Normative data for two tests of face matching under ecological conditions

Lisa Stacchi, Eva Huguenin-Elie, Roberto Caldara & Meike Ramon

Department of Psychology, University of Fribourg, Fribourg, Switzerland

Corresponding author:

Meike Ramon

University of Fribourg

Department of Psychology

Faucigny 2

1700 Fribourg

Switzerland

meike.ramon@gmail.com

SIGNIFICANCE STATEMENT

How do humans process unfamiliar faces, and how can we reliably identify individuals that are most proficient at it? Motivated by its relevance in applied contexts, much empirical work has sought to answer these questions. Controlled laboratory tests have been developed to understand the contribution of different variables and inter-individual differences. However, such face processing tests involving stimuli derived from ideal conditions, or manipulations and tasks that are not representative of real life, may lack ecological validity. This crucial consideration is often overlooked when laboratory tests are used to predict real-life proficiency. The present study followed the rationale that traditionally used controlled tests should be paired with more realistic, and ecologically meaningful ones – in terms of the stimuli and tasks performed. Testing large and heterogenous samples, we standardized two underused tests of facial identity matching: the Yearbook Test (YBT) and the Face Identity Card Sorting Test (FICST). These procedurally simple tests mimic real-life challenges in face perception, as they assess unfamiliar facial identity matching across superficial image changes, or substantial age-related change in appearance. Beyond providing normative data, we describe how performance measured by these tests relates to that observed on more commonly used tests of face recognition (CFMT+) and perception (EFCT; PICT). Our findings suggest that (i) the YBT and FICST are easy-to-use, preferable alternatives to pairwise face matching tasks, which are prone to speed-accuracy trade-offs; (ii) challenging and ecologically valid tests should complement highly controlled measures when aiming to identify individuals with superior face processing abilities for real-life purposes.

1 **ABSTRACT**

2 **Background:** Unfamiliar face processing is an ability that varies considerably across
3 individuals. Numerous studies have aimed to identify underlying determinants using controlled
4 experimental procedures. While such tests can isolate variables that influence face
5 processing, they usually involve somewhat unrealistic situations and stimuli. As a
6 consequence, the extent to which performance observed in laboratory settings is informative
7 for predicting real-life proficiency remains unclarified.

8 **Results:** We present normative data for two ecologically valid, but underused tests of face
9 matching: the Yearbook Test (YBT; Bruck et al., 1991) and the Facial Identity Card Sorting
10 Test (FICST; Jenkins et al., 2011). The YBT (n=252) measures identity matching across
11 substantial age-related changes in facial appearance, while the FICST (n=218) assesses the
12 ability to process unfamiliar facial identity despite superficial image variations. To determine
13 both tests' predictive value, a subsample (n=181) also completed a commonly used test of
14 face recognition (Cambridge Face Memory Test long form (CFMT+); Russell et al., 2009), and
15 two tests of face perception (Expertise in Facial Comparison Test (EFCT) and Person
16 Identification Challenge Test (PICT); White et al., 2015).

17 **Conclusions:** Focusing on the top performers identified independently per test, we made two
18 important observations: (1) YBT and FICST performance can predict CFMT+ scores and vice-
19 versa; (2) EFCT and PICT scores neither reliably predict superior performance in ecologically
20 meaningful and challenging tests of face matching, nor in the most commonly used test of
21 face recognition. These findings emphasize the necessity for using challenging and
22 ecologically relevant, and thus highly sensitive tasks of unfamiliar face processing to identify
23 high performing individuals in the normal population.

24 **KEY WORDS**

25 Superior face processing ability; Face perception; Face matching; Face discrimination; Face
26 recognition; Natural image variations

BACKGROUND

In our everyday lives we efficiently process multiple sources of constantly changing facial information. This common notion, that human face processing is highly proficient, underlies a vast body of research, and for the most it coincides with our own personal experiences. However, an increasing number of studies challenges the idea that face processing is *generally* highly proficient. Extremely high levels of proficiency are observed for processing the facial identity of individuals encountered repeatedly in every-day life – those that are personally familiar to us (for a review see Ramon & Gobbini, 2018). For unfamiliar faces, on the other hand, our ability to process facial identity varies considerably across individuals (Bruce, Bindemann & Lander, 2018; Fysh, 2018), and is much more error-prone (e.g., Burton, Wilson, Cowan, & Bruce, 1999; Bruce, Henderson, Newman, & Burton, 2001; Hancock, Bruce, & Burton, 2000; Jenkins & Burton, 2011; Jenkins, White, Van Montfort, & Burton, 2011; Megreya & Burton, 2006; Ramon & Van Belle, 2016; Ramon & Gobbini, 2018).

Empirical studies of facial identity processing have aimed to isolate and characterize the impact of different controllable variables. Psychophysical studies have for instance determined the information that is diagnostic for identity matching (e.g., Pachai, Sekuler & Bennett, 2013; Pachai, Sekuler, Bennett, Schyns & Ramon, 2017; Watier & Collin, 2009; Papinutto, Lao, Ramon, Caldara & Miellet, 2017). Notwithstanding the informative value of evidence provided through these and other highly controlled experiments, the degree to which they reflect real-world proficiency in facial identity processing remains unknown (Ramon, Bobak & White, in press).

A growing body of literature is expressing the need for more ecological assessment of face processing abilities (Bate, Frowd, Bennetts, Hasshim, Murray et al., 2018; Lander, Bruce & Bindemann, 2018; Ramon et al., in press). With increasing interest in individuals with remarkable face processing abilities – so-called super-recognizers (SRs) – the demand for tests with applied value and real-life validity has become even more crucial (Ramon et al., in press). SRs aside, two aspects are problematic for our understanding of normal face processing proficiency. First, different lab-based experiments can show no to moderate correlations (e.g., Rezlescu, Susilo, Wilmer & Caramazza, 2017; Fysh, 2018). Moreover, the degree to which performance observed under highly controlled experimental conditions relates to real-world ability remains unknown (Ramon et al., in press).

