mean score odd items = 19.27/24, SD = 2.19), it was not very high ($r = .435, p < .001$). Inter-item correlations were much higher for RTs (mean RT for the eight even items = 9.69 sec., SD = 3.29 sec.; mean RT for the eight odd items = 10.67 sec., SD = 3.78 sec; $r = .883, p < .001$).

Sex differences in performance

We collected data on the –BFRT-*c* in 307 participants, with about two-thirds of females (202 females and 105 males, no age difference ($t(305) = 0.404, p > .5$). There was no main effect of participant's sex on accuracy rates ($F(1,305) = 2.74 < p > .05$) but a significant interaction with face's sex was observed ($F(1,305) = 8.95, p < .01$): as shown on Figure 4A, female faces were better recognized by female participants (mean = 22.63/27, S.D. = 2.14) than by male participants (mean = 21.89/27; S.D.= 2.37; $t(305) = 2.79, p < .01$), whereas male faces were recognized equally well by females (mean = 22.41/27, S.D. = 1.84) and males (mean = 22.48/27, S.D. = 1.92; $t(305) = .29, ns$). The same pattern of results was observed when the scores on the second part of the test only were considered (no significant main effect of participant's sex: $F(1,305) = 2.59, ns$; no significant main effect of face's sex: $F(1,305) = 2.65, ns$; significant interaction between the two factors: $F(1,305) = 10.50, p < .01$). In terms of RTs, female participants outperformed male participants irrespective of the sex of the face. This is true if we

consider the total time to respond to female items ($N=3+8=11$) *versus* male items ($N=3+8=11$), as revealed by a significant main effect of participant's sex ($F(1, 305) = 14.97, p < .001$) which did not interact with face's sex ($F(1,305) = .49, ns$; see Figure 4 B). This is also valid if we consider the mean response time for female items ($N = 8$) *versus* male items ($N=8$) in the second part of the test (main effect of participant's sex: $F(1,305) = 15.16, p < .001$; interaction with face's sex ($F(1,305) = .67, ns$). Note that the ANOVAs conducted on RTs also showed a main effect of face's sex, with male faces being responded faster than female faces, both in male participants (total time: 95.71 sec (33.19) vs 103.11 sec (36.38), $t(104) = 4.695 (p < .001)$; mean time second part: 10.84 sec (3.69) vs 11.59 sec. (4.05), $t(104) = 4.00, p < .001$) and in female participants (total time: 82.72 sec (26.08) vs 88.80 sec (29.35), $t(201) = 5.58, p < .001$; mean time second part: 9.36 sec (3.08) vs 9.93 sec (3.42), $t(201) = 4.47, p < .001$).

As shown in Table 1, the very same pattern of results (with a female advantage restricted to female faces in terms of accuracy and observed for both male and female faces in terms of RTs) was observed when the samples were equal in number (105 males compared to 105 females). Here, contrary to the norms collected on the CFMT (Bowles et al., 2009; Duchaine & Nakayama, 2006a), the advantage in time-related performance was not associated with a larger standard deviation for female participants. In fact, standard deviation was smaller for females than males, even for equal sample sizes, with the difference reaching or approaching significance for most measures (Total time female faces: significant difference in one out of the two comparisons¹ [Levene's test: $F = 7.74, p < .01$ and $F = 2.16, ns$, respectively]; Total time male faces: significant difference in one out of the two comparisons with the difference approaching significance in the other one

¹ 105 males vs 105 females sample 1; 105 males vs. 105 females sample 2.

[Levene's test: $F = 9.81, p < .01$ and $F = 2.97, p = .09$, respectively]; Mean response time second part female faces : significant difference in one out of the two comparisons [Levene's test: $F = 5.17, p < .05$ and $F = 1.88, ns$, respectively]; Mean response time second part male faces: significant difference in one out of the two comparisons with the difference approaching significance in the other one [Levene's test: $F = 8.39, p < .01$ and $F = 2.75, p = .09$, respectively]). Hence, regarding time-related measures, cut-off scores (P95) to be used at the $-BFRT-c$ in a diagnostic approach should ideally be determined separately for males and females. The cut-off scores determined for each sex are presented in Table 2.

