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RESEARCH ARTICLE

Individual differences in visual acuity and face matching ability

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Summary

The visual acuity of the eyes varies outside the range of normal vision, requiring corrective lenses, but also within the normal range. This study investigated whether both types of variation relate to individual differences in face-identity matching, considering this applied task requires perception of detail. Across two experiments, face-matching accuracy correlated with variation in acuity when this fell outside the normal range of vision and was uncorrected with glasses or contact lenses. In contrast, variation in visual acuity within the normal range did not affect face-matching accuracy, whereas matching accuracy at a given level of acuity could vary substantially. These results indicate that visual acuity is only a problem for occupations performing face-identity matching when below-normal acuity is not diagnosed or adequately corrected. In turn, these findings suggest that variation in acuity within the normal range is not a contributing factor to individual differences in face matching accuracy.

KEYWORDS

face matching, facial comparison, individual differences, visual acuity

1 | INTRODUCTION

Unfamiliar face matching requires the classification of pairs of photos as depicting the same person (i.e., an identity match) or as two different people (a mismatch). This task is often studied as a laboratory analogue to important applied settings, such as passport control at airports and borders (see, e.g., Bobak, Dowsett, & Bate, 2016; Fysh & Bindemann, 2018; White, Kemp, Jenkins, Matheson, & Burton, 2014), where face matching is employed routinely to verify the identities of travelers. A substantial body of psychological research now demonstrates that face matching is generally prone to error (for a review, see Fysh & Bindemann, 2017a, 2017b), but it is also marked by substantial differences in ability between individuals (e.g., Bindemann, Avetisyan, & Rakow, 2012; Burton, White, & McNeill, 2010; White et al., 2014). For example, in the short version of the Glasgow Face Matching Test, which has been used extensively in this research domain, mean accuracy across observers is at 81%, with individual performance ranging from 51 to 100% (Burton et al., 2010). Similarly, in the more difficult Kent Face Matching Test, mean accuracy is at 66% across observers, with individual performance ranging from 40 to 88% (Fysh & Bindemann, 2018).

These individual differences in face identification persist across numerous behavioral tests and manipulations (for a review, see Lander, Bruce, & Bindemann, 2018), and appear to be rooted in a variety of higher-level processes, ranging from face-specific factors (Cepulic, Wilhelm, Sommer, & Hildebrandt, 2018; Verhallen et al., 2017), general visual factors, such as object processing ability (Burton et al., 2010; Megreya & Burton, 2006; Woodhead & Baddeley, 1981), to nonvisual aspects such as facets of personality (Bate, Parris, Haslam, & Kay, 2010; Megreya & Bindemann, 2013). In this study, we examine a *low-level* factor that may also contribute to the individual differences observed in face matching, but that has so far not been examined in this field, reflecting variation in visual acuity both outside of and within the accepted normal range of vision.

Visual acuity refers to the clarity, or resolution, with which a stimulus can be seen. It is natural that acuity has *some* relationship to the visual identification of stimuli. All visual cognitive processes begin in the eye, as a stimulus must first be seen before it can be processed. If this acquisition of visual information is impaired, for example, through refractive errors that lead to poor eyesight, then high-level identification processes will be impeded too. However, in addition to broader variation in visual acuity due to eyesight problems, *finer* variation, within what is considered to be the normal range of acuity, also exists. Normal vision is considered to be 20/20, referring to what an observer can see at a distance of 20 ft (by metric standards this refers to 6/6 m) compared to what should be seen at this distance by the general population (Hellem & Heiting, 2019; Vimont, 2016). However, the accepted range of normal vision actually falls between 20/25 (6/7.5) and 20/12 (6/4), where the latter is considered to be "better than average" (International Council of Ophthalmology, 2002). This range is quite substantial, equating to a difference of four lines on a Snellen eye chart used to measure visual acuity (for an illustration, see Figure 2 further on).

There are good reasons why face matching might be affected by such variation in normal visual acuity. In photo-identity documents such as passports, face portraits are typically presented at small size, emphasizing the need for good vision. In the United Kingdom, for example, the area of the face in passport photographs must measure merely between 29 and 34 mm in height, leading to a loss of visual detail compared to larger face photographs. In turn, this indicates that visual acuity at the lower end of normal vision may also lead to a loss of information for observers to perform perceptual tasks. The question arises of whether such information loss impacts on face-matching accuracy. The recognition of familiar faces, of people that are well known to observers, is typically explained by a reliance on holistic facial information, whereby the identity of faces is processed as a single percept that can be perceived at a glance (see, e.g., Maurer, Le Grand, & Mondloch, 2002; Rezlescu, Susilo, Wilmer, & Caramazza, 2017; Richler & Gauthier, 2014). Moreover, such information appears to be accessible from the low-spatial frequency content of faces, indicating that fine visual detail provided by high-acuity vision is not necessary for accurate identification (see, e.g., Costen, Parker, & Craw, 1996; Goffaux, Hault, Michel, Vuong, & Rossion, 2005; Goffaux & Rossion, 2006). Consistent with these observations, familiar faces can be identified when displayed as heavily pixelated images (Bachmann, 1991; Lander, Bruce, & Hill, 2001; see also Demanet, Dhont, Notebaert, Pattyn, & Vandierendonck, 2007) or at small sizes, for short durations, and in regions of the visual field where acuity is reduced (see, e.g., Bindemann, Burton, & Jenkins, 2005; Bindemann, Jenkins, & Burton, 2007; Jenkins, Lavie, & Driver, 2003).

Contrary to the recognition of familiar faces, however, holistic information appears to be of less importance for the identity matching of unfamiliar faces. For example, unfamiliar face matching accuracy does not correlate with the Composite Face Test (Verhallen et al., 2017) and is not impaired by stimulus inversion (Megreya & Burton, 2006), both of which are tests that are typically applied as indexes of holistic face processing. In turn, unfamiliar face matching correlates with object processing tests that rely on identification of individual features (Burton et al., 2010; Megreya & Burton, 2006) and matching accuracy improves as more viewing time is available, suggesting that at-a-glance holistic processing strategies limit performance in this task (Bindemann, Fysh, Cross, & Watts, 2016; Fysh & Bindemann, 2017a, 2017b; Özbek & Bindemann, 2011). In addition, accuracy for the matching of unfamiliar faces decreases dramatically when image resolution is reduced through manipulations such as pixelation (Bindemann, Attard, Leach, & Johnston, 2013). Taken together, these findings indicate a reliance on finer visual detail in the identity matching of unfamiliar faces, which has to be acquired over time with multiple eye movements. Consequently, variation between observers in visual acuity within the normal range might also link to their face matching accuracy.

To investigate this question, we first assessed observers' vision with three standard acuity tests to ensure accuracy of measurement. These comprised of the Landolt C acuity test, which requires observers to determine the orientation of the letter "C" shown at different sizes and rotation (The Freiburg Visual Acuity and Contrast Test [FrACT], Bach, 2007), and two Snellen wall charts, in which observers have to read lines of letters which systematically decrease in size. These test data were then compared to confirm accurate measurement of visual acuity. This was followed by the Kent Face Matching Test (KFMT; Fysh & Bindemann, 2018) to provide a measure of face matching ability for comparison with observers' visual acuity. In Experiment 1, we applied these acuity tests and the KFMT twice on a within-subjects basis, to examine observers who use visual correction, such as glasses or contact lenses, with uncorrected and corrected-to-normal vision. The rationale for this was to establish a general relationship between visual acuity and face matching, by comparing individual accuracy under uncorrected vision, before exploring whether this persists also when individual variation in acuity within the normal (corrected) range is considered. Specifically, we expected observers to exhibit better face-matching performance when vision was corrected than when not. We also expected uncorrected visual acuity to vary greatly in this participant group so that, if visual acuity relates to face perception at an individual level, such a relationship should be found here. The question of main interest was whether a similar correlation exists between visual acuity and face matching for (corrected) vision within the normal range.