We sought to address the void concerning ecologically meaningful assessment of facial identity processing. To this end, we tested a large group of individuals of all ages (N=252) with previously reported, but in our opinion underused tests of facial identity matching.

1 These tests tap into invariance of facial representations by measuring face matching ability
 2 across two ecologically relevant dimensions. The Yearbook Test (YBT; for examples see
 3 Figure 1) captures identity matching across significant age-dependent changes in facial
 4 appearance (i.e., 25 years; Bruck, Cavanaugh, & Ceci, 1991). The Face Identity Card Sorting
 5 Test (FICST; see Figure 1) probes the ability of telling together, and telling apart identities
 6 across superficial image variations (lighting, make-up, hair-style, etc.; Jenkins et al., 2011;
 7 Andrews, Jenkins, Cursiter, & Burton, 2015). As such, these two measures probe face
 8 processing skills that are critical for real-life processing of facial identity, e.g. encountering
 9 acquaintances after considerable time periods, or determining whether different images depict
 10 the same or different identities.

Face matching

A. Facial Image Card Sorting Test (FICST)

B. Yearbook Test (YBT)

Face discrimination

C. Expertise in Facial Comparison Test (EFCT)

Face recognition

D. Cambridge Face Recognition Test (CFMT+)

12 **Figure 1. Examples of stimulus material presented in the tests of face processing administered in this**
 13 **study.** Observers completed tests of face matching involving naturally occurring **a.** image-related variations
 14 (FICST; Jenkins et al., 2011), or **b.** ageing-related variations (Bruck et al., 1991). Additional measures included
 15 previously established tests of **c.** face discrimination (EFCT and PICT; White et al., 2015) and **d.** face recognition
 16 (CFMT+; Russell et al., 2009). Consent / rights for publication was obtained for individuals depicted.

17 Beyond providing normative data for these ecologically meaningful identity matching
 18 tests, we sought to determine the relationship between performance measures provided by
 19 the YBT and FICST, with those obtained through three previously employed tests of face
 20 matching and recognition. To this end a subsample of observers completed the long version

of the Cambridge Face Memory Test (long form; CFMT+; Russel, Duchaine, & Nakayama, 2009), as well as the Expertise in Facial Comparison Test (EFCT) and the Person Identification Challenge Test (PICT) (White, Phillips, Hahn, Hill & O'Toole, 2015). The CFMT+ represents the measure most commonly used to identity superior face processing skill (cf. Bobak, Pampoulov & Bate, 2016; Noyes, Phillips, & O'Toole, 2017; Ramon et al., in press). The EFCT and PICT have been reported to provide normally distributed performance accuracy scores and according to some are among the most commonly used tools to assess face processing ability, both in and outside laboratory settings (cf. Phillips, Yates, Beveridge & Givens, 2017).

To anticipate our findings, the results reveal that facial identity matching is considerably impacted by superficial image variations and age-related changes in appearance. Importantly, even though the YBT and FICST, as well as the EFCT and PICT rely on simultaneous matching of facial identity, performance on the latter tests appears to be unrelated to ecologically meaningful facial identity matching skill. These results emphasize the need to assess face processing abilities from various angles, and under consideration of test-specific procedural constraints, in order to obtain a more complete understanding of the variability observed across paradigms. Specifically, investigating abilities under both highly controlled, as well as more realistic conditions can provide a more comprehensive understanding of observers' abilities, and potentially higher predictive power for performance in applied settings. Based on our findings, we advocate for increased use of ecologically meaningful measures such as the YBT and FICST, at which observers are less likely to excel by using strategies that can go unnoticed when accuracy scores are considered in isolation (e.g., Noyes, Hill & O'Toole, 2018; Phillips, Yates, Hu, Hahn, Noyes, et al., 2018) and may only be uncovered when speed-accuracy trade-offs are accounted for (cf. Luce, 1986; Heitz, 2014).

RESULTS

Descriptive analyses

Normative data for the Yearbook Test (YBT). The normative data collected from 252 observers are reported in Table 1 and visualized in Figure 2A. On average, observers correctly matched 8.8 ± 4.0 (median: 8.0) of the 35 analyzable items (see Methods), with female observers correctly matching roughly two items more compared to male observers.

1 **Table 1. Normative data: number of correct identities matched achieved in the YBT.**

	Female participants (n=151)	Male participants (n=101)	All participants (N=252)
Mean (SD)	9.5(4.1)	7.7(3.6)	8.8(4.0)
Median	9	7	8

2 *Normative data for the Facial Identity Card Sorting Test (FICST).* The normative data
3 obtained from 218 participants are reported in Table 2 and visualized in Figure 2B. On
4 average, during Phase 1 observers perceived 7.6 ± 4.9 (median: 7) identities and made 2.4 ± 3.3
5 (median: 1) errors. In Phase 2, the average number of errors was 3.4 ± 4.4 (median: 2). Female
6 observers provided fewer piles than males and made somewhat fewer mistakes across both
7 phases.

8 **Table 2. Normative data: numbers of piles and errors expressed in the FICST.**

	Female participants (n=120)	Male participants (n=98)	All participants (N=218)
Phase 1			
Number of piles			
Mean (SD)	7(4.6)	8.3(5.1)	7.6(4.9)
Median	6	7	7
Total number of errors			
Mean (SD)	2.3(3.2)	2.6(3.4)	2.4(3.3)
Median	1	1	1
FICST score			
Mean (SD)	7.3 (5.1)	8.9 (5.4)	8.0 (5.3)
Median	6.0	8.5	8.0
Phase 2			
Total number of errors			
Mean (SD)	2.9(3.7)	4.1 (5.0)	3.4(4.4)
Median	2	2	2

Figure 2. Distribution of scores obtained for the YBT and FICST. Across both tasks, low and high scores are represented on the left and right, respectively.