Figure 4. Sex differences in performance at the BFRT-c. In terms of accuracy (A), females outperformed males for female faces only. In terms of RTs (B), females outperformed males for both female and male faces.

		Females Sample 1 (FS1) (N=105)	Females Sample 2 (FS2) (N=105)	Males (M) (N=105)	Tests' results	
					FS1 vs M	FS2 vs M
Score /27	Female faces	22.59 (2.01)	22.72 (2.26)	21.88 (2.37)	Sex subj.: <i>ns</i> Sex face: <i>ns</i>	Sex subj.: <i>ns</i> Sex face: <i>ns</i>
	Male faces	22.38 (1.82)	22.47 (1.85)	22.48 (1.92)	Interaction: $p < .01$	Interaction: $p < .01$
Score /24	Female faces	19.65 (1.93)	19.77 (2.25)	18.92 (2.32)	Sex subj.: <i>ns</i> Sex face: <i>ns</i>	Sex subj.: <i>ns</i> Sex face: <i>ns</i>
	Male faces	19.44 (1.80)	19.51 (1.82)	19.58 (1.83)	Interaction: $p < .01$	Interaction: $p < .01$
Total RT ¹	Female faces	88.63 sec. (27.19)	87.72 sec. (31.15)	103.11 sec. (36.38)	Sex subj.: $p < .001$ Sex face: $p < .001$	Sex subj.: $p < .01$ Sex face: $p < .001$
	Male faces	81.06 sec. (23.86)	83.32 sec. (27.97)	95.71 sec. (33.19)	Interaction: <i>ns</i>	Interaction: <i>ns</i>
Mean RT Second part ²	Female faces	9.91 sec. (3.25)	9.81 sec. (3.56)	11.59 sec. (4.05)	Sex subj.: $p < .001$ Sex face: $p < .001$	Sex subj.: $p < .01$ Sex face: $p < .001$
	Male faces	9.19 sec. (2.84)	9.41 sec. (3.28)	10.84 sec. (3.69)	Interaction: <i>ns</i>	Interaction: <i>ns</i>

Table 1. The female advantage, restricted to female faces in accuracy but observed for both female and male faces in RTs, was observed when the 105 males were compared to an equal number of females selected with an alphabetic criterion (either the 105 first females of the alphabetic list of female participants [Females Sample 1] or the 105 last females of the alphabetic list [Females Sample 2], in each case matched in age (both $p > .4$)).

¹ Calculated on 11 items (3 +8) for each sex of faces

² Calculated on 8 items for each sex of faces

		MALE AND FEMALE SUBJECTS			
Global perf. (/54)	Cut-off (P5)	39-40			
	% in our sample	< 39		< 40	
		≈ 4 % (12/307)		≈ 8 % (25/307)	
Perf. second part (/48)	Cut-off (P5)	33-34			
	% in our sample	< 33		< 34	
		≈ 2,5 % (8/307)		≈ 7,5 % (23/307)	
		MALE SUBJECTS		FEMALE SUBJECTS	
Total time (sec.)	Cut-off (P95)	342.04		265.90	
	% in our sample	> 342.04	> 265.90	> 342.04	> 265.90
		≈ 5 % (5/105)	≈ 16 % (17/105)	≈ 1 % (2/202)	≈ 5 % (10/202)
Mean time second part (sec.)	Cut-off (P95)	18.38		15.55	
	% in our sample	> 18.38	> 15.55	> 18.38	> 15.55
		≈ 5 % (5/105)	≈ 15 % (16/105)	≈ 1.5 % (3/202)	≈ 5 % (10/202)

Table 2. Cut-off values for male and female subjects on the main measures of the BFRT-*c*, as determined by performance of participants in our sample (307: 105 males, 202 females). For accuracy-measures, the percentage of participants in our sample performing below the cut-off score is indicated. For time-related measures, the percentage of participants in our sample performing above the cut-off and above the cut-off determined for the other group is indicated.