In addition to the KFMT, we also examined performance with corrected vision on two further tests of face processing, comprising of the Cambridge Face Memory Test (CFMT; Duchaine, & Nakayama, 2006) and the Cambridge Face Perception Test (CFPT; Duchaine, Germine, & Nakayama, 2007). These tests have been used widely to study face processing and provide robust measures of individual differences in ability (e.g., Bobak et al., 2016; Bobak, Parris, Gregory, Bennetts, & Bate, 2017; Fysh & Bindemann, 2018). We included these tests here for two reasons. First, if correlations with the KFMT and visual acuity *are* found, then we sought to determine whether these effects are persistent, by being evident also with other tests of face processing. Second, each of these face tests is designed to explore different aspects of unfamiliar face processing. The KFMT assesses identification of unfamiliar faces when memory demands are minimized (matching), the CFMT measures recognition of newly learned faces (memory), while the CFPT examines the perception of fine differences between highly-similar faces (discrimination). In combination, these tests may therefore provide further insight into which face processes might be impacted particularly by variation in acuity within the normal range.

2 | EXPERIMENT 1

3 | METHOD

3.1 | Participants

Fifty-one students (42 females, 9 males) from the University of Kent with a mean age of 20.1 years (*SD* = 5.3) participated in this study for course credit. Participants were required to complete the experiment twice, with corrective eye-wear (either glasses or contact lenses) and without.

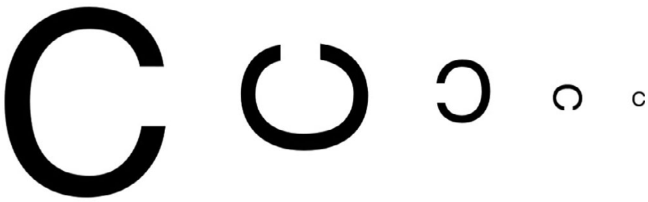

FIGURE 1 Examples of possible orientations and sizes of the letter "C" used in the The Freiburg Visual Acuity and Contrast Test (FrACT) test, not to scale

3.2 | Stimuli and procedure

The experiment materials consisted of three tests to measure visual acuity, comprising of the Landolt C acuity test and two Snellen charts, followed by the KFMT. Participants completed these four tests once with uncorrected vision (i.e., without glasses or contact lenses) and then for a second time with corrected vision (i.e., with corrective lenses). Following the second completion of the KFMT, participants also performed the CFMT and CFPT with corrected vision. These acuity and face tests are described in detail below.

Landolt C acuity test: Visual acuity was measured first with the Landolt C acuity test included in FrACT (Bach, 2007). In this test, the letter "C" appeared onscreen in one of four orientations—upright or turned at 90, 180, or 270°. Participants were asked to press the arrow key on a standard computer keyboard that corresponded with the direction the gap of the "C" was facing onscreen. During the test, letter size changed automatically based on the responses given, where correct responses led to smaller and more difficult to discern letter orientations while incorrect answers had the opposite effect. Figure 1 illustrates the differences in the degrees of rotation and stimulus sizes

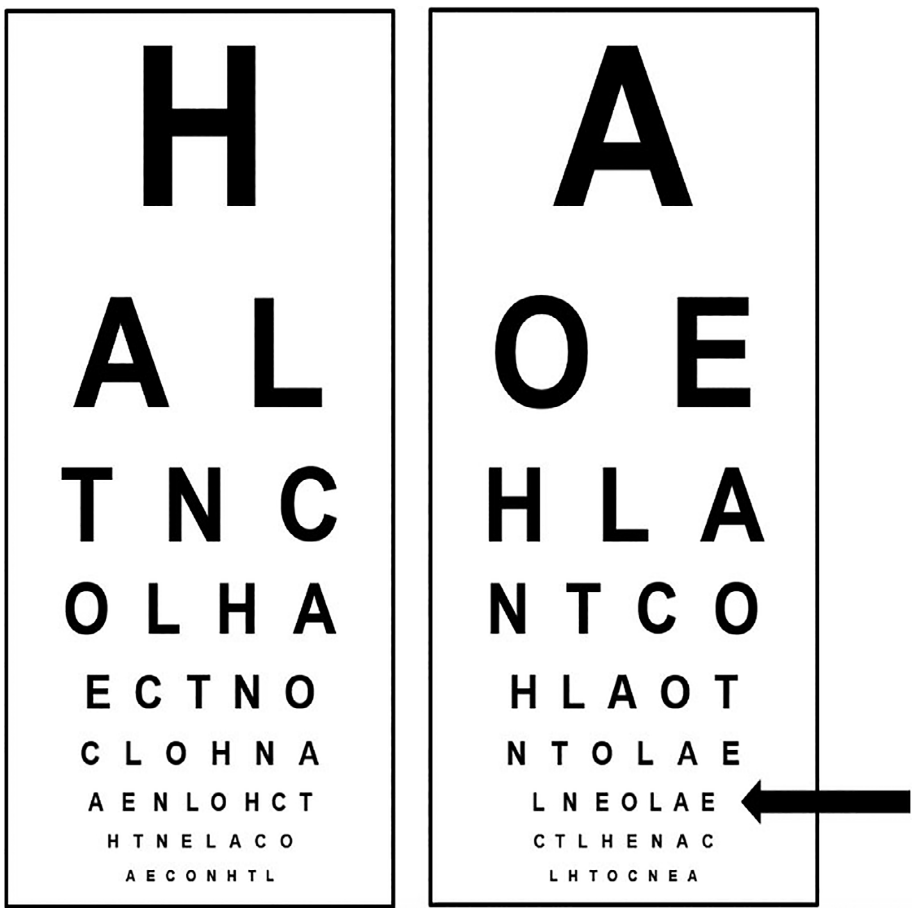

FIGURE 2 Recreations of HAL and AOE Snellen visual acuity charts, not to scale. When viewed at the correct distance and size, the furthest line from the top that can be read without error approximates the viewer's acuity. The three smallest lines fall within the normal range of vision

used during the test. If at any time the correct orientation became indiscernible and a clear choice could not be made participants were told to guess. In this manner, each participant completed 24 trials at a distance of 1.75 m, whilst seated at a desktop computer. Acuity in this test is measured in a 20/X imperial Snellen fraction, which was converted to a 6/X metric Snellen fraction for data analysis.

Snellen charts: After the computer-based vision test, participants were asked to read two standard Snellen acuity wall charts, comprising of the HAL and AOE, from a distance of 3 m. Each of these charts consists of nine lines of letters, which decrease in size from top to bottom, printed on a wall-mounted white plastic background measuring 32 × 15 cm (see Figure 2). Participants were asked to start at the top and read out each line. The result of the lowest line read aloud accurately was recorded as a metric 6/X Snellen fraction, where “X” corresponds to the lowest line that a participant was able to read correctly. Specifically, this value represents the distance at which an individual with normal vision can identify the lines that the participant can see at 6 m. For example, a Snellen fraction of 6/12 corresponds to the fifth line from the bottom of the chart, and indicates that the participant would need to stand at 6 m to accurately read the same line that an individual with normal vision can read at 12 m. A value of X higher than 6 therefore indicates that a participant has poorer vision than average and vice versa.

KFMT: Participants then completed the short version of the KFMT (Fysh & Bindemann, 2018) using PsychoPy software (Peirce, 2007). The test is comprised of 20 match face pairs, in which two different photographs of the same identity are combined, and 20 mismatch pairs, in which the faces of two different people are shown (e.g., see Figure 3). Each face pair consists of one photo taken in a laboratory setting with a digital camera scaled to 283 × 332 pixels, and one photo taken from a participant's student ID scaled to 142 × 192 pixels at a resolution of 72 ppi. The stimuli were displayed on a 24 in monitor (51.7 × 32.5 cm) and viewed at a consistent distance of 1 m using a table-mounted chinrest. During each trial, participants determined whether the observed photo pair depicted an identity match or mismatch using two keys on a standard computer keyboard.