Normative data for observers who participated in all five tests. Finally, Figure 3 and Table 3 summarize the normative data obtained for the subsample of 181 observers who participated in all tests (YBT, FICST, CFMT+, EFCT and PICT). Mirroring the observations made for the larger sample (see Table 1), in the YBT observers correctly matched 8.8 ± 3.9 (median: 8.0) of the 35 items, again with female observers correctly matching roughly two items more than males. For the FICST, as in the larger sample (see Table 2), in Phase 1 observers perceived on average 7.4 ± 4.6 (median: 7) identities and made 2.4 ± 3.3 (median: 1) errors; in Phase 2 they made on average 3.4 ± 4.4 (median: 2) errors. Female observers provided less piles than males and made less mistakes. For the CFMT+, observers achieved an average raw score of 66 (median: 65), with females performing better than male observers. The results for the EFCT and PICT (see Table 3) were similar, in that mean and average

accuracy scores did not differ as a function of gender, although female observers responded faster than males, leading to lower inverse efficiency (IE) scores for females compared to males. Additionally, accuracy scores were higher for the EFCT than the PICT, leading to comparatively higher IE scores (i.e., inferior performance) for the PICT, as compared to the EFCT.

Table 3. Normative data for participants who completed the YBT, FICST, CFMT+, EFCT and PICT.

	Female participants (n=103)	Male participants (n=78)	All participants (n=181)
YBT			
Mean (SD)	9.7(3.9)	7.6(3.6)	8.8 (3.9)
Median	9	7	8
FICST			
Phase 1			
Number of piles			
Mean (SD)	6.9(4.5)	8.1(4.7)	7.4(4.6)
Median	6	7	7
Total number of errors			
Mean (SD)	2.3(3.3)	2.8(3.7)	2.5(3.4)
Median	1	1	1
FICST score			
Mean (SD)	7.2(4.9)	9.0(5.2)	8.0(5.1)
Median	6	9	8
Phase 2			
Total number of errors			
Mean (SD)	2.7(3.5)	4.4(5.2)	3.4(4.4)
Median	2	2	2
CFMT+ raw score			
Mean (SD)	67.2(11.7)	64.2(12.0)	65.9(11.9)
Median	66	64	65
EFCT			
Mean accuracy in % (SD)	78.9(7.5)	76.5(8.8)	77.9(8.2)
Median accuracy	80.0	76.1	78.6
Mean RT in s (SD)	3.9(1.9)	5.6(3.3)	4.7(2.7)
Median RT in s	3.5	4.5	4.0
EFCT Inverse efficiency score			
Mean (SD)	5.0(2.4)	7.3(4.2)	6.0(3.5)
Median	4.8	6.1	5.1
PICT			
Mean accuracy in % (SD)	72.9(11.7)	72.7(10.1)	72.8(11.0)
Median accuracy	72.5	72.5	72.5
Mean RT in s (SD)	4.3(2.4)	5.7(3.4)	4.9(3)
Median RT in s	3.5	4.9s	4.1
PICT Inverse efficiency score			
Mean (SD)	6.2(5.3)	7.8(4.6)	6.9(5.1)
Median	5.4	6.5	5.8

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2
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4 **Figure 3. Distributions of scores obtained for observers who participated in the YBT, FICTS, CFMT+, EFCT, and PICT.** Note that low and high performance are represented on the left and right of the x-axes, respectively (i.e., high IE scores for the EFCT and PICT indicate low performance); for visualization purposes, one extreme value was removed for the CFMT+ and PICT, respectively.

1 Correlation analyses

2 Table 4 summarizes the results of Spearman correlations computed between the five tests,
 3 which are visualized in Figure 4. These analyses revealed the following significant (Bonferroni-
 4 corrected for multiple comparisons) relationships. First, we observed a significant positive
 5 relationship between the YBT and CFMT+ raw scores: greater numbers of correctly matched
 6 identities in the YBT were associated with more items recognized in the CFMT+. Second, a
 7 positive relationship also emerged between the IE scores obtained for EFCT and PICT; better
 8 EFCT performance (i.e., lower IE scores) was associated with better PICT performance. Third,
 9 we found a significant negative relationship between YBT and FICST scores, as well as
 10 between the YBT and PICT, and YBT and EFCT IE scores. These correlations indicate that
 11 greater numbers of correctly matched YBT items were associated with (a) less errors and piles
 12 in the FICST, and (b) and better performance for the PICT and EFCT. Finally, EFCT IE scores
 13 also correlated negatively with CFMT+ raw scores, indicating that higher CFMT+ performance
 14 was associated with more proficient EFCT performance. None of the remaining relationships
 15 reached significance.

Table 4. Correlation coefficients computed for the CFMT+, YBT, FICST, EFCT and PICT

	CFMT+ score	YBT score	FICST score	PICT IES	EFCT IES
CFMT+ score		.46*	-.19	-.10	-.24*
YBT score			-.37*	-.26*	-.24*
FICST score				.06	.12
PICT IES					.78*
EFCT IES					

Asterisks indicate significant correlations (Bonferroni-corrected; $p < .005$). Note that for the FICST, PICT, and EFCT, lower values indicate better performance (see Methods section). IES: inverse efficiency score.

1

2 **Figure 4. Significant correlations between measures.** Visualized here are the significant correlations (see Table 5), between the YBT and FICST, CFMT+, PICT and EFCT
3 (top row to bottom left), as well as EFCT and CFMT+ (bottom middle), and PICT (bottom right), respectively. Red lines indicate the median of each test.