Performance on “lighting direction” versus “head rotation” items

We also compared participants' performance on items requiring to match a target face with three face photographs taken from different angles (“head rotation” (HR) items, $N = 8$) versus on items requiring to match a target face with three face photographs taken under different lighting conditions (“lighting direction” (LD), $N = 8$; see examples in Figure 1). The results revealed a substantial advantage for HR items, both in terms of accuracy (HR items: mean = 21.34/24, S.D. = 1.84; LD items: mean = 17.59/24, S.D. = 2.088; $t(306) = 31.395$, $p < .001$) and mean RTs (HR items: mean = 8.57 sec., S.D. = 3.01 sec.; LD items: mean = 11.80 sec., S.D. = 4.21 sec. ; $t(306) = 22.178$, $p < .001$). In fact, the overwhelming majority of participants had a higher score (285 out of 307 participants; see Figure 5A) and a faster mean RT (288 out of 307; see Figure 5B) when having to match faces across head rotation than across lighting direction differences. Only a tiny fraction of participants showed a slight advantage for matching faces across lighting direction changes, in accuracy ($N=5$), or in RTs ($N=17$, with 14 showing a RT advantage for LD items smaller than one second).

A **B**

Figure 5. "HR" items of the BFRT-c are better performed than "LD" items both in terms of accuracy (A) and mean RT (B).

Item analyses

Finally, we performed an item analysis across participants. The first six items of the BFRT-*c* were all succeeded by most of participants, with a mean score ranging between 0.96/1 (item 6: 296 participants out of 307 scoring 1/1) and 0.99/1 (item 4: 305 participants scoring 1/1) but there were striking differences among the sixteen items of the second part of the test (see Figure 6A), with a mean score ranging from 1.83/3 or 61% (item 13: 561 good responses out of 921 (307 participants * 3 choices) --- a value still above chance level --- to 2.91/3 or 97% (item 17: 895 good responses out of 921). The distribution of participants scoring 3/3, 2/3, 1/3 or 0/3 correct on each item (see Figure. 7A) also suggests that some items are more difficult than others in this second part of the test. Indeed, whereas some items were almost always perfectly succeeded (i.e., 3 out of 3 correct responses), other items were rarely perfectly succeeded by the participants. Note that, except for item 13 (a LD item) where a small proportion of participants (10 out of 307) scored 0/3, a null score on a second part item was extremely rare. Unsurprisingly, the most difficult items were mostly LD items, although there were exceptions.

In terms of mean response time, the six first items ranged between 2.27 seconds (item 4) and 3.68 seconds (item 2). For the sixteen items of the second part of the test, the range was wide (see Figure 6B), from 6.12 seconds (item 17 again) to 14.66 seconds (item 13 again), with a consistency observed with accuracy: the items which were responded faster were also the ones which were better succeeded in terms of accuracy (see Figures 6-7).

A **B**

Figure 6. Mean score (A, max score = 3) and mean response time (B) for each item of the second part of the BFRT-c (average of 307 participants). Items are ordered from the lowest mean score (item 13: 1.83/3) to the highest mean score (item 17: 2.91) and from the largest mean RT (item 13: 14.66 sec.) to the shortest mean RT (item 17: 6.12 sec.). LD items are represented in light grey and HR items are represented in dark grey.

A **B**

Figure 7. A: number of individuals scoring 3/3, 2/3, 1/3 and 0/3 on each item of the second part of the BFRT-c. B: number of individuals responding within 5, 10, 15, 20, 25 and 30 seconds on each item. (HR)= 'Head rotation' item, (LD) = 'lighting direction' item.

DISCUSSION

Performance and variability: the BFRT-c as a sensitive clinical test

We report an average performance at the computerized version of the BFRT of 44.81 out of 54 (83%), a score which is remarkably close to that of the control subjects in the original study reporting the test (45.3 or 83.9%; Benton & Van Allen, 1968). Standard deviation (3.44, or 6.37%) is smaller in our sample than reported originally (4.5, or 8.33%) but this could easily be accounted for by the homogenous population tested here compared to the wide age range covered in that original study (16-65 years of age, see Benton & Van Allen, 1968).

An obvious aspect of our observations on the BFRT-c is that the first 6 items, requiring finding only one face target among 6 faces, without any change of viewpoint or lighting (i.e., virtually identical images) should be used only as practice trials: the overwhelming majority of participants perform at ceiling and very rapidly on these items. As a matter of fact, the prosopagnosic patient PS (Rossion et al., 2003) tested recently (2015) with this version of the BFRT-c obtained a score of 5/6 on these items, for a score of 35/54 in total (Liu-Shuang et al., 2016). Even when removing these trials, performance in our sample of subjects remains relatively high (38.92/48, i.e. 81%), with a low standard deviation (3.34, i.e. 7%). We recommend using the second part of the test only to evaluate one's abilities at individual face matching with the BFRT-c in future studies.