CFMT: After completing the acuity and face matching tasks a second time, participants were given the CFMT. Face stimuli in this computerized task consist of images of 52 males, comprising six target and 46 foil identities. The test is split into three blocks. In the first block, participants study three different orientations of a target face for 3 s and are then asked to identify the target from an array of the target and two foil identities. This process is repeated for each target. The second block requires participants to observe six different target faces for 20 s before identifying a new view of a target face from a three-face array. The third block is procedurally identical to the second, except for the addition of Gaussian noise to the stimuli to increase difficulty. For further detail, see Duchaine and Nakayama (2006).

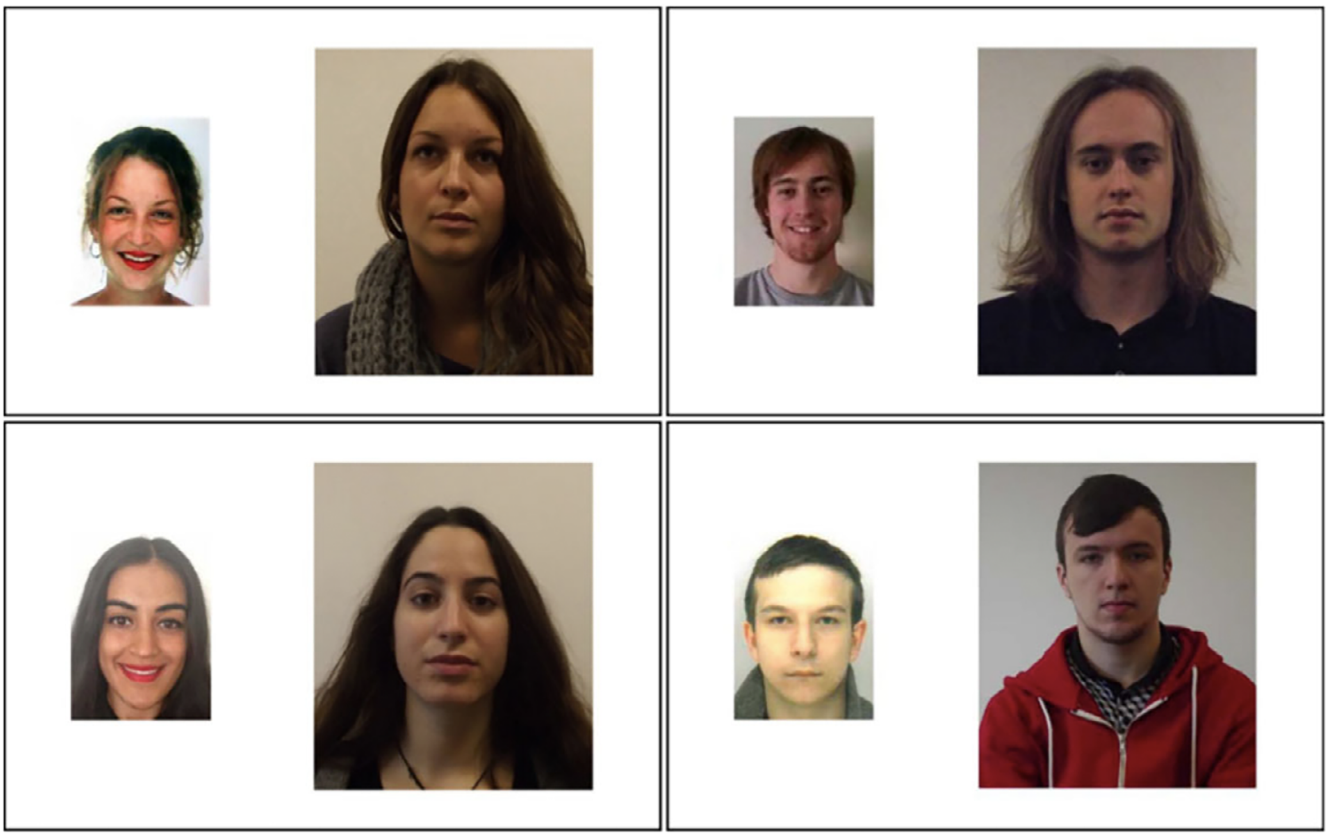

FIGURE 3 Match (top) and mismatch (bottom) examples from the Kent Face Matching Test

CFPT: Finally, participants completed the CFPT (Duchaine et al., 2007) at the same computer as the previous face tests. In the CFPT, participants view a target face above a line-up of six similar face photos which have been altered to differ from the target at varying degrees by morphing it with another identity. Using a timer built into the test to count down, participants are given 1 min to sort the line-up from most similar to the target photo to least similar. This sorting task is completed a total of 18 times, including two practice trials, with different faces and line-ups. Half of the total trials use upright and half inverted faces. For further detail, see Duchaine and Nakayama (2006).

4 | RESULTS

4.1 | Visual acuity

All acuity scores are reported as the value "X" in a 6/X Snellen fraction, where lower values indicate better acuity and higher values indicate worse acuity. Scores from the Landolt C and Snellen charts were analyzed using bivariate correlation to assess the reliability of visual acuity measurement. These correlations are illustrated in Figure 4 and demonstrate positive relationships between all three measures when participants' vision was uncorrected, all $rs \geq .81$, $p < .001$, and corrected, $rs \geq .53$, $p < .001$. This indicates that the visual acuity tests were reliable and converged in measurement.

In a next step, mean total acuities were calculated for each participant by taking the average of the three acuity tests, and compared for corrected and uncorrected vision to confirm that visual acuity was lower without corrective lenses ($M = 20.26$, $SD = 16.53$, Range = 4.50–62.50) than with ($M = 4.74$, $SD = 0.89$, Range = 3.87–8.30), $t(50) = 6.18$, $p < .001$. In addition, and as one would expect, variation in acuity level was also higher among participants when vision was uncorrected, as illustrated in Figure 5.

4.2 | Kent Face Matching Test

To determine if differences in visual acuity relate to face matching, accuracy on match and mismatch trials of the KFMT was compared for corrected and uncorrected vision. These data are illustrated in Figure 6. A 2 (vision: uncorrected vs. corrected) × 2 (trial type: match vs. mismatch) within-subject ANOVA of this data did not show a main effect of trial type, $F(1, 50) = 0.00$, $p = .95$, $\eta_p^2 = 0.00$, but revealed a main effect of vision, $F(1, 50) = 42.70$, $p < .001$, $\eta_p^2 = 0.46$, due to higher matching accuracy with corrected vision. An interaction between factors was also found, $F(1, 50) = 26.70$, $p < .001$, $\eta_p^2 = 0.35$. Analysis of simple main effects showed that correction of vision improved accuracy on match trials, $F(1, 50) = 62.37$, $p < .001$,