1 Analyses of top performing individuals

2 Table 5 summarizes the following: (a) reference scores computed across individuals identified
 3 as the top 5% performing individuals independently per test (n=9); (b) their respective
 4 performance on the remaining tests; (c) the mean and standard deviation for each test based
 5 on the normative sample. For the YBT, high performing individuals identified via the CFMT+
 6 and FICST performed more similarly to the reference score, as compared to the top
 7 performers identified via the EFCT and PICT (Table 5, Figure 5A). Moreover, CFMT+ and
 8 FICST high performers obtained an average YBT score that was one standard deviation
 9 above the mean of the normative sample. Focusing on FICST performance patterns, CFMT+
 10 and YBT top performers' means were more similar to the FICST top performers' reference
 11 mean, compared to those of the EFCT and PICT high performers (Table 5, Figure 5B).
 12 Additionally, with respect to the FICST normative average, CFMT+, YBT and EFCT top
 13 performers scored better, but within one standard deviation of the mean. Focusing on the
 14 CFMT+, YBT's and FICST's high performers scored above the normative average and more
 15 similarly to the CFMT+ top performers' reference mean. This was contrasted by the PICT and
 16 EFCT top performers, who also exhibited average performance that was below the CFMT+
 17 normative average. Finally, top performers identified for the EFCT and PICT performed better
 18 on these tests than the normative sample and more similarly to the tests' top performers'
 19 reference mean, than high performing individuals identified via the CFMT+, YBT and FICST
 20 (Supplemental Figure S1).

Table 5. Top performers' mean performance for each of the five administered tests.

		CFMT+	YBT	FICST	EFCT	PICT
Top 5% performers for	CFMT+	88.9	13.9	4.4	4.9	5.9
	YBT	75.8	17.8	4.0	4.2	4.8
	FICST	75	13.3	0.0	5.2	6.3
	EFCT	64.1	9.0	6.3	1.9	2.4
	PICT	64.8	7.7	10.2	2.0	2.2
Mean of the normative data (n=181)		65.9±11.9	8.8±3.9	8.0±5.1	6.0±3.5	6.9±5.1

Reference mean scores computed for the top performers of a given test are bold-typed.

Figure 5. YBT and FICST scores of the top performers identified independently per test. Visualized here are performance levels of individuals identified as the top performers (colored symbols) for the YBT (red circles), FICST (blue crosses), CFMT+ (green squares), EFCT (purple triangles) and PICT (orange asterisks), and their relative location among observations made (grey dots) for the YBT (**A**) and FICST (**B**). High performers identified based on the CFMT+, YBT and FICST are more consistently located above the YBT and FICST median (black dashed horizontal line), thereby exhibiting better performance than individuals identified as top performers based on the EFCT and PICT.

DISCUSSION

Despite decades of research, human ability for processing facial identity continues to attract considerable attention. While previously, group studies have dominated the field, more recently an increasing interest in individual differences has emerged – both at the behavioral and neural level (cf. Bruce et al., 2018; Stacchi, Liu-Shuang, Ramon & Caldara, under revision). Here we aimed to advance our knowledge of individual differences in face processing by standardizing two procedurally simple, but highly challenging behavioral tests. Both involve two ecologically relevant aspects of face cognition by probing invariant face identity matching across commonly neglected naturally occurring conditions: ageing and superficial image variations. Therefore, we considered both tests as promising in terms of filling the current void regarding applied screening tests that are both highly reliable and sensitive for identification of superior face processing skill (see also Ramon et al., in press).

Assessment of face perception vs. recognition – procedural considerations

Processing of facial identity is commonly assessed with laboratory-based tests of face *perception* or *recognition*. These are separate processes that require careful terminological distinction (cf. Ramon & Gobbini, 2018; Ramon, 2018a; Ramon et al., in press), and should not be used interchangeably, or considered analogous to other processes (such as face *identification*, see e.g., Noyes et al., 2018; Phillips et al., 2018).

Tests of *face perception* can involve simultaneous matching (or discrimination) among image pairs (e.g., Ramon & Rossion, 2010; Fysh, 2018), triplets (e.g., Barton, Press, Keenan & O'Connor, 2002; Busigny, Joubert, Felician, Ceccaldi & Rossion, 2010), 1-to-n matching scenarios (e.g., Bruce et al., 1999; Rezlescu, Pitcher & Duchaine, 2012; Pachai et al., 2017), or can comprise delayed matching (e.g., Ramon & Van Belle, 2016; Ramon, Busigny & Rossion, 2010). In the context of such lab-based face perception tests, consideration of both accuracy and reaction times (RTs) is necessary in order to accurately characterize individual face processing abilities. This is especially important for tests that involve decisions for individual trials with long or unlimited duration, and/or are insufficiently calibrated to clear two standard deviations from the control mean (e.g., Glasgow Face Matching Test (GFMT); Burton, White, & McNeill, 2010; White et al., 2015; Fysh, 2018; Fysh & Bindemann, 2018; Bate et al., 2018). To illustrate, time-consuming piecemeal matching strategies may enable normal performance even in highly impaired clinical populations, such as prosopagnosia (cf. Marotta, McKeeff, & Behrmann, 2002).

1 Tests of *face recognition* involve intentional learning of previously unfamiliar identities,
2 which are later recognized as “old” among novel ones (e.g., Russel et al., 2009; Bate et al.,
3 2018; Bobak, Dowset, & Bate, 2016). In the context of such face recognition tests, where
4 encoding duration is classically predetermined, longer decision times cannot compensate for
5 an inefficiently encoded stimulus. Given the decreased likelihood of speed-accuracy trade-
6 offs in face recognition tests, RTs are oftentimes neglected (e.g., Blais, Jack, Scheepers,
7 Fiset, & Caldara, 2008).