Considering accuracy rates only, these observations do not support the view that typical human adults – here recruited simply on the basis of their self-reported absence of face identity recognition difficulties - vary substantially in their ability to individualize faces. In general, this claim is generally based on accuracy rates at tests involving recognition memory for previously unfamiliar face such as the CFMT (e.g., Duchaine &

Nakayama, 2006a; see also Woodhead & Baddeley, 1981). However, several studies have also reported relatively large individual differences on unfamiliar face matching (Bruce et al., 1999; Bruce et al., 2001; Burton et al., 2010; Duchaine et al., 2007; Megreya & Burton, 2006).

As mentioned in the introduction, these studies relied on more complex and sometimes ambiguous tasks, involving substantial additional cognitive factors and strategies than in an individual face matching test with simultaneous picture presentation such as the BFRT-*c*, where the limited number of faces to match is constant and known by the participant. For instance, Duchaine et al. (2007) measured performance at a task requiring to order morphed face series for similarity (CFPT), Burton et al. (2010) at a response bias-prone same/different task with very different pictures of identical faces, and other studies required finding a target face in (target-present and target-absent) arrays of 10 similarly looking faces (Bruce et al., 1999; Megreya & Burton, 2006; see also Bruce et al., 2001). As a matter of fact, response times are usually not reported in these face matching tasks, and are probably extremely prolonged and highly variable across participants (e.g., Özbek & Bindemann, 2014; see below). Note that we do not claim here that these tasks are less appropriate than the BFRT-*c* to evaluate people's ability to match unfamiliar faces. However, we believe that interindividual variability in individual face matching as measured with behavioral tasks may be largely overestimated, due to the variability in terms of general cognitive processes involved in the tasks used in many tests. Moreover, in a clinical context, an unfamiliar face matching test should not involve too many cognitive processes, which may be differentially affected in a patient population, and should be relatively fast to administer. Overall, performance in terms of percent accuracy for the BFRT-*c* is far from

ceiling, yet is well above chance level, with very little variance, all these features making it a good diagnostic clinical test.

The importance of RT measures

It has sometimes been claimed that the traditional neuropsychological BFRT would be invalid because of a lack of sensitivity to individual face processing difficulties: individuals presenting (developmental) prosopagnosia would be frequently falsely diagnosed as normal (Bowles et al., 2009; Duchaine & Nakayama, 2004, 2006a) and typical participants could achieve reasonable scores even when most of the internal part of the face is masked, preventing normal processing of the face stimuli (Duchaine & Weidenfeld, 2003). In fact, as mentioned in the introduction, Benton himself noted that some patients with acquired prosopagnosia could achieve relatively normal or borderline accuracy scores at this test (Benton, 1980; 1990; Benton & Van Allen, 1972; see e.g., Busigny & Rossion, 2010; Delvenne et al., 2004; De Renzi et al., 1991; Gainotti, 2013; McNeil & Warrington, 1991). However, these observations do not invalidate the BFRT, which is still failed by the wide majority of patients with acquired prosopagnosia, and has been useful in strengthening the dominant role of the right hemisphere in individual face recognition by evaluating cohorts of patients (Benton & Van Allen, 1968; 1972; Trahan, 1997; Young et al., 1993; Tranel, Vianna, Manzel, Damasio, & Grabowski, 2009). Moreover, the BFRT is associated with a large face inversion effect in the normal population (i.e., about 20%) but a lack of inversion effect in acquired prosopagnosia (Busigny & Rossion, 2010; McNeil & Warrington, 1991), indicating that performance at this test is not merely based on simple image matching but truly captures human expertise at individualizing faces.