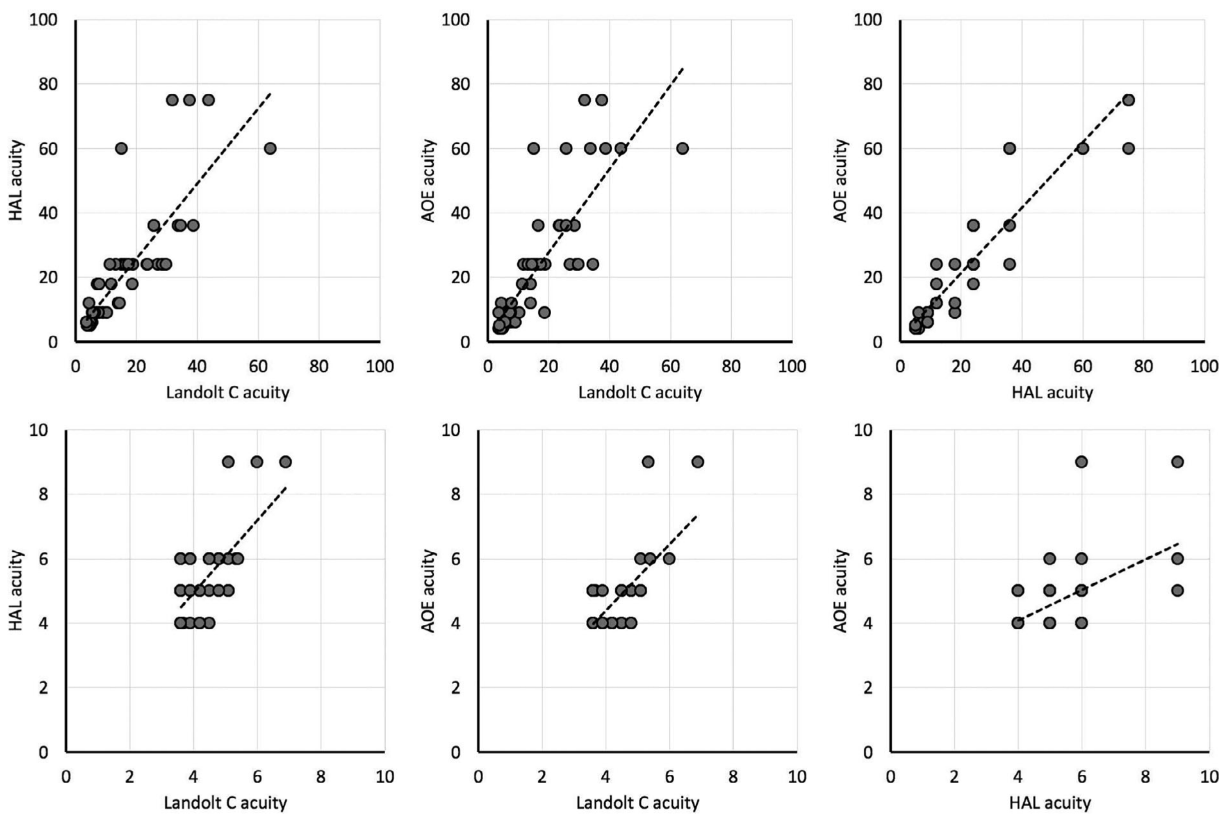

FIGURE 4 Correlation of visual acuity tests under uncorrected (top row) and corrected vision (bottom row) in Experiment 1. Acuity is reported as the value of "X" in a Snellen fraction (6/X)

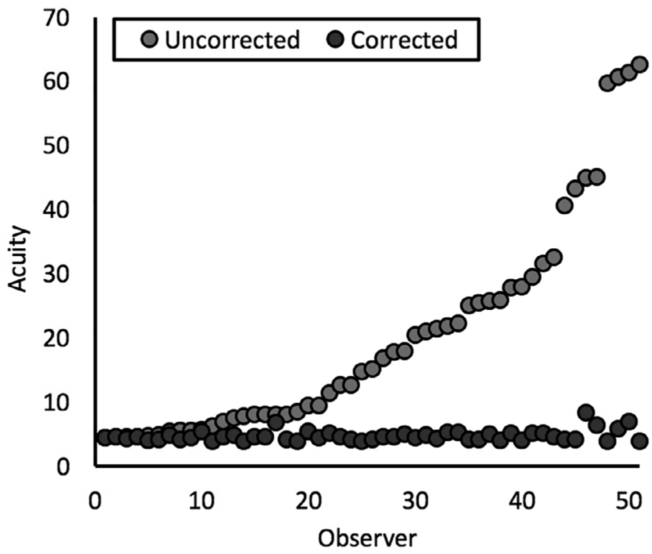

FIGURE 5 Range of acuity in the uncorrected and corrected conditions of Experiment 1, sorted from best to worst individual

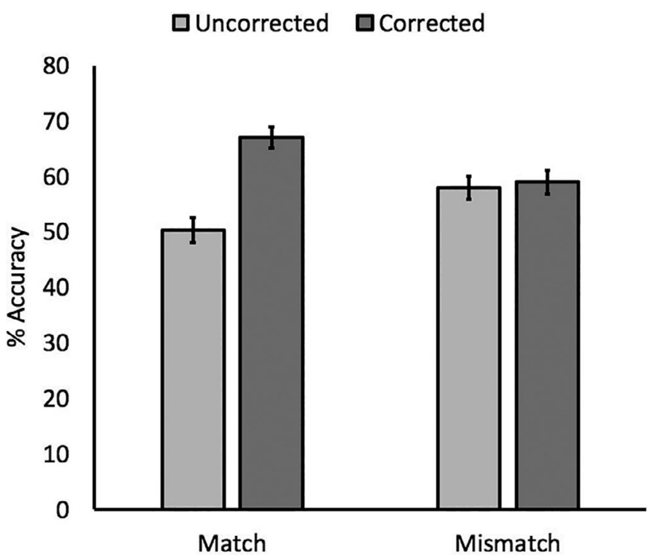

FIGURE 6 Mean accuracy on the Kent Face Matching Test (KFMT) with uncorrected and corrected vision in Experiment 1. Error bars represent the standard error of the means

η_p^2 = 0.56, but not mismatch trials, $F(1, 50) = 0.30$, $p = .58$, $\eta_p^2 = 0.01$. In addition, match accuracy also exceeded mismatch accuracy when vision was corrected, $F(1, 50) = 5.60$, $p < .05$, $\eta_p^2 = 0.10$, whereas mismatch accuracy was higher than match accuracy with uncorrected vision, $F(1, 50) = 4.77$, $p < .05$, $\eta_p^2 = 0.09$.

To examine the relationship of visual acuity and face matching on an individual level, acuity scores with uncorrected and corrected vision were correlated with match and mismatch performance on the KFMT (see Figure 7). With uncorrected vision, mismatch accuracy did not correlate with acuity, $r = -.170$, $p = .234$, but match accuracy decreased as uncorrected vision worsened, $r = -.427$, $p < .01$. A similar correlation was observed with visual acuity when match and mismatch scores were combined into an overall accuracy measure, $r = -.501$, $p < .001$. With corrected vision, on the other hand, no correlations for acuity and match, $r = .086$, $p = .550$, mismatch, $r = -.012$, $p = .936$, and overall accuracy, $r = .060$, $p = .676$, were found.

Match and mismatch accuracy on the KFMT were also converted into signal detection measures of sensitivity (*d′*) and bias (*criterion*). Consistent with the percentage accuracy data, a paired-sample *t* test revealed higher sensitivity with corrected than uncorrected vision (M = 0.72, *SD* = 0.46 vs. M = 0.23, *SD* = 0.53), $t(50) = 6.15$, $p < .001$. This effect was accompanied by a correlation of *d′* and acuity under uncorrected vision, $r = -.496$, $p < .001$, whereby sensitivity decreased as uncorrected vision worsened. This correlation was not present when vision was corrected, $r = .036$, $p = .804$. In addition, a bias was also observed to make more match than mismatch decisions with corrected compared to uncorrected vision (M = −0.11, *SD* = 0.35 vs. M = 0.10, *SD* = 0.36), $t(50) = 4.91$, $p < .001$, but correlations of criterion and acuity were not found, both with uncorrected or corrected vision, $r = .163$, $p = .252$ and $r = -.047$, $p = .741$, respectively.

4.3 | Cambridge Face Memory Test and Cambridge Face Perception Test

In the absence of correlations for corrected visual acuity and performance on the KFMT, we sought to compare these measures with the CFMT and CFPT to determine if *any* correlations with visual acuity in the normal range can be found. Overall accuracy on the CFMT was 73.1% (*SD* = 11.2), with individual accuracy ranging from 50.0% to 90.2%. On the CFPT, accuracy is measured as the mean number of deviations from the correct order of the face images on each trial and stood at 4.45 (*SD* = 3.21, Range = 1.5–17.8) and 8.69 (*SD* = 2.09, Range = 3.5–14.8) in the upright and inverted face conditions, $t(52) = 12.26$, $p < .001$. Variation in corrected visual acuity was not correlated with performance on the CFMT, $r = .030$ $p = .835$, but demonstrated a positive relationship with accuracy on the upright and inverted CFPT conditions, $r = .436$, $p < .001$ and $r = .473$, $p < .001$, respectively (see Figure 8).

