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Bindemann, Markus and Attard, Janice and Leach, Amy and Johnston, Robert A. (2013) The effect of image pixelation on unfamiliar face matching. *Applied Cognitive Psychology*, 27 (6). pp. 707-717. ISSN 0888-4080.

DOI

<https://doi.org/10.1002/acp.2970>

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The effect of image pixelation on unfamiliar face matching

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Word count (main text and references but excluding abstract and figure captions): 7499

Abstract

Low-resolution, pixelated images from CCTV can be used to compare the perpetrators of crime with high-resolution photographs of potential suspects. The current study investigated the accuracy of person identification under these conditions, by comparing high-resolution and pixelated photographs of unfamiliar faces in a series of matching tasks. Performance decreased gradually with different levels of pixelation and was close to chance with a horizontal image resolution of only 8 pixel bands per face (Experiment 1). Matching accuracy could be improved by reducing the size of pixelated faces (Experiment 2) or by varying the size of the to-be-compared-with high-resolution face image (Experiment 3). In addition, pixelation produced effects that appear to be separable from other factors that might affect matching performance, such as changes in face view (Experiment 4). These findings reaffirm that criminal identifications from CCTV must be treated with caution and provide some basic estimates for identification accuracy with different pixelation levels. This study also highlights potential methods for improving performance in this task.

Introduction

In unfamiliar face matching, observers are presented with pairs of unknown faces and have to decide whether these depict the same person or two different people. This task is of considerable applied importance. In criminal investigations, for example, images from closed-circuit television (CCTV) can be used in an attempt to match the perpetrator of a recorded crime with photographs of potential suspects (see, e.g., Costigan, 2007; Davies & Thasen, 2000; Davis & Valentine, 2009; Lee, Wilkinson, Memon, & Houston, 2009). Despite its applied usage, face matching is an error-prone task. Under seemingly optimized laboratory conditions, in which pairs of to-be-matched faces are depicted in the same lighting, expression and view, identification errors are typically made 10% to 30% of the time (see, e.g., Bindemann, Avetisyan, & Blackwell, 2010; Bindemann, Avetisyan, & Rakow, 2012; Burton, White & McNeill, 2010; Megreya, Bindemann, & Harvard, 2011; Megreya, White, & Burton, 2011). Accuracy declines even further under different task demands, for example, when a target has to be compared to two (Henderson, Bruce, & Burton, 2001), five (Bindemann, Sandford, Gillatt, Avetisyan, & Megreya, 2012; Megreya, Bindemann, Havard, & Burton, 2013) or ten concurrent faces (e.g., Bruce et al., 1999; Megreya & Burton, 2006).

An understanding of these matching errors has informed psychological theories of face processing (e.g., Burton, Jenkins, Hancock, & White, 2005; Burton, Jenkins, & Schweinberger, 2011; Jenkins & Burton, 2011) and forensic identification (Jenkins & Burton, 2008; Megreya & Burton, 2008), and also has led to developments that might reduce errors of person identification in practical settings (see, e.g., Bindemann, Avetisyan, & Rakow; 2012; Bindemann, Brown, Koyas, & Russ, 2012; Burton et al., 2010; White, Kemp, Jenkins, & Burton, in press). Consequently, the study of face matching is now firmly established as a research topic of theoretical and applied importance.

In this study, we investigate a factor that has so far received limited attention in this context. While face matching is often measured under highly controlled conditions, (e.g., Bindemann et al., 2010, 2012; Burton et al., 2010; Megreya & Burton, 2006), many factors can make this task more difficult. Of these, poor image quality has been linked consistently to reduced performance in investigations of person identification from CCTV (e.g., Burton, Wilson, Cowan, & Bruce, 1999; Henderson et al., 2001; Liu, Seetzen, Burton, & Chaudhuri, 2003; Lee et al., 2009). In these studies, image quality is loosely defined in terms of factors such as poor lighting or low contrast, but the range of specific factors that are present and the exact levels of degradation are typically difficult to define.

One factor that is inherent in all CCTV footage and that can be quantified with relative ease reflects the image resolution of a recording device. Most previous studies on person identification in this field have utilized footage from analogue recording equipment (see, e.g., Bruce et al., 1999; Burton et al., 1999; Henderson et al., 2001; Liu et al., 2003). In analogue video cameras, image resolution is measured in scan-lines, which reflect the maximum number of horizontal strips that can be resolved in a picture. In newer digital recording systems, on the other hand, visual resolution depends on a rectangular grid pattern of sensors, where the size and number of sensors determines the quality of an image. These differences between analogue and digital equipment exert distinct effects on picture quality. Whereas the definition of old analogue CCTV images suffers from film-grain noise (for examples, see, e.g., Burton et al., 1999), digital footage has a distinctive ‘blocked’ or pixelated appearance. Consider the example in Figure 1, which represents a still frame of digital CCTV of the first author (MB), taken at a viewing distance of approximately five meters. Pixelation introduces two sources of noise in such footage. Due to the limited resolution of the recording device, incoming

visual information within a given square area is combined into blocks of uniform luminance, which remove high-spatial frequency detail from the original image. In addition, pixelation introduces spurious high-spatial frequency noise, reflecting the vertical and horizontal lines that are introduced by the blocked structure of the image.

Only a few studies have attempted to quantify the influence of such image pixelation on face identification accuracy (e.g., Harmon, 1973; Bachmann, 1991; Costen, Parker, & Craw, 1994, 1996). These studies have shown that accuracy is best for faces with a horizontal resolution of between 16 and 32 pixels per face (Costen et al., 1994, 1996), whereas performance decreases abruptly when this is reduced to only 15 pixels/face (Bachmann, 1991). However, even with very low spatial resolution, identification of pixelated faces can remain possible to some extent. Salvador Dalí's *Lincoln in Dalívision* represents perhaps the most famous example of this. In this artwork, a heavily pixelated image of Abraham Lincoln's face is embedded within another painting (*Gala looking at the Mediterranean Sea*). Despite the low resolution of Lincoln's face, it remains recognizable in this context, particularly as the viewing distance between observer and image increases. A similar finding has been obtained in psychological research. Lander, Bruce, and Hill (2001) found, for example, that approximately 50% of famous face photographs with a horizontal resolution of only 10 pixels per face could still be identified (see also Demanet, Dhont, Notebaert, Pattyn, & Vandierendonck, 2007). This suggests that pixelated faces with an extremely low spatial resolution can contain sufficient information for person identification.