8 ***The YBT and FICST as novel tests of superior face perception***

9 Arguably, one of the most commonly employed measures of face processing is the CFMT+
10 (Russell et al., 2009), which has been used to assess face *recognition*, while the CFPT
11 (Duchaine, Germine & Nakayama, 2007) was developed as a measure to assess face
12 *perception*. In terms of identifying individuals with *superior* skills, the CFMT+ has been
13 frequently deployed, while authors have advised against deploying the CFPT to this end (e.g.,
14 Bobak, Pampoulov, & Bate, 2016). This seems reasonable: high performance on a test of face
15 recognition could be indicative of superior face perception or memory. However, superior
16 scores on the CFPT, which involves similarity-based judgements, could be achieved through
17 non-face-specific strategies (e.g. focusing on image resolution). Face matching tests created
18 as alternative assessment tools for face perception (e.g., GFMT; Burton et al., 2010; White et
19 al., 2015) unfortunately often lack sensitivity (Fysh, 2018; Fysh & Bindemann, 2018; Bate et
20 al., 2018), or disregard potential speed-accuracy trade-offs, which are particularly relevant
21 given unlimited processing time and simple binary decisions. Thus, there is currently no
22 accepted “gold standard test” of face perception.

23 Here, we aimed to provide normative data for the YBT and FICST as two ecologically
24 meaningful and challenging tests of face perception where the aforementioned procedural
25 considerations can be neglected altogether. The YBT assesses unfamiliar face matching
26 across substantial age-related changes, while the FICST demonstrates the effect of superficial
27 or ambient image changes on perception of facial identity (see Figure 1). Both tests were
28 standardized on a large and heterogenous cohort, the data of which will be readily provided
29 upon request to promote their respective usage.

30 A comparable number of observers achieved perfect scores for the FICST and fell within
31 the 95th percentile for the YBT, respectively. However, for the YBT no observer achieved the
32 highest possible score of 35 correct identity matches. Thus, the ecologically relevant and
33 challenging face matching tests standardized here are characterized by higher task difficulty
34 than tests that have previously been employed as “standard screening” (Noyes et al., 2018)

tools, despite their aforementioned lack of sensitivity in both healthy observers, and individuals with developmental prosopagnosia (e.g., White et al., 2017). Conversely, floor effects, which are a common problem when aiming to calibrate challenging tasks suitable for identifying high performance (cf. Crowds matching test; Bate et al., 2018), were found for neither the YBT nor FICST. Thus, we believe that these tests provide much needed alternatives of unfamiliar face matching, that are easy-to-use in the context of identifying superior face perception skill.

Based on our observations, we suggest that the YBT and FICST applied in combination may serve as procedurally simple screening tests. Indications of potentially superior face processing skill provided through these measures ought to be verified through further computer-based testing under more controlled conditions. Considering the different sources of variation implemented across both tests, these tests may serve as powerful tools for screening of employees in applied professional settings, such as law enforcement (Ramon, 2018b; Ramon et al., in press).

Evaluation of the YBT and FICST as predictors of face processing skill – comparison with CFMT+, EFCT and PICT

To determine the relationship with previously deployed tests of face cognition, the YBT and FICST were complemented by the most commonly used measure of face recognition (CFMT+, Russell et al., 2009), and two frequently reported tests of face perception: the EFCT and PICT (White et al., 2015). As recently, here the EFCT and PICT were employed under unconstrained viewing conditions (Noyes et al., 2018; Phillips et al., 2018). The majority of studies involving these same/different face matching tests have focused exclusively on accuracy scores obtained in highly homogenous and/or small samples of young observers, but have neglected RTs (e.g., Noyes et al., 2018; Phillips et al., 2018). Contrariwise, here we considered *both* accuracy *and* RTs. Aiming to account for the “pedestrian notion” of speed-accuracy trade-offs (Heitz, 2014, p.1; see also Luce, 1986), which can be found in healthy as well abnormal populations (Marotta et al., 2002; Tarr, 2003; Behrmann, Avidan, Marotta, & Kimchi, 2005; Herzmann, Danthiir, Schacht, Sommer, & Wilhelm, 2008; Ramon & Rossion, 2010; Ramon et al., 2010; Biotti et al, 2017; White et al., 2017; Geskin & Behrmann, 2018) and may vary across age (Hildebrandt, Herzmann, Sommer & Wilhelm, 2010), analyses were performed on a composite scores encapsulating both measures. Thus, alongside providing normative data for the YBT and FICST, their respective value was assessed relative to tests that have been previously used as “standard screening” tests (Noyes et al., 2018; Bobak et al., 2016b) of individual face processing skill.

As noted, the distribution of data observed for the YBT and FICST demonstrate that they indeed provide challenging tools to assess unfamiliar facial identity matching. Interestingly, the highest correlation was found between the YBT and the procedurally distinct face recognition test (CFMT+, Russell et al., 2009), and the YBT and FICST. Weaker correlations emerged between the YBT and PICT, and YBT and EFCT, respectively. On the other hand, the FICST correlated with neither the EFCT, nor PICT, which – likely due to their procedural similarity – correlated highly with one another. The stronger relationship observed between YBT, FICST and CFMT+ is further supported by investigation of test scores of observers identified independently per test as top performers. High performing individuals identified via the YBT, FICST and CFMT+ scored more similarly to each other than individuals identified as top performers in the EFCT and PICT (Figure 5).

This suggests that in comparison to the YBT, the EFCT and PICT have comparatively limited value in terms of predicting individuals' face recognition ability, when speed-accuracy trade-offs are taken into account in large and heterogenous samples. Moreover, the EFCT and PICT cannot predict invariant perception of facial identity across highly varied photographs, which capture the changes occurring under natural viewing conditions and are also referred to as 'ambient images' (Jenkins et al., 2011; Sutherland et al., 2013).

We emphasize that, in order to screen for potentially superior face processing skills, ecologically meaningful and sufficiently sensitive tasks must be employed. High performance accuracy alone observed when same/different decisions are provided with virtually no time constraints – e.g. 30s here, or even three months in Phillips et al. (2018) – should not be considered a reliable basis to identify, or validate superior ability. To maximize test sensitivity, especially in the context of procedurally simple paired matching tasks under unconstrained viewing conditions, all relevant behavioral measures obtainable – i.e. accuracy *and* RTs - need to be considered.