5 | DISCUSSION

This experiment examined the link between visual acuity and face matching accuracy. The three tests of visual acuity, comprising of the computerized Landolt C and the HAL and AOE Snellen wall charts, converged strongly, indicating good measurement. As expected, these measures also revealed poorer and more varied visual acuity across participants without visual correction than when vision was corrected in the same observers with glasses or contact lenses. In line with these general observations, and as expected also, accuracy on the KFMT was lower when vision was uncorrected. This was characterized in particular by a general increase in accuracy with corrected vision on match trials, whereas performance for identity mismatches was similar with uncorrected and corrected vision.

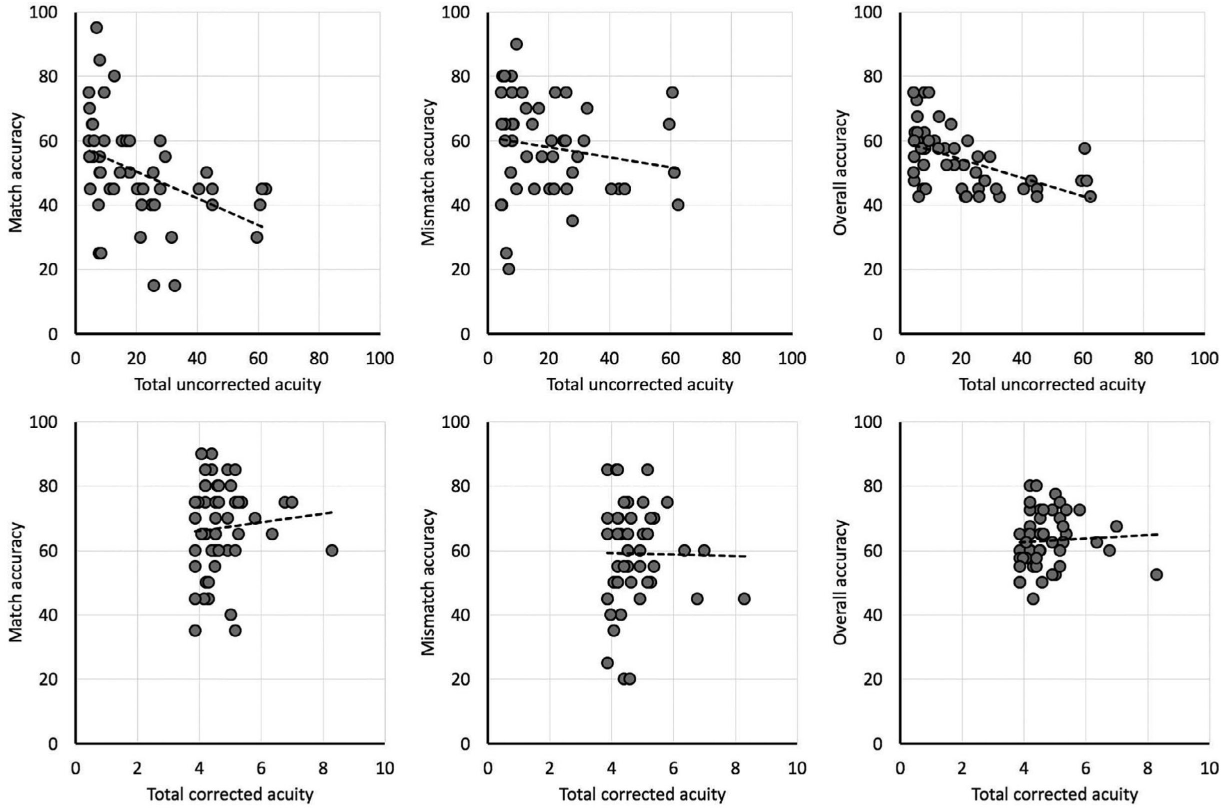

FIGURE 7 Correlation of visual acuity and match, mismatch and overall accuracy on the Kent Face Matching Test (KFMT) for uncorrected vision (top row) and corrected vision (bottom row) in Experiment 1

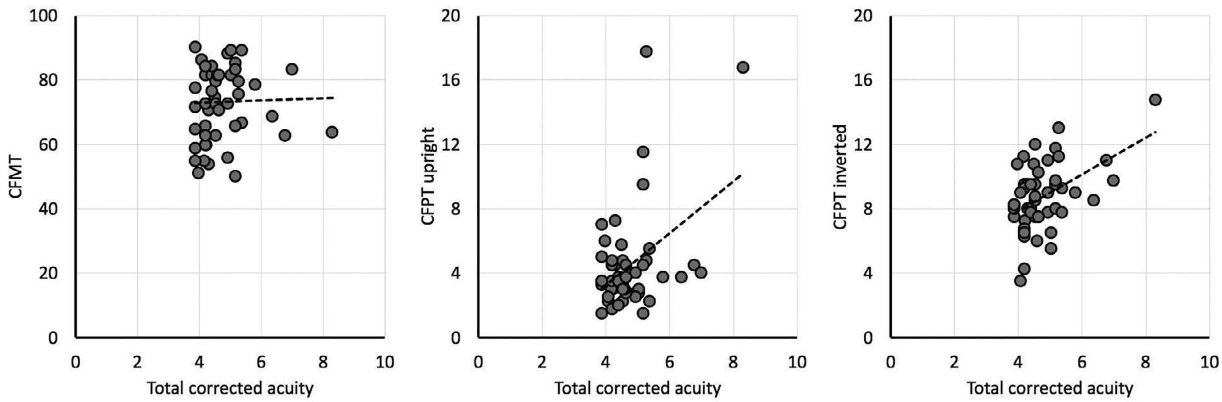

FIGURE 8 Correlation of visual acuity and the Cambridge Face Memory Test (CFMT) and Cambridge Face Perception Test (CFPT) upright and inverted in Experiment 1

As in previous research, performance on the KFMT was also marked by broad individual differences between observers (see Fysh, 2018; Fysh & Bindemann, 2018). The question of main interest was whether these individual differences relate to visual acuity, particularly when vision is corrected to be within the normal range. With uncorrected vision, overall accuracy as well as performance on match trials of the KFMT correlated negatively with acuity, indicating that better vision increased face matching accuracy. With corrected vision, on the other hand, no such correlations were observed.

We also included the CFMT and CFPT to provide additional measures that reflect different processes with unfamiliar faces. For the CFMT, which measures recognition memory for newly learned faces (Duchaine & Nakayama, 2006), no correlation with visual acuity within the normal range was found. For the CFPT, on the other hand, such correlations were present, which suggests that visual acuity within the normal range is important for making the very fine perceptual discriminations between morphed faces that are required for this test (Duchaine et al., 2007). In this context, the absence of such correlations with accuracy on the KFMT indicates that face matching is not reliant on similar fine detail.

Before we consider the differences between these tests further, we note however that corrected visual acuity was very good in Experiment 1 (mean group acuity was 6/4.74 with 6/6 widely recognized to be average vision), and variation in acuity across observers was limited, with a *SD* of 0.89 and a range of 3.87–8.30. This narrow range of corrected vision may not be indicative of the true variation in acuity that exists in the general population, where some observers may have worse vision than 6/6 but also not use corrective lenses because they do not feel sufficiently impaired. Thus, testing a population whose vision has not been corrected may lead to a greater variation of acuity within the normal range and may reveal a relationship with face matching accuracy even if this was not evident in Experiment 1. We conducted a further experiment to address this possibility.