These previous studies have examined the effect of pixelation on person identification with familiarized faces in recognition memory paradigms (Bachmann, 1991; Costen et al., 1994, 1996) or have assessed the recognition of famous faces in naming tasks (Demanet et al., 2007; Lander et al., 2001). By contrast, the effect of image

pixelation on the identity matching of *unfamiliar* faces has so far not been investigated systematically. This issue is imperative for several reasons. Firstly, forensic identification tasks often involve unfamiliar people, who are completely unknown to the participating observers (see, e.g., Jenkins & Burton, 2011; Memon, Havard, Clifford, Gabbert, & Watt, 2011). The identification of unfamiliar faces is much more error-prone under challenging viewing conditions than the recognition of famous and familiar faces (see, e.g., Burton et al., 1999; Bruce, Henderson, Newman, & Burton, 2001), and unfamiliar faces appear to be processed in a qualitatively different way (Megreya & Burton, 2006). It is therefore important also to examine the identification of pixelated images of unfamiliar faces and one might expect that these are affected particularly strongly by this manipulation. However, in contrast to the naming and recognition memory paradigms that are used to examine the identification of famous and familiarized faces (e.g., Bachmann, 1991; Costen et al., 1994, 1996; Lander et al., 2001), the *matching* of pairs of unfamiliar faces also allows for an immediate, side-by-side comparison of a pixelated face image with its unpixelated, high-resolution counterpart. This raises the alternative possibility that the effect of pixelation on the identification of unfamiliar faces might be mitigated by the nature of the matching task.

In this study, we begin to investigate these questions with a series of four experiments. In these experiments, observers are presented with pairs of faces, which comprise a high-quality photograph and a pixelated image. In Experiment 1, our aim is to determine how different levels of pixelation affect observers' ability to categorize these face pairs as identity matches (i.e., two photographs depicting the same person) or mismatches (depicting two different people). The pixelated faces were therefore presented at a horizontal image resolution of 20, 14 or 8 pixels per face. These levels are derived from a recent investigation into face pixelation (Demanet et al., 2007) and are

typical also of other studies in this area (Bachmann, 1991; Costen et al., 1994, 1996; Lander et al., 2001). Moreover, these pixelation levels fall within (20 horizontal pixels/face), closely match (14 horizontal pixels/face), or fall outside (8 horizontal pixels/face) the range of spatial frequencies needed for the successful recognition of familiarized faces (see Bachmann, 1991; Costen et al., 1994, 1996).

Experiment 1

In Experiment 1, the effect of pixelation was assessed in a matching task in which observers were shown pairs of unfamiliar faces comprising either two different photographs of the same person or of two different people. Performance in this task was compared across four conditions. In the “original” condition, each pair consisted of high-resolution photographs of two faces, which were shown in the same frontal view. This condition is derived directly from previous studies in this field and provides a baseline for best-possible performance (see, e.g., Bindemann, Avetisyan, & Rakow, 2012; Burton et al., 2010; Megreya, Bindemann, & Harvard, 2011). In the three remaining conditions, observers were presented with pairs of faces comprising a high-resolution photograph and a pixelated image. Three levels of pixelation were applied, corresponding to a horizontal image resolution of 20, 14 or 8 pixels per face. The initial aim here was to assess the extent to which these levels of pixelation impair observers’ face matching accuracy compared to the baseline.

Method

Participants

Twenty undergraduate students (17 female, 3 male) from the University of Kent volunteered to participate in this experiment. The participants had a mean age of 20.9 years (range = 18 to 27) and all reported normal or corrected-to-normal vision.

Stimuli and Procedure

The stimuli consisted of 160 face pairs from the Glasgow Face Matching Test (see Burton et al., 2010). Half of these pairs depicted identity matches, in which two different photographs of the same person were shown, while the other half depicted identity mismatches, in which two different people were depicted. In addition, these pairs were split evenly to depict male or female faces. The faces were all shown in grayscale, with a neutral expression, and in a frontal view. In addition, all extraneous background was removed but the face outline and hairstyle were shown intact. The resulting face images measured maximally 350 pixels in width at a resolution of 72 ppi. In each pair, these faces were positioned in such a way that the horizontal distance between the centre of each face measured 500 pixels.

In each match and mismatch display, one face image was taken with a high-quality digital camera, while the other was a still frame of a person's face from high-quality video footage. For identity matches, these pictures were only taken a few minutes apart and under the same lighting conditions. The resulting match pairs therefore provide similar but not identical images of a person to ensure that the task cannot be done using simple pictorial matching (see, e.g., Bruce, 1982).

To produce the pixelation conditions, four versions were created of each face pair. These corresponded to the original, high-resolution face pairs and three versions in which one of the faces in a pair (the image taken from video) was pixelated. Three levels of pixelation were applied corresponding to a horizontal resolution of 20,

14, or 8 pixels per face. The faces were pixelated with the Mosaic function in Adobe Photoshop software (Version 10.0.1). This function transforms images into sub-sampled blocks of uniform luminance by converting a pixel within a given square area into a weighted average of itself and its surrounding pixels. Thus, the pixels of the original face images were replaced with a smaller number of larger pixels. For this experiment, this manipulation was applied by measuring the width across the widest point of each face, and by converting the face then according to this dimension into a new image with a horizontal resolution of 20, 14 or 8 pixels per face. This resulted in a total of 640 experimental displays, comprising 80 match and 80 mismatch trials in the original, and 20, 14, and 8 pixel resolution condition. Example stimuli for these conditions are shown in Figure 2.

Note that all faces were equated in terms of their width, but varied in height according to their natural aspect ratios. As a consequence, the vertical resolution of the pixelated faces differed from the horizontal resolution and also varied slightly across identities. For example, for the stimuli provided in Figure 2, the vertical resolution of the pixelated faces equates to 29, 20, and 11 pixels per face for the 20, 14, and 8 pixel conditions, respectively. We have chosen to manipulate the resolution of the faces in this manner for consistency with other studies in this field (e.g., Demanet et al., 2007; Lander et al., 2001).

In the experiment, each trial began with the presentation of a central fixation cross for 1 second, followed by stimulus display, which was removed from view when a response was registered. Participants were informed of the different experimental conditions in advance. They were asked to classify all face pairs as identity matches or mismatches as accurately as possible, by pressing one of two keys on a standard computer keyboard. Each participant was shown 80 match and 80 mismatch pairs,

consisting of 20 match and 20 mismatch trials for each of the four display conditions (original, 20, 14, 8 pixel resolution). The stimulus set was rotated around conditions, so that each face pair was only shown once to each participant in any of the conditions. However, over the course of the experiment the presentation of face pairs was counterbalanced across participants, so that each stimulus appeared in each condition an equal number of times. The presentation of the conditions was randomly intermixed throughout the task and participants were given short breaks every 40 trials.

Results

The mean percentage accuracy for match and mismatch trials, and the combined performance for these display types, was analysed across the four experimental conditions. This data is illustrated in Figure 3 and shows that accuracy was at 90% and 85% for the original match and mismatch displays. In contrast to this condition, performance declined sharply with pixelation. For match trials and overall accuracy, a graded pattern was found, whereby accuracy decreased with spatial resolution. For mismatch trials, performance also appeared substantially reduced in the pixelated face condition, but was more similar across different pixelation levels.

To analyse these observations formally, a one-factor within-subjects ANOVA was conducted first on the overall data, which showed a main of pixelation, $F(3,57) = 83.88$, $p < 0.001$. Tukey HSD test showed that this reflects higher accuracy for the original stimulus displays than the 20, 14, and 8 pixel conditions, all $qs \geq 15.20$, $ps \leq 0.001$. In addition, accuracy was also higher for the 20 pixel than the 8 pixel condition, $q = 5.15$, $p < 0.01$, while performance with a 14 pixel resolution fell in-between these conditions and did not differ from either, both $qs \leq 2.73$.