Future directions and conclusions

Having provided normative data for two challenging and ecologically meaningful tests of facial identity matching, the question is: how should these measures be validated and further developed? The next steps will lie in establishing how previously reported, empirically and professionally identified SRs perform in the YBT and the FICST, and establishing how performance in the YBT and FICST relates to performance in real-life settings, such as law enforcement (Ramon, 2018b; Ramon et al., in press). Finally, additional improvements can be made regarding implementation of the YBT. On the one hand, a wisdom of crowds approach (cf. Phillips et al., 2018; Bardsley, Summersby, Kemp, & White, 2018) to determine the correct

1 responses for the currently missing five items for their subsequent inclusion will be beneficial
2 to increase the test's reliability. Finally, considering the demanding nature of this test,
3 development of a less time-consuming short version comprising items most likely correctly
4 matched by healthy observers may be a fruitful endeavor.

5 Our observations support the view that identification and validation of superior face
6 processing proficiency requires a battery of tests covering different aspects or levels of face
7 processing, that require careful conceptual distinction (Fysh, 2018; Bate et al., 2018; Ramon,
8 2018a), and "should be assessed with more than a single test" (Herzmann et al., 2008, p.842).
9 Moreover, the tests used to this aim need to be ecological meaningful and sufficiently
10 sensitive. To this end, accuracy scores recorded for face matching under "best-case
11 scenarios" (Fysh 2018) are insufficient – including e.g. moderate time periods between image
12 creation, or use of well lit, frontal faces as required for reliable computer-based identity
13 matching (Philipps et al., 2017; 2018). Considering the increasing demand for identification
14 and deployment of so-called Super-Recognizers in applied settings (Ramon et al., in press),
15 our findings emphasize the need for assessment of face cognition using real world conditions
16 that are challenging for humans, as opposed to algorithms (Phillips et al., 2018).

17 **METHODS**

18 *Participants*

19 A total of 252 observers (150 female; age range: 18-80 years) completed the
20 aforementioned YBT. Of this cohort, 218 additionally completed the FICST; in addition to the
21 YBT and FICST, 181 observers completed the CFMT+, EFCT, PICT, and CFPT. Detailed
22 demographic information for each sample is provided in Table 1. This entire cohort included
23 (under)graduate students from the University of Fribourg, who received course credit for
24 participation, as well as individuals from a wide range of professional fields and with varying
25 levels of educational (experimenters' family, friends, colleagues and acquaintances), who
26 participated voluntarily without compensation. All procedures were approved by the local
27 Ethical Committee and conducted following the tenets of the Declaration of Helsinki (Puri,
28 Suresh, Gogtay & Thatte, 2009); written informed consent was obtained from each participant.

Table 6. Demographic information for all samples reported.

	Female	Male	All
YBT			
Sample size	n=151	n=101	N=252
Handedness Right / Left / Ambidextrous	137 / 14 / 0	87 / 12 / 2	224 / 26 / 2
Mean age (SD)	25.8 (8.6) range:18-56	29.2 (12.9) range:18-62	29.0 (12.7) range:18-80
FICST			
Sample size	n=120	n=98	N=218
Handedness R / L / A	111 / 9 / 0	84 / 12 / 2	195 / 21 / 2
Mean age (SD)	28.2 (12.6) range:18-79	31.7 (13.6) range:18-80	29.8 (13.1) range:18-80
All tests			
Sample size	n=103	n=78	N=181
Handedness R / L / A	94 / 9 / 0	67 / 10 / 1	161 / 19 / 1
Mean age (SD)	27.6 (12.4) range:18-79	31.2 (13.8) range:18-80	29.2 (13.1) range:18-80

Materials and procedures

Each observer completed the paper-based YBT; if participation was not terminated, additional tests were administered. These included the paper-based FICST, as well as four computer-based tests (CFMT+; EFCT; PICT; CFPT), which were completed (in randomized order) using the standalone Java applications provided by the authors of the original studies. Performance measures were recorded in keeping with previously adopted procedures, or involved additional measures (e.g., RT registration) and are detailed below. Examples of stimulus material presented in each experiment is displayed in Figure 1. Note that due to the relatively infrequent usage of the YBT and FICST, we provide a list of aspects requiring careful consideration for appropriate application.

Tests of face perception standardized in this study

Yearbook Test (YBT). This test of *face perception* involves the original material reported in Bruck, Cavanagh and Ceci (1991). It was originally designed to test recognition and identification of personally familiar faces (classmates from high school) 25 years later at a high school reunion (Bruck et al., 1991). We used this test as a measure of simultaneous unfamiliar *face matching* across age-related changes in facial appearance. The material consists of eight pages portraying images of same-gendered individuals. On each page, five (younger) target identities are depicted on the left, along with 10 probe stimuli on the right (see Figure 1b). Probe stimuli comprised the five target and foil identities of the same age (i.e. 25 years older than target stimuli), respectively. Images (220 x 350mm) included variations in

viewpoint and depicted paraphernalia and external cues. Contrary to the original study (Bruck et al., 1991), none of the participants were familiar with any one of the depicted identities. Therefore, participants were instructed to neglect the middle columns designed for familiar face recognition and identification, and to simply indicate (by providing a number), which of the probe stimuli corresponded to a given target face. For each observer, we report the raw score of correctly matched identities. Note that only 35 items could be analyzed as the remaining five were not identifiable by the authors of the YBT (personal communication; Bruck & Cavanaugh, 2018).