6 | EXPERIMENT 2

In Experiment 1, only participants who required visual correction aids were tested. This revealed a relationship between visual acuity and face matching accuracy when vision was uncorrected but not when corrective lenses were used. It is possible, however, that this result reflects the narrow range in corrected visual acuity in this group, which may not be representative of observers who do not use visual aids. To investigate this possibility, Experiment 2 was identical in procedure to Experiment 1 but included only participants who believed they did not need corrective lenses in order to see within the normal range of vision. Thus, rather than conditions in which performance was compared for uncorrected and corrected vision, participants repeated the acuity tests and KFMT without further manipulation, followed by the CFMT and CFPT. This design also allowed us to test for the presence of practice effects.

7 | METHOD

7.1 | Participants, stimuli, and procedure

Forty students (31 females, 9 males) from the University of Kent with a mean age of 20.1 years (*SD* = 5.3) participated in this experiment for a small fee. Participants were only asked to take part if they believed they had normal vision without the use of corrective lenses, such as glasses or contacts. The stimuli and procedure were identical to Experiment 1. Thus, participants completed the Landolt C, HAL and AOE acuity tests, followed by the short version of the KFMT (time 1). These tests were then repeated (time 2), followed by the CFMT and CFPT.

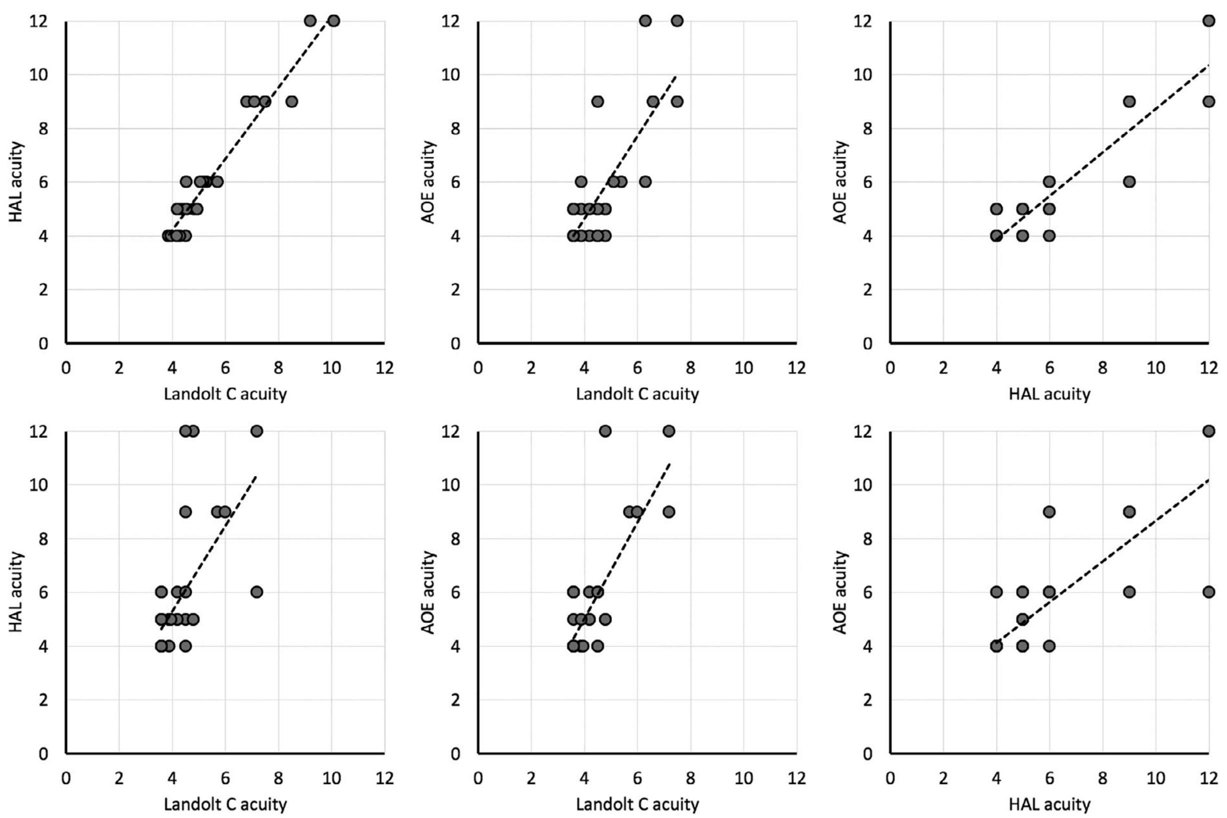

FIGURE 9 Correlation of visual acuity tests at time 1 (top row) and time 2 (bottom row) in Experiment 2

8 | RESULTS

8.1 | Visual acuity

Similarly to Experiment 1, positive relationships were found between the Landolt C, and HAL and AOE Snellen charts, both during the first acuity measurement (time 1), all *rs* => .740, $p < .001$, and the second measurement (time 2), all *rs* => .533, $p < .001$. These correlations are illustrated in Figure 9. In addition, the average combined acuity for the three tests during time 1 was comparable to time 2, 5.00 (*SD* = 1.50, Range = 3.87–10.10) versus 4.86 (*SD* = 1.39, Range = 3.87–9.60), $t(39) = 1.53$, $p = .135$, and correlated strongly, $r = .919$, $p < .001$. Individual acuity scores are illustrated in Figure 10.

8.2 | Kent Face Matching Test

Next, mean performance on the KFMT was analyzed for time 1 and time 2 to observe differences in accuracy that may be the result of trial type or practice. For this purpose, a 2 (time: time 1 vs. time 2) × 2 (trial type: match vs. mismatch) within-subject ANOVA was conducted, which did not show a main effect of time, $F(1, 39) = 0.94$, $p = .34$, $\eta_p^2 = .02$, or trial type, $F(1, 39) = 0.52$, $p = .48$, $\eta_p^2 = .01$, but revealed an interaction between factors, $F(1, 39) = 44.60$, $p < .001$, $\eta_p^2 = .53$. These data are illustrated in Figure 11. Analysis of simple main effects showed that match and mismatch accuracy was comparable at time 1, $F(1, 39) = 1.29$, $p = .26$, $\eta_p^2 = .03$, but match accuracy was higher than mismatch accuracy at time 2, $F(1, 39) = 7.50$, $p < .01$, $\eta_p^2 = .16$. In addition, match accuracy was also higher at time 2 than at time 1, $F(1, 39) = 17.01$, $p < .001$, $\eta_p^2 = .30$, whereas mismatch accuracy was lower at time 2 than at time 1, $F(1, 39) = 10.19$, $p < .01$, $\eta_p^2 = .21$.

To examine the relationship of visual acuity and face matching on an individual level, acuity scores at time 1 and time 2 were correlated with match and mismatch performance on the KFMT (see Figure 12). At time 1, mismatch and overall accuracy did not correlate with acuity, $r = .190$, $p = .239$ and $r = -.280$, $p = .080$, but match accuracy decreased as vision worsened, $r = -.506$, $p < .01$. At time 2, no correlations with acuity were observed for match, $r = -.264$, $p = .100$, mismatch, $r = .128$, $p = .431$, and overall accuracy, $r = -.132$, $p = .415$.

Once again, match and mismatch accuracy on the KFMT were also converted into signal detection measures of sensitivity (*d′*) and bias (*criterion*). A paired-sample *t* test revealed no difference in sensitivity between time 1 and time 2 (M = 0.71, *SD* = 0.59 vs. M = 0.81, *SD* = 0.54), $t(39) = 0.95$, $p = .347$, and no correlations of sensitivity and acuity at time 1, $r = -.272$, $p = .090$, or time 2, $r = -.141$, $p = .386$. For criterion, a bias to make more mismatch than match responses was observed at time 1 (M = 0.07, *SD* = 0.39) compared to time 2 (M = −0.16, *SD* = 0.36), $t(39) = 6.72$, $p < .001$. This was accompanied by a correlation of criterion and acuity at time 1, $r = .412$, $p < .01$, whereby the proportion of responses that were match decisions decreased with declining acuity. The correlation of criterion and acuity at time 2 was not significant, $r = .229$, $p = .156$.