To analyse performance separately for match and mismatch trials, a 2 (match, mismatch) x 4 (original, 20, 14, 8 pixel resolution) within-subjects ANOVA was conducted next. This showed no main effect of trial type, $F(1,19) = 0.17, p = 0.69$, but the main effect of pixelation, $F(3,57) = 83.88, p < 0.001$, and an interaction between both factors was found, $F(3,57) = 4.10, p = 0.01$. Analysis of simple main effects found no effect of trial type for each of the experimental conditions, all $F_s(1,19) \leq 1.87, p_s \geq 0.19$, but a simple main effect of pixelation was found for match trials, $F(3,57) = 67.63, p = 0.001$, and mismatch trials, $F(3,57) = 26.33, p = 0.001$. For match trials, Tukey HSD test showed that accuracy was higher in the original condition than all pixelation conditions, all $q_s \geq 11.15, p_s \leq 0.001$. In addition, accuracy was also improved in the 20 and 14 pixel conditions compared to faces with an 8 pixel resolution, both $q_s \geq 4.78, p_s \leq 0.01$, while the 20 and 14 pixel conditions did not differ, $q = 3.41$. For mismatch trials, accuracy was also higher in the original condition than for all pixelation conditions, all $q_s \geq 9.44, p_s \leq 0.001$, but the pixelated face conditions did not differ from each other, all $q_s \leq 1.36$.

In an additional step of the analysis, we sought to determine whether performance in the experimental conditions differed from the chance level for a binary decision task (i.e., 50%). For this purpose, a series of uncorrected one-sample t-tests was conducted to compare overall, match, and mismatch accuracy with chance. For the overall accuracy data and for mismatch trials, performance in all experimental conditions was above this level, all $t_s(19) \geq 3.18, p_s \leq 0.01$ and all $t_s(19) \geq 2.84, p_s \leq 0.05$, respectively. For match trials, only accuracy in the original and 20 pixel condition exceeded chance, both $t_s(19) \geq 2.92, p_s \leq 0.01$, whereas performance in the 14 and 8 pixel conditions did not, both $t_s(19) \leq 1.66, p_s \geq 0.11$.

Discussion

This experiment examined how different levels of pixelation affect face-matching accuracy. For the original high-resolution displays, accuracy was at 90% for match and 85% mismatch displays. This level of performance is comparable to the normative data for this face set (Burton et al., 2010) and converges with other recent investigations (e.g., Bindemann et al., 2012; Özbek & Bindemann, 2011). By contrast, performance declined sharply in the pixelated conditions. For match trials, a graded response pattern was found whereby accuracy was better for the original displays than all pixelated conditions, but was reliably better still in the 20 pixel condition than with a horizontal resolution of 8 pixels per face. For mismatch trials, performance was also reduced substantially by pixelation but appeared more evenly matched across the different image resolutions. These effects were also substantial in numerical terms. For example, match accuracy decreased from 90% in the original condition to only 66% in the 20 pixel condition, and performance was at a chance, at 48%, for match trials in the 8 pixel condition. And mismatch accuracy also decreased from 85% to close to chance, at around 60%, in all pixelation conditions.

These findings demonstrate that image pixelation exerts a strong effect on unfamiliar face matching, by reducing identification accuracy dramatically. Pixelation also appears to affect unfamiliar face matching more severely than the recognition of familiarized or famous faces. With familiarized faces, for example, recognition accuracy is best with a spatial resolution of at least 16 pixels per face but then decreases abruptly with a lower resolution (Bachmann, 1991; Costen et al., 1994, 1996). If similar limits apply to unfamiliar face matching, then Experiment 1 should have shown a sharp drop in accuracy between the 20 and 14 pixel conditions. By contrast, the biggest numerical difference, of 20% to 25%, was observed between the high-resolution images and the 20 pixel condition. In addition, Lander, Bruce, and Hill (2001) found that approximately

50% of famous face photographs with a resolution of only 10 pixels/face could still be identified. It is difficult to provide a measure of chance for such naming tasks (though this could reasonably be set at 0%), but this level of performance clearly reflects a considerable number of correct identifications. By contrast, the 8 pixel condition here reduced matching accuracy to close to chance for a binary decision task (i.e., 50% for match versus mismatch decisions).

Experiment 1 therefore indicates that unfamiliar face matching is affected substantially by the low resolution that pixelated images provide. A question emerging from this finding is whether this extremely low level of identification accuracy can be enhanced in some way. The recognition of pixelated faces can be improved by image blurring, which serves to reduce the visual noise that is introduced by blocking (Harmon & Julesz, 1973; Morrone, Burr, & Ross, 1983). A similar effect can be achieved by viewing images from distance or by reducing their size. Considering that faces in surveillance footage are often captured from a distance and appear very small, this raises the question of whether matching accuracy can be improved by reducing face size. This is examined in Experiment 2.

Experiment 2

In this experiment, face size was reduced in an attempt to improve matching accuracy. For this purpose, only the 20 pixel condition was retained from Experiment 1, as this showed a clear reduction in matching accuracy compared to the original displays but also yielded the best overall performance of all pixelation conditions. This intermediate level of performance therefore provides scope for improvement in matching accuracy with a reduction in image size, but also allows for the possibility that performance might decline. In Experiment 2, three new conditions were created from

these 20 pixel displays, by reducing the faces in each stimulus pair to a 1/2, 1/4, or 1/8 of their original size to create a medium, small and very small image condition. A visual inspection of the resulting stimuli suggests that the impact of pixelation on these faces is reduced (see Figure 4). Here we wish to examine if this can improve face matching or whether these small image formats only serve to reduce accuracy further.

Method

Participants

Twenty undergraduate students (11 female, 9 male) from the University of Kent volunteered to participate in this experiment. The participants had a mean age of 20.9 years (range = 18 to 38) and all reported normal or corrected-to-normal vision. None had participated in Experiment 1.

Stimuli and Procedure

The stimuli and procedure were identical to Experiment 1, except for the following changes. Only the 20 pixel displays were retained for this experiment. These consisted of 80 match and 80 mismatch stimuli, which were shown in the same size as in Experiment 1 in the “large” image conditions. To produce further size conditions, three more versions were created of each match and mismatch display. In these displays, the faces were systematically reduced to 1/2, 1/4, or 1/8 of their original size to create a “medium”, “small” and “very small” condition. Applying this image transformation to all 20 pixel face pairs resulted in a total of 640 experimental displays, comprising 80 match and 80 mismatch stimuli in each of the four conditions. Examples of these stimuli are provided in Figure 4. In all other respects, the design and procedure were identical to those of Experiment 1.

Results

The mean percentage accuracy for the experimental conditions is illustrated in Figure 5. This data shows that overall performance improved as the size of the faces was reduced, except for the small and very small image conditions, for which accuracy appeared to be more comparable. A one-factor within-subjects ANOVA of this data confirms these observations with a main effect of pixelation, $F(3,57) = 14.46, p < 0.001$. Tukey HSD test shows that this reflects higher accuracy for the small and very small faces than for the medium, both $qs \geq 4.51, ps \leq 0.05$, and large face displays, both $qs \geq 7.05, ps \leq 0.001$. Finally, performance for the small and very small faces, $q = 1.03$, and, equally, for the medium and large faces did not differ, $q = 2.52$.