Facial Identity Card Sorting Test (FICST). This *face perception* test involves a simultaneous card sorting procedure as reported by Jenkins, White, Van Montfort, and Burton (2011), and represents a measure of *face matching* across image-related variation in facial appearance. A selection of 40 images, half of which each depicted one of two Dutch celebrities (Chantel Janzen, Bridget Maasland), kindly provided by Jenkins and Burton (personal communication) were used as stimulus material (multiple sets of 40 laminated greyscale images sized 38x50mm). The twenty ‘ambient images’ (Jenkins et al., 2011; Sutherland et al., 2013) of each individual entailed natural face variability that occur in real life, as they were taken from publicly available photographs of each celebrity found on the internet. When instructed to group 40 such ambient images by the number of perceived identities, observers who are unfamiliar with the depicted identities report perceiving a median of 7.5 identities (mode 9; range 3–16; Jenkins et al., 2011; see also Andrews et al., 2015). Here, the 40 image cards were randomly positioned (in upright orientation) in front of observers, who had unlimited time to group them according to the subjectively and distinctly perceived identities, with each group of pictures is representing a single individual (for an example of similar image variations, see Figure 1a). The experiment ended if observers spontaneously and correctly grouped the images correctly into two categories. However, if observers formed a different number of groups, or formed two groups containing errors, they completed a second sorting phase. In Phase 2, the cards were again mixed and spread out randomly; however, observers were now instructed to separate the 40 images into two groups. Observers’ sorting responses were photographed; for each phase, the number of piles and total number of errors was registered (note that an identity match was considered erroneous if it did not correspond to a given group’s predominant identity). Analyses were performed on a composite score calculated based on both measures obtained during the first sorting phase (see below).

Optimal YBT and FICST application – methodological considerations

Based on our experience, we point out three aspects that require careful consideration to ensure most efficient and informative application of the YBT and FICST. The first pertains to the number of trials *contained* in the YBT, relative to the number of currently analyzable trials. As mentioned, the authors of this test were able to provide the correct responses for 35 of the total of 40 items. Currently, efforts are underway to determine the most probable correct responses for the missing items using a wisdom of crowd approach (cf. Phillips et al., 2018; Balsdon et al., 2018) by testing a large number of high performing individuals to ensure maximal validity of such data-driven estimates. Once generated, the normative data provided here can be re-evaluated to include responses for the currently not considered items, and the test could be employed in two versions.

The second consideration relates to application of the FICST. Naturally, it is imperative that observers have no prior information regarding the number of identities displayed, i.e. should not have participated in an experiment with a similar procedural setup. As evident from the data reported for Phase 2, observers are clearly more proficient when provided top-down information regarding the decisional space in which identity matches are to be provided (cf. Ramon, 2018a; Ramon, Sokhn, Lao & Caldara, 2018; Ramon, Sokhn & Caldara, under revision). Relatedly, attention must also be paid the possibility of observers being familiar with the two Dutch celebrities depicted. Such knowledge would serve as an effective prior facilitating identity grouping (see Jenkins et al., 2011; Andrews et al., 2015). Even if different versions of this test were created in the future that involved different set sizes with varied numbers of individuals depicted, prior completion or knowledge of the original FICST may decrease the initially observed effect of identity separation and grouping reported here and elsewhere (Jenkins et al., 2011; Andrews et al., 2015).

A final, seemingly trivial consideration concerns the quality of image material used both for the YBT and FICST. As noted, we were kindly provided with a physical copy of the original YBT used by Bruck et al. (1991); a large number of digital image copies of both Dutch celebrities were provided to recreate a version akin to the FICST reported by Jenkins et al., (2011). We observed quality and appearance variations in the reproduction and duplication process. To ensure that observers were confronted with identical image material, we opted for use of FICST material (printed and laminated for repeated usage), and reproduced the YBT based on its scanned version using the same printer (and printer settings). As done already (Bobak, 2018; personal communication), researchers interested in using this material should contact the corresponding author to receive a replica to be used without further

reproduction until the potential impact of reproduction-related quality variations on observers' performance is established.

Commonly reported tests of face recognition and perception included in this study

Cambridge Face Memory Test – long form (CFMT+). This computer-based test was developed by Russel et al. (2009) with the aim to assess *face recognition* for experimentally learned identities. This computer-based test comprises three increasingly difficult parts (see Figure 1d), in which greyscaled cropped male face stimuli are presented (6 target identities, 46 distractors). Participants encode images of target identities from different viewpoints before subsequently selecting the target identity among two distractors. As this test progresses, the trials become increasingly more difficult, as illumination, orientation, and information availability are manipulated (see Figure 1c). For each observer, we recorded the number of correct responses obtained across the total of 102 items of the CFMT+.

Expertise in Facial Comparison Test (EFCT). This test of *face perception* was reported by White et al. (2015) and assesses *face discrimination* ability measured in the context of a computer-based simultaneous matching task. Half of the (total of 84) trials depict the same identity, the remainder involve pairs of identities that were deliberately “similar-looking” (White et al., 2015). To better approximate its more recent application (cf. e.g., Noyes et al., 2018; Phillips et al., 2018), observers provided binary same/different responses for colored uncropped faces with varied facial expressions and on different backgrounds (see Figure 1c), which were presented for a maximum of 30s (vs. 5 or 7 scale responses, and 2s presentation durations; cf. White et al., 2015)¹. For each observer, we recorded accuracy and reaction time. As discussed below (see *Analyses*), we deem consideration of both accuracy and RTs *at the individual level* (as opposed to merely the group level; e.g. White et al., 2017) especially relevant when aiming to provide normative data from a large and heterogenous sample against which individual performance can be reliably compared.

Person identification challenge test (PICT). This test of *face perception* involves the same procedure and experimental settings, and hence process as the EFCT (White et al., 2015). The only difference is that stimuli portray individuals from a greater distance, and therefore display more external cues and environmental information. This test involved the

¹ We adopted this long presentation duration to ensure that decisions were made based on perceptual matching, and not contaminated by decisional processes or memory after stimulus offset. Additionally, we reasoned that this presentation duration exceeds the time required by healthy observers to perform this task.

same testing procedure (presentation duration, responses registered, computed composite score to account for speed-accuracy trade-offs) as described above for the EFCT.