8.3 | Cambridge Face Memory Test and Cambridge Face Perception Test

As in Experiment 1, we also compared acuity and face matching accuracy measures with the CFMT and CFPT. On the CFMT, overall accuracy was 68% (*SD* = 10.25). Accuracy on the CFPT, again measured by the number of deviations from the correct order of faces, was at 4.20 (*SD* = 3.21) and 8.69 (*SD* = 2.09) in the upright and inverted face conditions, $t(39) = 19.23$, $p < .001$. Variation in visual acuity within the

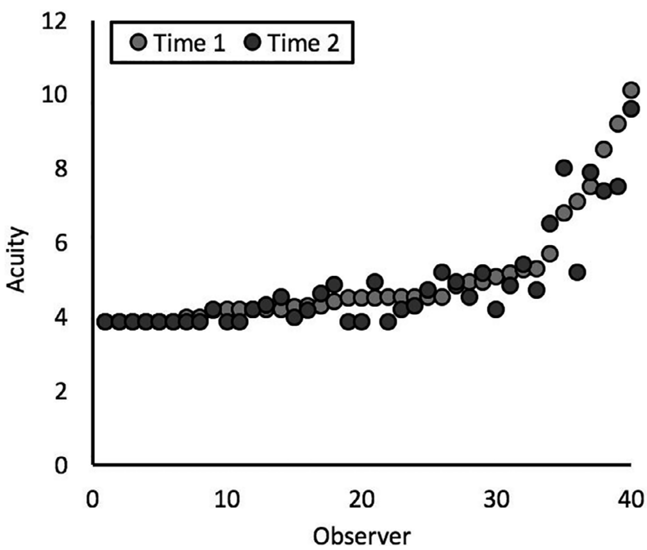

FIGURE 10 Range of acuity at time 1 and time 2 of Experiment 2, sorted from best to worst individual

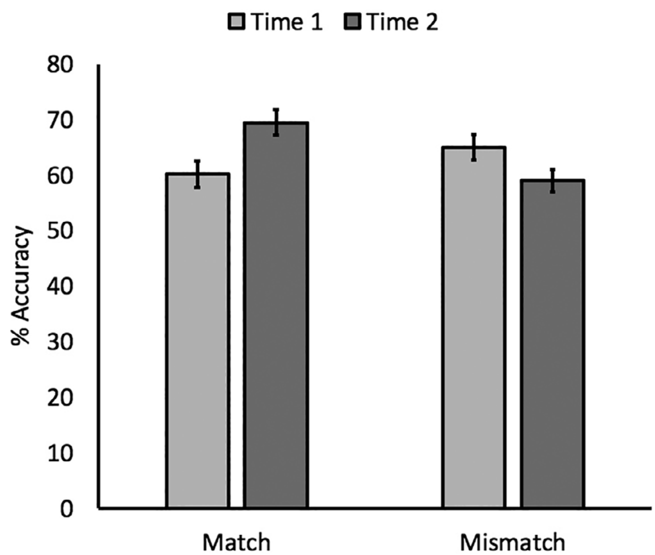

FIGURE 11 Mean accuracy on the Kent Face Matching Test (KFMT) at time 1 and time 2 in Experiment 2. Error bars represent the standard error of the means

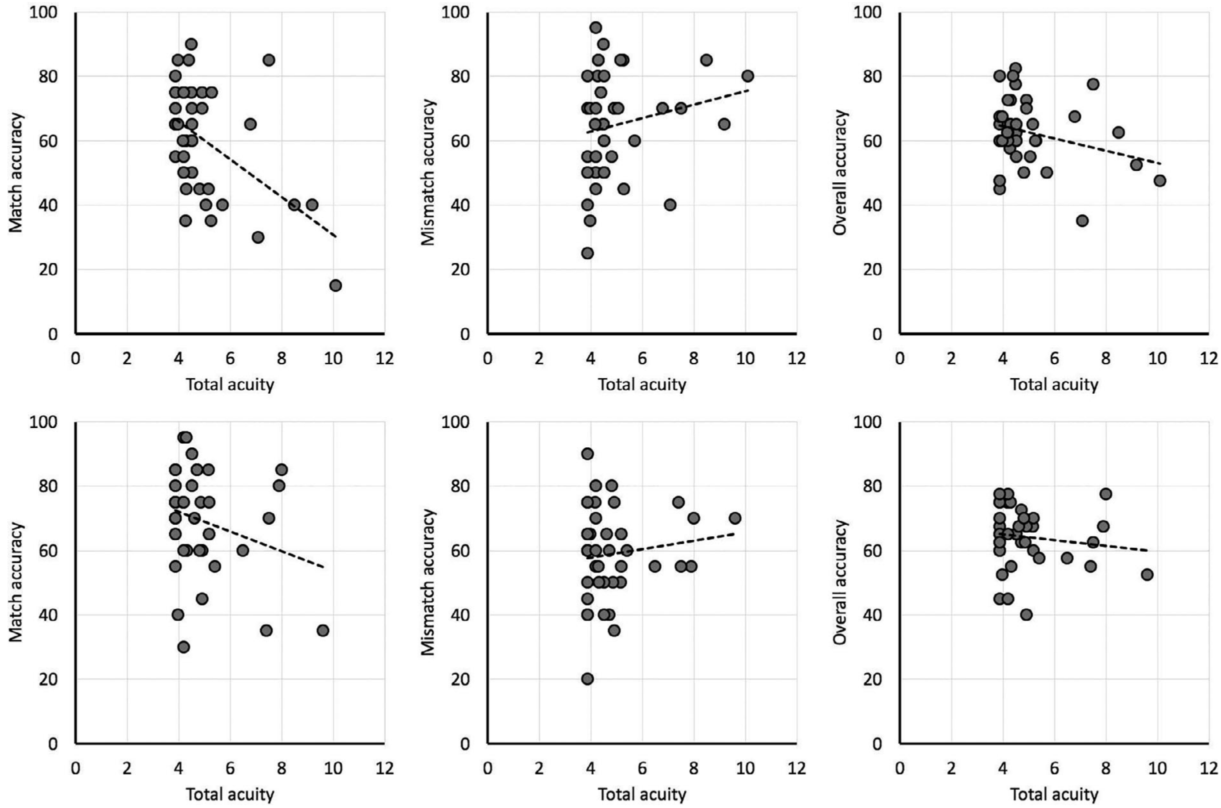

FIGURE 12 Correlation of visual acuity and match, mismatch and overall accuracy on the Kent Face Matching Test (KFMT) at time 1 (top row) and time 2 (bottom row) in Experiment 2

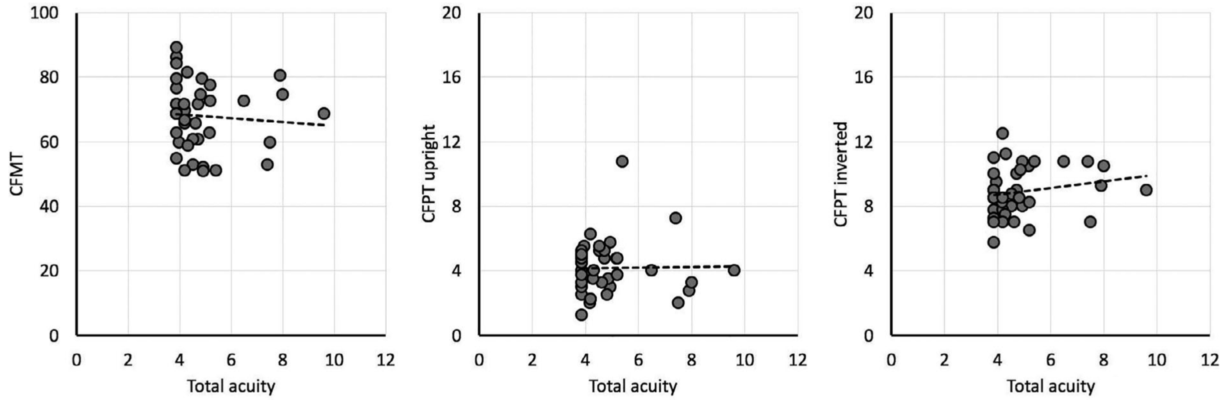

FIGURE 13 Correlation of visual acuity and the Cambridge Face Memory Test (CFMT) and Cambridge Face Perception Test (CFPT) upright and inverted in Experiment 2

normal range was not correlated with performance on the CFMT, $r = -.069$, $p = .674$, or the upright and inverted conditions of the CFPT, $r = .017$, $p = .918$ and $r = .194$, $p = .231$, respectively. These data are illustrated in Figure 13.