A similar pattern emerges when match and mismatch trials are considered separately. For example, both types of face pair show that accuracy is improved with small and very small faces compared to the medium and large conditions. Accordingly, a 2 (match, mismatch) $\times 4$ (large, medium, small, very small) within-subjects ANOVA revealed only the same main effect of image size as the overall data, $F(3,57) = 14.46, p < 0.001$, whereas a main effect of trial type, $F(1,19) = 2.62, p = 0.12$, or an interaction between trial type and size was not found, $F(3,57) = 1.75, p = 0.17$.

As in Experiment 1, we also sought to determine whether performance in the experimental conditions differed from chance. A series of uncorrected one-sample t -tests showed that overall accuracy, all $ts(19) \geq 7.52, ps \leq 0.001$, match accuracy, all $ts(19) \geq 2.39, ps \leq 0.05$, and mismatch accuracy, all $ts(19) \geq 4.07, ps \leq 0.01$, was above chance in all conditions.

Discussion

This experiment replicates the poor matching performance of the 20 pixel condition that was first observed in Experiment 1. The current experiment extends these findings in an important way, by showing that the effect of pixelation can be reversed partially by reducing image size. A reduction of 75%, to present the faces at only 1/4 of their original size, appeared to be most effective for increasing accuracy. This led to an improvement of 13% on match and 12% on mismatch trials compared to the large face condition. However, a further reduction in image size, to just 1/8 of the original face dimensions, did not improve performance further. These results therefore show that the detrimental effect of pixelation can be offset to some extent by reducing image size.

Experiment 3

The identification of unfamiliar faces appears to be strongly dependent on image similarity, whereby performance declines when face photographs differ in, for example, lighting, age, or facial expression (for reviews, see, e.g., Hancock, Bruce, & Burton, 2000; Johnston & Edmonds, 2009). In Experiment 2, the high-resolution and the pixelated faces were therefore always adjusted in size together, to equalize these stimuli according to this dimension. However, it has also been shown that person identification from CCTV is best when a small, poor-resolution image of a face is compared to a large high-resolution photograph (Liu et al., 2003). While this work utilized footage from analogue CCTV, this finding raises the possibility that matching accuracy can be improved further in the current experiments when small pixelated faces are compared with large high-resolution images. To explore this possibility systematically, Experiment 3 compared face matching across four conditions. Each of these conditions combined a high-resolution image with a pixelated face. In contrast to Experiment 2, these faces

were either presented at their original size, or both faces in a pair were presented at 1/4 of their original size, or only the high-resolution image or the pixelated face was reduced in size by this margin.

Method

Participants

Twenty undergraduate students (13 female, 7 male) from the University of Kent volunteered to participate in this experiment. The participants had a mean age of 20.4 years (range = 18 to 28) and all reported normal or corrected-to-normal vision. None had participated in the preceding experiments.

Stimuli and Procedure

Face-matching accuracy was measured again across four conditions. In these, a high-resolution face was always combined with a face with a horizontal resolution of 20 pixels in the stimulus displays. The size of these images was varied systematically across displays, so that both faces in a pair were either presented in their original dimensions (i.e., measuring 350 pixels in width at a resolution of 72 ppi), or one of these faces, or both, were displayed at 1/4 of this size. The experimental conditions therefore involved combining a large high-resolution face and a large pixelated face (in the ORIGINAL-PIXELATED condition), combining a large high-resolution face with a small pixelated face (in the ORIGINAL-pixelated condition), combining a small high-resolution face with a large pixelated face (in the original-PIXELATED condition), and combining two small faces in a stimulus display (in the original-pixelated condition). Applying these manipulations to the 20 pixel stimuli from Experiment 1 resulted in a total of 640 experimental displays, comprising 80 match and 80 mismatch displays for each of the

four conditions. Example stimuli for these conditions are shown in Figure 6. In all other respects, the design and procedure were identical to those of the preceding experiments.

Results

The mean percentage accuracy for the experimental conditions is provided in Figure 7. An inspection of the overall accuracy data shows that performance was best for the small pixelated faces, regardless of the size of the high-resolution images. The observations were confirmed by a 2 (size of high-resolution face) x 2 (size of pixelated face) within-subjects ANOVA, which found no main effect of size for the high-resolution face, $F(1,19) = 0.59, p = 0.45$, or an interaction between both factors, $F(1,19) = 0.82, p = 0.38$, but showed a main effect of size for the pixelated face, $F(1,19) = 7.57, p < 0.05$. This reflects higher overall accuracy for small (70.0%) than large pixelated faces (64.4%).

To analyse performance for match and mismatch trials, a 2 (trial type) x 2 (size of high-resolution face) x 2 (size of pixelated face) within-subjects ANOVA was conducted next, which revealed a three-way interaction, $F(1,19) = 14.79, p < 0.01$. To interpret this interaction, performance for match and mismatch trials was analysed separately. For match trials, a 2 (size of high-resolution face) x 2 (size of pixelated face) ANOVA found no main effect of size for the high resolution face, $F(1,19) = 0.58, p = 0.46$, or the pixelated face, $F(1,19) = 1.13, p = 0.30$, but an interaction between these factors, $F(1,19) = 10.57, p < 0.01$. Analysis of simple main effects showed that large pixelated faces were matched more accurately to small than to large high-resolution faces, $F(1,19) = 4.61, p < 0.05$, but small pixelated faces were matched more accurately to large than to small high-resolution faces, $F(1,19) = 10.38, p < 0.01$. By contrast, there was no difference in the accuracy with which small and large pixelated faces were matched to

the small high-resolution images, $F(1,19) = 0.87, p = 0.36$, but small pixelated faces were matched more accurately than large pixelated faces to large high-resolution images, $F(1,19) = 5.92, p < 0.05$. Overall, the highest accuracy for match displays is therefore achieved when small pixelated faces are matched to their large high-resolution counterparts.

For mismatch trials, a main effect of size for the high-resolution face was not found, $F(1,19) = 3.32, p = 0.08$, but ANOVA showed a main effect of size for the pixelated face, $F(1,19) = 8.82, p < 0.01$, and an interaction between these factors, $F(1,19) = 7.96, p < 0.05$. Analysis of simple main effects showed that mismatch accuracy was comparable when small and large high-resolution faces were compared with large pixelated faces, $F(1,19) = 0.51, p = 0.49$, and when small and large pixelated faces were compared with large high-resolution faces, $F(1,19) = 0.30, p = 0.59$. By contrast, mismatch accuracy improved when small pixelated faces were compared with small rather than large high-resolution faces, $F(1,19) = 10.80, p < 0.01$, and, likewise, when small high-resolution faces were compared with small rather than large pixelated faces, $F(1,19) = 13.31, p < 0.01$. Overall, this analysis therefore indicates that mismatch identification is best when small pixelated faces are compared to small high-resolution images.