In addition to these three frequently applied tests, and as mentioned above, observers also completed the CFPT (Duchaine et al., 2007) – a test of *face perception* that involves sorting upright and inverted stimuli according to their similarity with a simultaneously presented target face. This test was not intended to be considered in our analyses; it was employed to enable our students to independently formulate and probe hypotheses using the data from the total database; this data, in addition to demographic participant data, will be provided upon request.

Analyses

The need for computation of composite scores

To take into account the behavioral measures registered for a given test, composite performance scores were calculated for all tests with exception of the YBT and CFMT+, for which only raw scores (i.e., number of correctly matched or recognized faces) were considered.

For the FICST, perfect performance involves separating the 40 images into two piles without inclusion errors. While previous studies considered only the number of piles as an index of performance (Jenkins et al., 2011; Andrews et al., 2015), here, we calculated a composite score in order to consider both possible sources of errors (inclusion and separation). This allows distinction between observers, who *randomly* vs. *accurately* create two identity piles. Any number of piles exceeding two was considered as additional mistake(s). Observers' FICST scores were computed by subtracting two from the sum of piles and errors. Thus, a score of zero corresponds to perfect performance; the higher the FICST score, the less proficient an observer's performance for grouping images by identity.

Note that for the YBT, FICST, and CFMT+, reaction times (RTs) were not considered as informative, for the following reasons. First, for the YBT and FICST, provided responses are not based on discrete pairs, and identity matches decisions can be changed, and – once made – determine the nature of the remaining responses. For the CFMT+, the presentation of the to-be-learned faces is fixed, while recognition decisions provided for the test face trio is unlimited. As in this context performance is determined by encoding proficiency and recognition ability, where longer decision times will not facilitate recognition performance, no systematic speed-accuracy trade-off is to be expected.

1 In comparison to these three tests, from a procedural perspective, the EFCT and PICT
2 are the least complex. Both require binary, perceptually-based decisions for stimuli presented
3 simultaneously without time constraints. In such an experimental context, we reasoned that
4 consideration of RTs is imperative. Under simultaneous matching conditions observers are –
5 compared to e.g. recognition tasks – more likely to display speed-accuracy trade-offs. Even
6 highly impaired prosopagnosic individuals can achieve accurate performance at the expense
7 of vastly prolonged RTs, which is why it is common practice to take into account RTs in studies
8 of both healthy and impaired individuals (e.g., Marotta et al., 2002; Tarr, 2003; Behrmann et
9 al., 2005; Biotti et al, 2017; Lao, Vizioli, & Caldara, 2013; White et al., 2017). Indeed, according
10 to many, “the notion of speed-accuracy tradeoff (SAT) is pedestrian” (Heitz, 2014, p.1; see
11 also Luce, 1986).

12 The highly heterogeneous distribution of reaction times observed for the EFCT and
13 PICT supports this notion and suggests that many healthy observers may indeed show speed-
14 accuracy trade-offs. Leaving aside the implications for studies that did not consider RTs and
15 therefore neglect the impact of speed-accuracy trade-offs (e.g., Burton et al., 2010; White et
16 al., 2015; Noyes et al., 2018; Phillips et al., 2018), here, we opted to consider both speed and
17 accuracy by computing observers’ inverse efficiency score (Townsend & Ashby, 1978). This
18 is crucial given our goal of providing normative data against which individual performance can
19 be compared in order to determine potentially superior performance.

20 **Statistics**

21 *Behavioral measures considered.* Behavioral responses from all five tests were subject to
22 descriptive and correlation analyses. Descriptive statistics are provided separately for all
23 measured behavioral responses, as well as composite scores. Correlation analyses were
24 performed on the YBT and CFMT+ raw scores, and (following the aforementioned sources of
25 errors and potential speed-accuracy trade-offs) the FICST, EFCT and PICT composite scores.

26 *Analyses of high performing individuals.* Additionally, in order to determine the
27 predictive value of a given test, we investigated how the top performers of each test scored
28 on the remaining ones. First, independently for each of the five tests, we identified those
29 participants whose scores were located in the top 5% bin (n=9). We then computed each
30 subsample’s mean performance and retained the value as a reference average. Finally, we

1 extracted the score of each subsample for each respective other test and compared the mean
2 to each test's reference average.

3 **LIST OF ABBREVIATIONS**

4 CFMT+: Long form of the Cambridge Face Memory Test; CFPT: Cambridge Face Perception
5 Test, EFCT: Expertise in Facial Comparison Test; FICST: Face Identification Card Sorting
6 Test; IE: inverse efficiency; IES: Inverse Efficiency Score; PICT: Person Identification
7 Challenge Test; RTs: reaction times; YBT: Yearbook Test.

8 **DECLARATIONS**

9 All procedures were approved by the local Ethical Committee (reference number 425).
10 Consent for publication was obtained for all individuals, whose data or likenesses are reported
11 in the manuscript. The datasets obtained and/or analyzed in this study are available from the
12 corresponding author on reasonable request. Test material used here will be made available
13 provided permission from the original authors. The authors declare that they have no
14 competing interests. LS contributed to research design, performed the research, analyzed and
15 interpreted the data, and wrote the manuscript. EHE performed the research, analyzed data,
16 and contributed to the manuscript preparation. RC provided resources to conduct the work,
17 and input regarding data interpretation. MR designed and performed the research, analyzed
18 and interpreted the data, and was the major contributor in writing the manuscript. LS and MR
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1 Supplemental information

2

3 **Figure S1. CFMT+, EFCT and PICT's score of the top performers identified independently for each test.**
 4 Visualized here are performance of individuals identified as the top (colored markers) based on the YBT (red
 5 red circles)-, FICST (blue crosses), CFMT+ (green squares), EFCT (purple triangles) and PICT (orange asterisks) and
 6 their relative location among all observations made (grey dots) for the CFMT+ (A), EFCT (B) and PICT (C).