9 | DISCUSSION

This experiment replicated the design of Experiment 1 but with observers who were not using corrective lenses. The aim was to examine whether testing of a population whose vision has not been corrected may lead to a larger range of acuity within the normal range, and whether this may reveal a relationship with face matching accuracy even if this was not evident in the preceding experiment. A larger range and variation in visual acuity was found in Experiment 2 compared to observers with corrected vision in Experiment 1 (Range = 3.87–8.30 vs. 3.87–10.10; *SD* = 0.89 versus 1.50), but measurement across the three tests of visual acuity (Landolt C, HAL, and AOE) again converged strongly. In addition, acuity also correlated strongly across time 1 and time 2, indicating robust measurement. Despite this, only a single correlation of acuity and face matching accuracy was found in Experiment 2, between acuity at time 1 and match trials, due to a decrease in accuracy with declining acuity. In addition, the signal detection analysis revealed a response bias, whereby the proportion of match decisions decreased with declining acuity. Considering the accuracy data in more detail in Figure 12, it appears that a small number of outliers were present, of observers with visual acuity outside of the normal range (of 6/7.5; see The International Council of Ophthalmology, 2002). Removal of the three observers with acuity of 8.5, 9.2, and 10.1 eliminates correlation of visual acuity and match accuracy, $r = -.208$, $p = .218$ (mismatch accuracy, $r = .047$, $p = .780$; overall accuracy, $r = -.122$, $p = .473$), as well as the correlation of acuity and criterion, $r = .127$, $p = .452$ (d' vs. acuity, $r = -.115$, $p = .499$).

This finding appears consistent with Experiment 1, by indicating that correlations of visual acuity and face matching can be found on match trials when variation in individuals' acuity is considered across a broader range. In Experiment 1, this was the case in the uncorrected vision condition, whereas in Experiment 2 this was found with observers who did not require visual correction, but only when the range of acuity under consideration included those people whose vision was at the lowest end and, in fact, just outside of the normal range. We suggest that this explains also why these correlations were observed only at time 1 and not time 2, where the same individuals did not exhibit acuity that was quite as low (cf. the lowest performers in Figure 12).

In addition to these findings, and as in Experiment 1 also, accuracy on the CFMT did not correlate with visual acuity either. We note, however, that a discrepancy across experiments also exists. Whereas accuracy on the upright and inverted CFPT correlated with visual acuity within the normal range in Experiment 1, such correlations were not observed in Experiment 2. To explore this discrepancy, we combined the data from both experiments (corrected vision condition in Experiment 1 and time 2 in Experiment 2) to explore these correlations with a larger sample ($N = 91$). This showed no correlation of visual acuity with accuracy on the CFMT, $r = -.039$, $p = .717$, or any measures of the KFMT, all $rs < -.115$, $p > .276$, but with upright and inverted performance on the CFPT, $r = .232$, $p < .05$ and $r = .318$, $p < .01$, respectively. These moderate correlations indicate that variation in normal visual acuity is related to some extent to the fine perceptual discriminations between morphed faces that are required for the CFPT. These findings are discussed further in Section 10.

10 | GENERAL DISCUSSION

The presence of individual differences in face matching ability has been well established (see Bindemann et al., 2013; Burton et al., 2010; Fysh & Bindemann, 2018; Megreya & Burton, 2008), but the reasons for the existence of such differences are still largely unknown. This study investigated a low-level factor that might contribute to these individual differences, by examining whether variation in visual acuity within the normal range affects the identity comparison of faces. Across two experiments, substantial individual differences in unfamiliar face matching ability were found. Both experiments demonstrate also that this affects face matching accuracy when vision outside of the normal range is considered. Accordingly, in Experiment 1 a correlation between accuracy on identity match trials and visual acuity was observed with participants requiring visual correction when this was not applied. Similarly, in Experiment 2 a correlation between vision and match accuracy was found when observers with visual acuity outside of the normal range were included in the analysis.

The question arises of why these correlations of visual acuity and matching accuracy were observed with identity matches but not mismatches. Some previous work suggests that face matches are more likely to be perceived as identity mismatches when viewing time is limited to only 200 milliseconds. This prevented direct fixation on the face stimuli, which appeared either side of a central fixation point (Özbek & Bindemann, 2011). Thus, these short display times only allowed for the peripheral viewing of faces, outside of the area of the visual field with the best acuity (see, e.g., Henderson, 2003). In combination with the use of two different photographs of the same person's face for identity match trials, these face pairs might appear to depict two different people under the low-acuity view that the peripheral exposure to these stimuli affords. Similarly, it is possible that, under the limits of visual acuity under investigation in the current experiments, identity matches might appear to depict different people also by virtue of the fact that different images of the same person are paired up in these stimulus displays.

However, although both experiments here show such correlations when vision is uncorrected (Experiment 1) or participants outside the normal range are included in analysis (Experiment 2), they also converge in showing that such correlations do not exist when only variation in visual acuity *within the normal range* is considered. Thus, these findings indicate that subtle variation in visual acuity does not contribute to the individual differences in face matching accuracy reported in previous work. Indeed, the current study clearly shows substantial variation in individual face matching performance even for observers with the *same* visual acuity (see Figures 7 and 12).

In addition to the KFMT, which assesses identification of unfamiliar faces when memory demands are minimized, the current study also included the CFMT to measure recognition of newly learned faces (memory), and the CFPT to examine the perception of fine differences between highly-similar faces (discrimination). With this combination of tests, we sought to gain insight into which face processes in particular variation in acuity within the normal range might impact. No correlations of face memory (CFMT) and visual acuity were found. For the CFPT, on the other hand, such correlations were observed in Experiment 1 and, though not present in Experiment 2, persisted when the data from both experiments were also combined. The CFPT requires very fine perceptual discriminations between highly-similar facial morphs, so it is fitting that performance in this task shows some relation to fine variation in visual acuity between observers. In turn, this indicates that identity matching decisions on the KFMT are based on a different level of detail than the CFPT requires. However, it has been pointed out previously that the subtle, artificially manipulated differences between face images that the CFPT provides may not resemble any real-world face perception tasks (see Bate et al., 2018). Thus, the correlation of visual acuity and performance on the CFPT here provides useful context for showing that such relationships can be observed, whilst also emphasizing that perceptual processes in unfamiliar face identification are not affected similarly when visual acuity within the normal range is considered.

The findings reported here may be important practically, for example, for security occupations that involve face identity matching. Whilst our findings suggest that variation in acuity within the normal range is not a contributing factor to individual differences in face matching accuracy, they indicate also that this can be a problem when visual acuity below the normal range is not diagnosed, or adequately corrected, or accepted to be sufficient regardless. Police officers in the United Kingdom are required to have 6/6 distance vision when entering the force (Gov.uk, 2017; Kent Police, 2019), but there is no evidence that continued vision tests are mandated. For U.S. Customs and Border Control, the visual acuity requirement is only at 6/12 (U.S. Customs and Border Control, 2018). Our data indicate that inadequate monitoring of visual acuity or the acceptance of visual acuity outside of the normal range is likely to affect the accuracy of the facial identification process in these occupational settings.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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