Finally, we again sought to determine whether performance in the experimental conditions differed from chance. A series of uncorrected one-sample t-tests showed that overall accuracy, all $ts(19) \geq 7.23, ps \leq 0.001$, and mismatch accuracy, all $ts(19) \geq 4.82, ps \leq 0.001$, was above chance in all conditions. For match trials, on the other hand, performance for all conditions was reliably above chance, all $ts(19) \geq 3.08, ps \leq 0.01$, except when two large faces were paired in ORIGINAL-PIXELATED displays, $t(19) = 1.83, p = 0.08$.

Discussion

Experiment 2 showed that the matching of pixelated to high-resolution faces can be improved when both types of images are reduced in size. This experiment examined whether performance can be enhanced further still by varying the size of these image types selectively. The results show that overall accuracy was best for small pixelated faces regardless of the size of the to-be-compared high-resolution image. However, a breakdown of the data by match and mismatch trials reveals different response patterns. For match trials, the best accuracy was achieved when small pixelated faces had to be matched to large high-resolution faces. For mismatch trials, on the other hand, identification was best when both the pixelated and the high-resolution face were presented at a small size. Experiment 3 therefore suggests that it would be beneficial to compare small pixelated faces with high-resolution faces of different sizes for making either accurate match or mismatch decisions.

These results are consistent with a previous investigation, which shows that a comparison of low-resolution CCTV images to large, high-quality face photographs leads to more accurate match decisions than when small face photographs are used (Liu et al., 2003). However, for mismatch decisions the results were more variable in previous work, by producing a small numerical advantage when low-resolution CCTV footage was compared to small face photographs in one experiment, but not in two other studies. Despite these discrepancies, the findings of Experiment 3 clearly converge with Experiment 2, by showing that face matching improves when the size of pixelated faces is reduced.

Experiment 4

The preceding experiments show that the identification of unfamiliar faces in a matching task decreases under image pixelation. However, these experiments still provide a highly optimized scenario for assessing matching accuracy as both faces in a pair were always shown in frontal view. In comparisons of CCTV images with photographs of potential suspects, the surveillance footage may not always yield pictures of faces in such a frontal view. As a small additional aim, we therefore sought to contrast the matching of high-resolution and pixelated faces across a change in view. Studies of recognition memory for familiarized faces have shown consistently that person identification declines across different views (e.g., Bruce, 1982; Hill, Schyns, & Akamatsu, 1997; Longmore, Liu, & Young, 2008; O'Toole, Edelman, & Bülthoff, 1998). This effect has been attributed to view-dependence, whereby sufficient visual information for the recognition of a face from, say, a profile view cannot be extracted from a previously seen frontal image. Consequently, one would expect accuracy to decline also when observers are asked to match a frontal to a profile face, compared to two frontal views. The question of main interest here is whether such a change in view affects face matching independently of, or interacts with, pixelation.

Method

Participants

Twenty undergraduate students (13 female, 7 male) from the University of Kent, with a mean age of 21.7 years (range = 19 to 30), volunteered to participate in this experiment. All reported normal or corrected-to-normal vision and none had participated in the preceding experiments.

Stimuli and Procedure

This experiment compared match and mismatch performance across four conditions. In these conditions, all faces were presented at full size (i.e., 350 pixels in width at a resolution of 72 ppi), but observers were either asked to match two frontal faces or a frontal to a profile view. In addition, in these face pairs a frontal face could be presented either in high-resolution or at a horizontal resolution of 20 pixels per face. Crossing these factors yielded four conditions, which involved combining two high-resolution frontal faces (in the frontal-original condition), or a high-resolution frontal and a profile face (the profile-original condition), or observers were shown a pixelated frontal face alongside a high-resolution frontal face (the frontal-pixelated condition) or alongside a high-resolution profile face (the profile-pixelated condition). As in the preceding experiments, this design resulted in a total of 640 experimental displays, comprising 80 match and 80 mismatch displays for each of the four conditions. Example stimuli for these conditions are shown in Figure 8. In all other respects, the design and procedure remained identical to the preceding experiments.

Results

The mean percentage accuracy for the experimental conditions is illustrated in Figure 9. An inspection of the overall accuracy data shows that performance was best when two high-resolution faces in a frontal view were combined in a pair, and decreased when observers were either asked to match a high-resolution to a pixelated face, and or when they had to compare frontal to profile views. These observations were confirmed by a 2 (face view) x 2 (image resolution) within-subjects ANOVA, which found a main effect of view, $F(1,19) = 12.01, p < 0.01$. This shows that matching accuracy was best when observers compared two frontal faces than a frontal with a profile view. In addition, a main effect of image resolution was also found, $F(1,19) =$

99.18, $p < 0.001$, which reflects a decrease in matching accuracy in the pixelated face conditions. The interaction between these factors was not significant, $F(1,19) = 0.06$, $p = 0.82$.

To analyse performance for match and mismatch trials, a 2 (trial type) x 2 (face view) x 2 (image resolution) within-subjects ANOVA was also conducted. This ANOVA shows the same main effects of view, $F(1,19) = 12.01$, $p < 0.01$, and image resolution, $F(1,19) = 99.18$, $p < 0.001$, as the overall data. In addition, an interaction of trial type and view was also found, $F(1,19) = 10.27$, $p < 0.01$. Analysis of simple main effects shows that mismatch detection was generally better when the frontal views were compared with frontal rather than profile faces, $F(1,19) = 21.80$, $p < 0.001$. None of the other simple main effects were significant, all $F_s(1,19) \leq 0.91$, $p_s \geq 0.35$. The main effect of trial type, $F(1,19) = 0.01$, $p = 0.94$, the remaining two-way interactions, both $F_s(1,19) \leq 3.15$, $p_s \geq 0.09$, and the three-way interaction also did not reach significance, $F(1,19) = 1.61$, $p = 0.22$.

Finally, a series of uncorrected one-sample t-tests showed that overall accuracy, all $t_s(19) \geq 3.79$, $p_s \leq 0.001$, and mismatch accuracy, all $t_s(19) \geq 2.48$, $p_s \leq 0.05$, was above chance in all experimental conditions. For match trials, performance for the high-resolution conditions was above chance, both $t_s(19) \geq 9.29$, $p_s \leq 0.001$, but not for the pixelated displays, both $t_s(19) \leq 1.66$, $p \geq 0.11$.

Discussion

This experiment compared the effect of pixelation on face matching accuracy across two faces in the same view or across different views. In line with the preceding experiments, performance was best when two high-resolution frontal views were presented and declined when the resolution of one of these faces was reduced. In

addition, performance declined also when observers were asked to match a frontal to a profile view. However, the effects of view and pixelation did not interact but produced independent and additive effects on face-matching accuracy. Although this finding is limited to the current conditions, it indicates that pixelation produces separable effects from other factors that might affect face-matching accuracy.

General Discussion

The effect of image pixelation has been investigated repeatedly with famous and familiarized faces in recognition paradigms, but this is the first study to examine this manipulation with unfamiliar faces in a matching task. In Experiment 1, observers were presented with pairs of faces that consisted either of two high-resolution photographs, or a high-resolution photograph and a pixelated image. In the original high-resolution condition, accuracy was at 85-90% for match and mismatch displays, but performance declined sharply with pixelation. On match trials, for example, performance decreased to only 66% with a horizontal resolution of 20 pixels per face, and was at only 48% correct in the 8 pixel condition. Similarly mismatch accuracy decreased to around 60% in all pixelated conditions.