Most importantly, criticisms of the BFRT essentially reflect the need to go beyond the mere accuracy score, i.e. adding RT measures, as in the present validation of the computerized version of the test. Here we found that participants took about 10 seconds by item on average for the second part of the test, which is less than 3 minutes for 16 items with 3 faces to match by item. Critically, variability in RTs (i.e., SD of 33.8% of the mean) was much higher than for percent accuracy rates, with some of the participants being particularly slow, which suggests that a fair proportion of individuals can indeed achieve a normal score at the BFRT(-c) at the expense of abnormally prolonged response times, probably revealing difficulties in individual face matching. Moreover, the prosopagnosic patient PS, who scored 30/48 in the BFRT-c, the lowest performance of all the sample of participants of the present study but one, was also extremely slow, taking 46.55 seconds on average to perform that second part of the BFRT-c. This 4.5-fold times increase relative to control participants cannot simply be accounted for by the age difference between PS and the participants of the present study (see Liu-Shuang et al., 2016, Table 1) or by a general slowing down at perceptual matching tasks for this patient (see e.g., Busigny et al., 2010) and thus undoubtedly reveals her prosopagnosic impairment.

In summary, reporting RTs at the BFRT-c appears critical to evaluate performance. Two caveats should be mentioned however. First, the nature of the task makes it virtually impossible to report RTs for correct trials only, since the participant has to find three targets for each item (unless RTs would be normalized in some way for the number of items correctly recognized at each panel). Second, since the test is not performed under strict time constraints, one can never exclude that prolonged RTs are due to excessive care and control rather than a genuine impairment at individual face matching. In this context, the two variables, percent accuracy and RTs, should always be taken into account

for a full evaluation. As a matter of fact, patients with prosopagnosia with extremely prolonged response times at the classical BFRT do not appear to take much advantage of this prolonged inspection to achieve very high scores: if they are not impaired in terms of accuracy rates, they nevertheless also generally perform in the lower range. This issue is particularly well illustrated in a study that Young et al. (1993) conducted on patients with posterior brain damage. Their two patients with right posterior brain lesions had borderline scores at the BFRT (40 and 38/54) but at the expense of extremely prolonged RTs (65.3 s and 50.4 s/item, respectively; for 23.4 s/item in their control group). Only one patient (out of 5) with left posterior brain damage was also significantly slowed down at the BFRT (40 s/item). However, this patient's accuracy was very high (48/54), in fact significantly above the control mean, prompting the authors to suggest that his increased time was due to his taking extra care with this task, rather than impaired performance *per se*. Hence, consideration of both accuracy rates and RTs is always appear necessary to evaluate performance at this test.

In general terms, this latter example serves as a useful reminder that a RT measure at this test, or any face matching test, does not reflect the speed at which individual faces are *perceptually matched*, but the speed at which a cascade of perceptual, decisional and motor processes are accomplished. Purer measure of the speed of individual face *perception* in neuropsychology will require the development of alternative tests measuring this process under time constraints and without explicit behavioral responses, such as for instance with fast periodic visual stimulation in electroencephalography (see Liu-Shuang et al., 2016).

Sex differences

We found that females outperformed males at the BFRT-c, a finding which is generally in agreement with the literature. Some studies showed that females perform better than males at face processing tasks (e.g., Bowles et al., 2009; Heisz, Pottruff, & Shore, 2013; McBain, Norton, & Chen, 2009; Megreya, Bindemann, & Havard, 2011; Rehnman & Herlitz 2007; Sommer, Hildebrandt, Kunina-Habenicht, Schacht, & Wilhelm, 2013), although this female advantage was not found in all studies, in particular in the original report of the BFRT (Benton & Van Allen, 1968). This advantage is also observed sometimes only in specific conditions (see Weirich, Hoffmann, Meißner, Heinz, & Bengner, 2011), could be specific for female faces (the so-called “female own-sex bias”; see e.g., Lewin & Herlitz, 2002; Lovén, Herlitz, & Rehnman, 2011; McKelvie, Standing, St Jean, & Law, 1993; Megreya et al., 2011) with a reversed effect occasionally reported for male faces (male observers better than female observers; see e.g., McKelvie et al., 1993). Whether this higher performance, both in terms of accuracy rates and correct RTs, reflects a higher level of expertise specifically at individual face matching or at recognizing different types of materials (not only faces) in episodic memory (see e.g., Herlitz, Nilsson, & Bäckman, 1997; Herlitz & Rehnman, 2008; Lewin, Wolgers, & Herlitz, 2001), or yet at other factors involved in this explicit face matching task (i.e., attention, decision making, association of the faces with semantic information, etc.) remains unknown and should be clarified with implicit measures. In any case, our data suggest that regarding time-related measures, cut-off scores (P95) to use at the BFRT-c in a diagnostic approach should be determined separately for males and females.