Compared to previous studies with familiar faces, these data indicate that the threshold at which pixelated unfamiliar faces can be identified appears to be much lower. For familiarized faces, for example, recognition accuracy is best with a horizontal image resolution of at least 16 pixels per face and decreases abruptly with a lower resolution (Bachmann, 1991; Costen et al., 1994, 1996). If similar limits apply to unfamiliar face matching, then Experiment 1 should have shown a sharp drop in accuracy between the 20 and 14 pixel conditions. By contrast, the biggest numerical difference, of around 20-25%, was observed between the high-resolution images and

the 20 pixel condition. Lander, Bruce, and Hill (2001) found also that around 50% of famous face photographs with a resolution of only 10 pixels per face could still be identified, which reflects a considerable number of correct identifications in a naming task. By contrast, the 8 pixel condition here reduced accuracy to close-to-chance, despite the fact that the matching paradigm allows for an immediate side-by-side comparison of two faces. These findings therefore reiterate that face matching is difficult (e.g., Bindemann, Avetisyan, & Rakow, 2012; Burton et al., 2010; Megreya & Burton, 2006) and demonstrate that this task becomes even more error-prone when a high-resolution face has to be matched to a pixelated image. Moreover, the current results indicate that extrapolating previous findings with familiar faces to unfamiliar face matching would lead to overly optimistic expectations of observers' ability to perform this task.

We liken our task to scenarios in which images of a perpetrator from CCTV might be compared with good-quality face photographs of potential suspects (see, e.g., Costigan, 2007; Davies & Thasen, 2000; Lee et al., 2009). Our data suggests that this task is highly error-prone when observers have to match a good-quality photograph to a pixelated image, and the degree of pixelation directly determines the likelihood that a correct identification can be made. Importantly, however, we also found that performance can be recovered at least partially by reducing the size of the to-be-matched faces. In Experiment 2, a reduction to 1/4 of the original face sizes led to a 12-13% improvement in accuracy for the 20 pixel condition. This is a substantial margin considering, for example, the difference in overall performance between the 20 pixel and the original face condition in Experiment 1, at 64% and 87% accuracy. It is particularly relevant that the manipulation of size can produce such an improvement as faces in surveillance footage are often captured from distance and, consequently, appear

very small. Perhaps counter to intuition, it should therefore be more beneficial to retain faces in small dimensions, or to reduce the size of a pixelated face even further, when such images are extracted for the purpose of person identification from CCTV.

In Experiment 3, we also investigated whether matching performance could be improved further by varying the size of the high-resolution and the pixelated faces independently. In this experiment, overall accuracy was best for small pixelated faces, regardless of the size of the high-resolution image. However, accuracy for match trials was best when small pixelated faces were compared with large high-resolution images, while mismatch accuracy was best when both the pixelated and the high-resolution face were presented at a small size. It is not clear why these size effects diverge for match and mismatch decisions, but differential patterns for these trial types have now been documented in many studies (see, e.g., Bindemann, Avetisyan, & Blackwell, 2010; Bruce, Burton & Dench, 1994; Lewis & Johnston, 1997; Megreya & Burton, 2006, 2007; Vokey & Read, 1992). Irrespective of a suitable explanation for these effects, the results of Experiment 3 remain important practically, by suggesting that small pixelated faces should be paired with high-resolution faces of different sizes to facilitate either accurate match or mismatch decisions.

Finally, whereas Experiments 1 to 3 examined matching only with photographs of frontal faces, CCTV may not provide footage of a perpetrator in this particular view. Experiment 4 therefore compared the matching of two frontal faces or a frontal and a profile face, to determine whether such a change in view interacts with the effect of image pixelation. The impact of changes in view on face recognition has been well documented (e.g., Bruce et al., 1999; Hill et al., 1997; O'Toole et al., 1998). Bruce (1982), for example, obtained recognition rates of 90% for familiarized faces across the same view, but this declined to only 72% across different views. Experiment 4 showed a

similar pattern for unfamiliar faces in the matching task. However, compared to recognition memory paradigms, this effect appears to be more modest in face matching, as overall performance dropped by just 7%. Moreover, the effect of pixelation appeared to be much greater than that of view (see Figure 9). Considering that a change in view is generally held to be one of the most damaging manipulations for recognition memory of faces (see, e.g., Johnston & Edmonds, 2009), the fact that pixelation exerts a greater effect here emphasizes the detrimental influence of this factor on person identification.

In summary, this study suggest that pixelation impairs unfamiliar face matching substantially, and much more so than the recognition of familiar faces. However, it is possible to reverse these effects to some extent by reducing the size of pixelated faces and by varying the size of a high-resolution comparison image. Moreover, pixelation may affect matching accuracy independently of, and more profoundly than, other factors, such as changes in face view. We believe that these findings are relevant to person identification from CCTV, which can require the matching of surveillance footage of a perpetrator to photographs of possible suspects. Our study indicates that this task poses considerable difficulty when pixelated footage is used. It is noteworthy that this problem might not be remedied by the development of higher-resolution digital cameras: The degree of image pixelation is a function of a target's distance from a surveillance camera, so any developments to increase the image resolution of CCTV will certainly reduce the pixelation of a face at a given distance. However, faces that are located further away may also come into view with improved resolution. These faces will appear pixelated still, according to their increased distance from a CCTV camera. The problem of image pixelation might therefore remain despite increasingly more sophisticated recording equipment. However, our study also shows that the identification of pixelated faces can be improved with some simple manipulations, such

as variation in image size. We hope that these findings will provide impetus for further research in this field.

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FIGURE 1. A CCTV image of a face, recorded at a viewing distance of approximately five meters. The face appears “blocked” or pixelated.



FIGURE 2. Example stimuli from Experiment 1, depicting an identity match in the original (top left), 20 pixel (top right), 14 pixel (bottom left), and 8 pixel (bottom right) conditions.

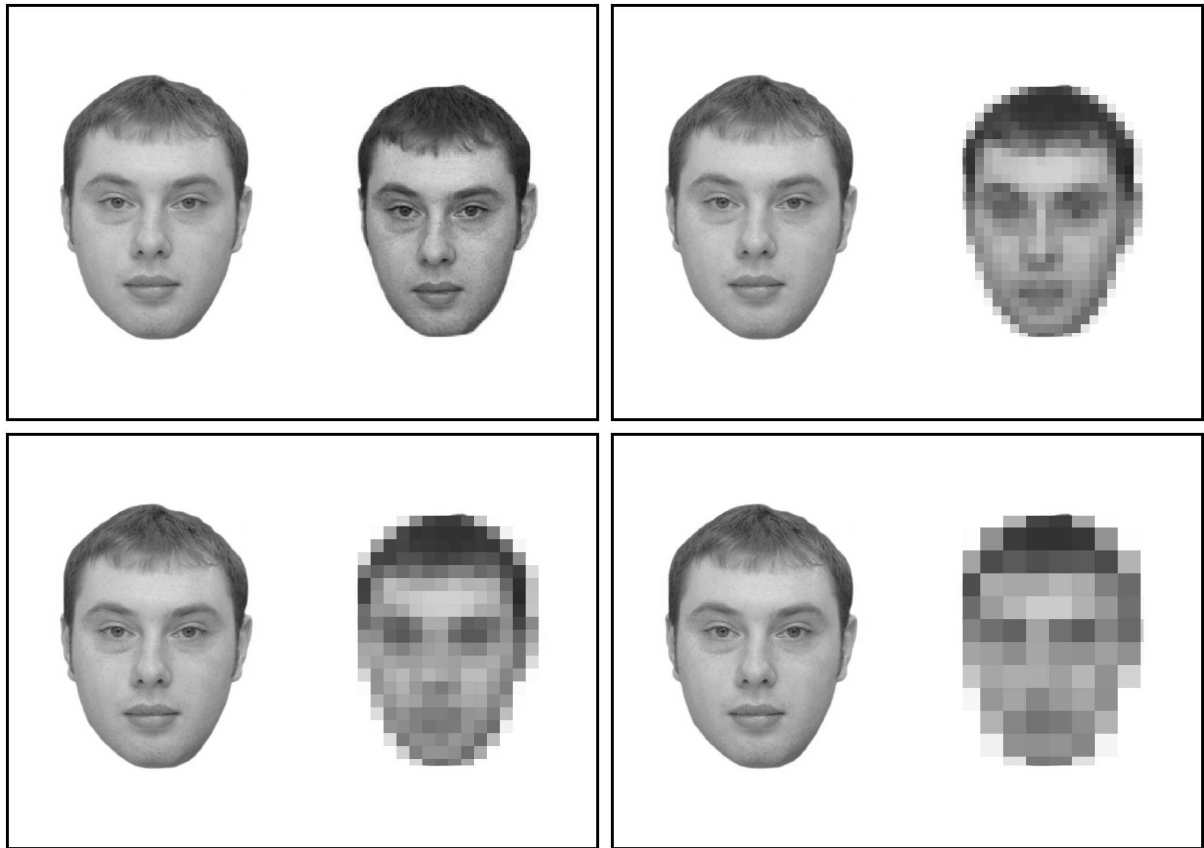


FIGURE 3. Percentage accuracy for match and mismatch trials, and overall accuracy, for the experimental conditions in Experiment 1.

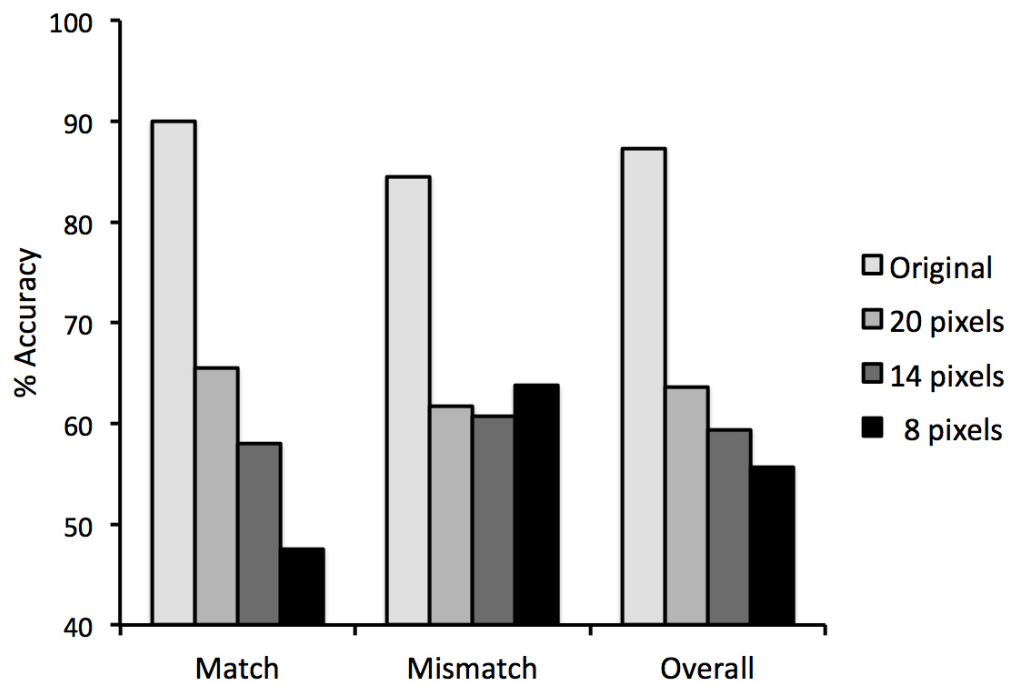


FIGURE 4. Example stimuli from Experiment 2, depicting an identity mismatch in the large (top left), medium (top right), small (bottom left), and very small (bottom right) size conditions.