Reliability and items variability

In our study, split-half reliability of the BFRT-*c* in accuracy rates was relatively low, but we believe that this is merely due to the small number of items (8 in each subpart of the test, for 3 responses in each item, and to the high variance in difficulty of the different items of the test (see Figure 6). Thus, it seems that the reliability of the BFRT-*c* would be better estimated by a measure of test-retest variability of accuracy rates and RTs on the exact same items, for instance at several weeks or months interval. Another factor that may come into play is that, contrary to other tests such as the CFMT or the CFPT (see Bowles et al., 2009), variance at the BFRT-*c* is low in the normal population, so that reliability based on interparticipants variability may be lower than for other tests. What is important to keep in mind here is that the reliability of a face processing test is determined by many factors that are more or less stable, and not necessarily the process of interest. For example, if performance at a given test depends heavily on generic memory or decision making processes, the test might be highly reliable for reasons that have nothing to do with how faces are perceived specifically. In this context, the high split-half reliability value observed for RTs at the BFRT-*c* is interesting, but should also be taken with caution: it may be also partly due to general factors such as simple processing speed (Schretlen, Pearlson, Anthony, & Yates, 2001).

The difficulty of unfamiliar face matching across variable lighting conditions

In the present study, we also found that matching faces across lighting changes was far more difficult than across head orientation changes. This new observation on the BFRT-*c* is in line with previous studies that have reported difficulties at unfamiliar face matching tasks with pictures under the same head orientation but with substantial lighting changes (Bruce et al., 1999; 2001; Jenkins et al., 2011; Megreya & Burton, 2006;

2008; Menon, White, & Kemp, 2015). Indeed, illumination parameters can change the overall magnitude of light intensity reflected back from an object, as well as the pattern of shading and shadows visible in an image (Tarr & Bulthoff, 1998). Both shading and shadows provide important cues about the three-dimensional shape of a face, and varying the direction of illumination can thus result in larger image differences than varying the head orientation of a face (O'Toole, Jiang, Roark, & Abdi, 2006; Tarr & Bulthoff, 1998). In fact, differences in lighting direction result in larger image differences than varying the identity (Adini, Moses, & Ullman, 1995). Hence, the faces of two different people shown under the same conditions of light and view look more similar in many ways—the same features are visible and receive direct illumination— and are more similar according to objective measures (Adini et al., 1995) than two pictures of a single person taken under different conditions (Hill & Bruce, 1996). Thus, this difference in lighting direction makes the images of the same face particularly difficult to match, but also prevent discriminating similar distractors, because differences on the same idiosyncratic features cannot be compared across changes of lighting direction.

An important and unresolved issue is whether these changes of lighting are particularly elevated in the BFRT(-c), in which pictures often miss important features, for instance of half of the face, or reflect the range of variations encountered in real life and that our visual system has to cope with. In any case, we are not aware of another test that has these two kinds of manipulations separated (see Figure 1). Our data strongly suggest to also report separate scores at the BFRT-c for the two types of trials. Interestingly, the prosopagnosic patient PS also showed an advantage for HR items like normal participants, but this advantage was quite small compared to the advantage observed in healthy subjects (HR items score: 16/24, mean RT: 45.7 sec.; LD items score: 14/24, mean

RT: 47.4 sec.; Liu-Shuang et al., 2016). Hence, her impairment was relatively more marked for HR than LD trials overall.

CONCLUSIONS

In conclusion, our normative dataset on a computerized version of the BFRT, the BFRT-*c*, refute the view that the BFRT would not be a valid test of individualization of faces, as long as the time taken to match individual faces is considered. The BFRT is not associated with a large variability across individuals and yet performance is well above chance and below ceiling, making it a very good clinical test to use in complement with other measures of individual face recognition. Our normative dataset also supports other findings that females outperform male participants at face matching tasks, and that performance is much more affected by lighting changes than head rotations. Overall, this normative dataset supports the validity of the BFRT-*c* as a key component of a battery of tests identifying clinical impairments at individual face recognition such as observed in prosopagnosia following brain damage.

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