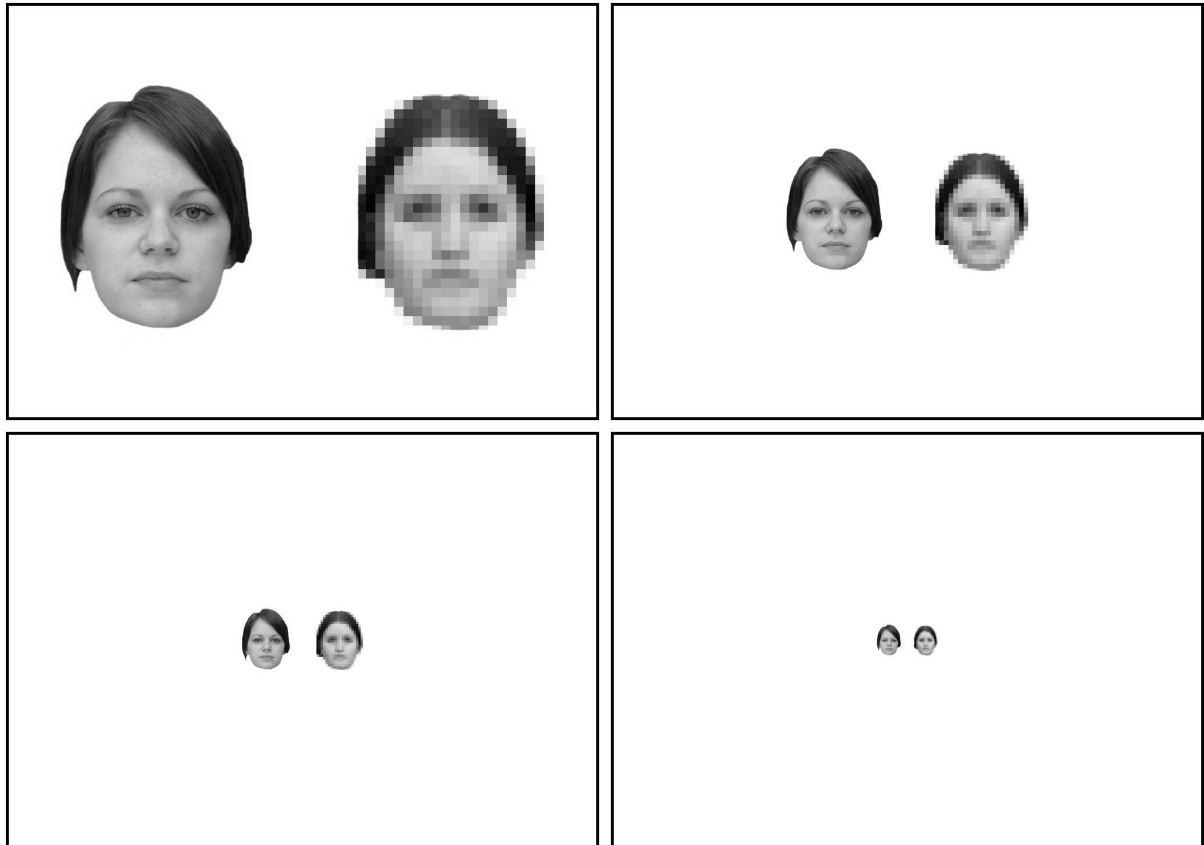


FIGURE 5. Percentage accuracy for match and mismatch trials, and overall accuracy, for the experimental conditions in Experiment 2.

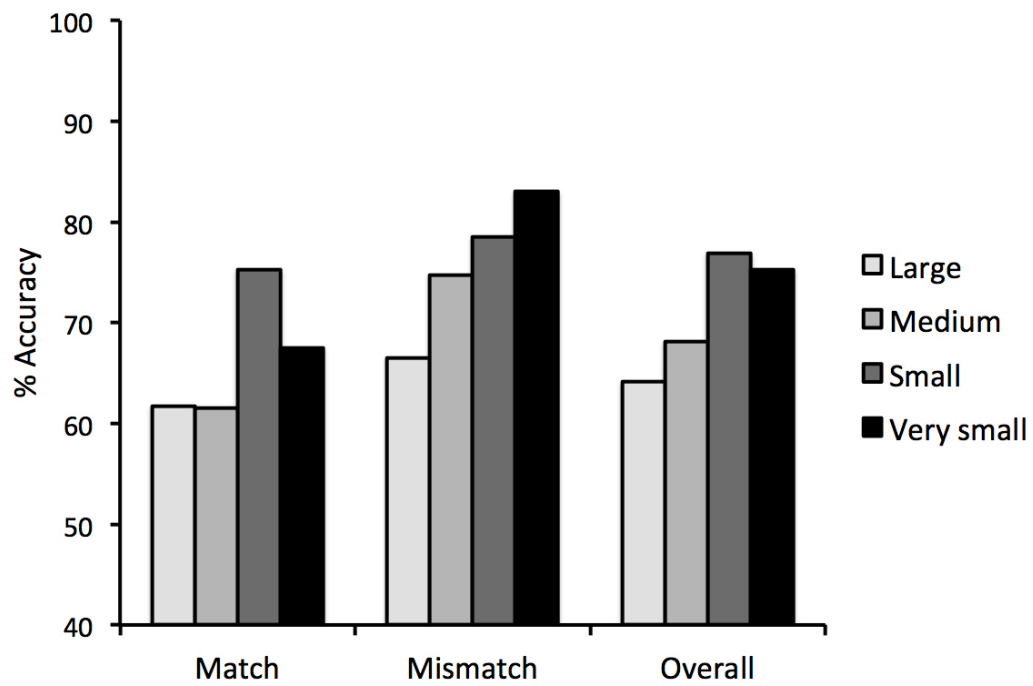


FIGURE 6. Example stimuli from Experiment 3, depicting an identity match in the ORIGINAL-PIXELATED (top left), ORIGINAL-pixelated (top right), original-PIXELATED (bottom left), and original-pixelated (bottom right) size conditions.

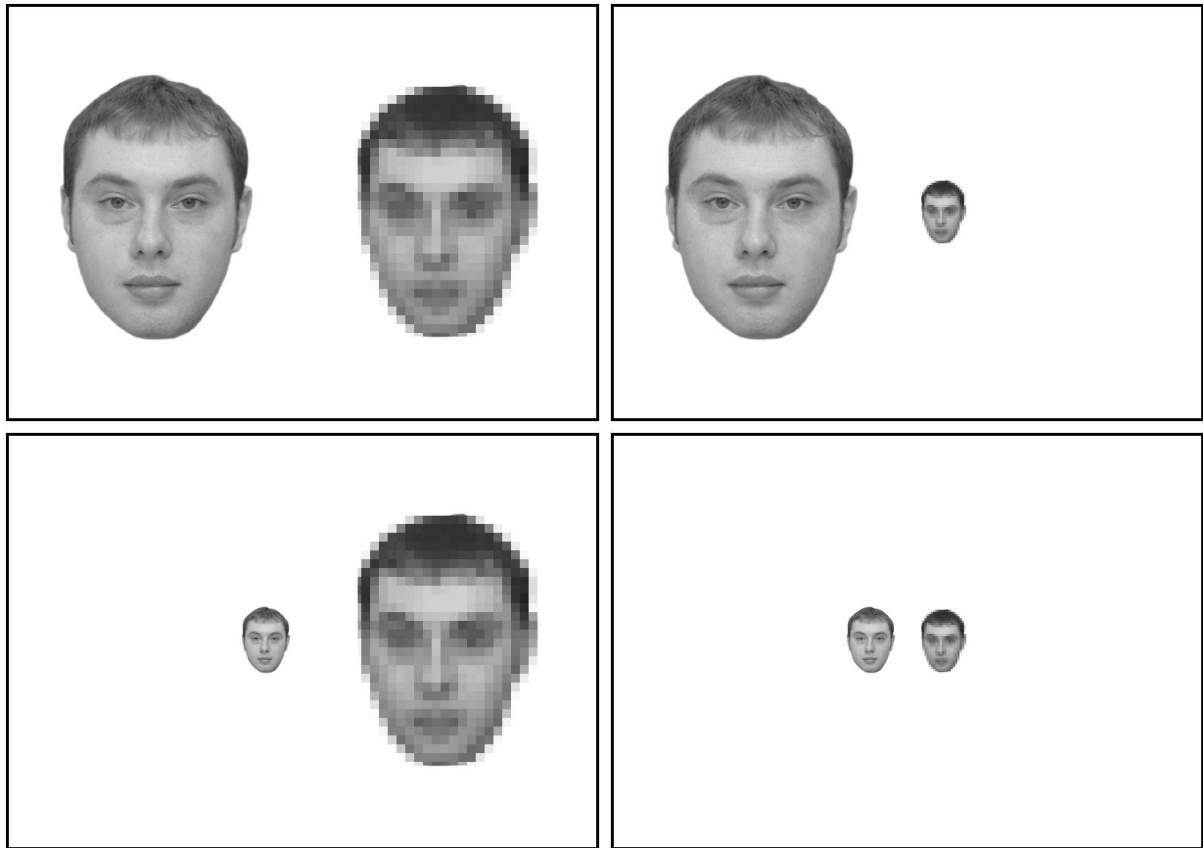


FIGURE 7. Percentage accuracy for match and mismatch trials, and overall accuracy, for the experimental conditions in Experiment 3.

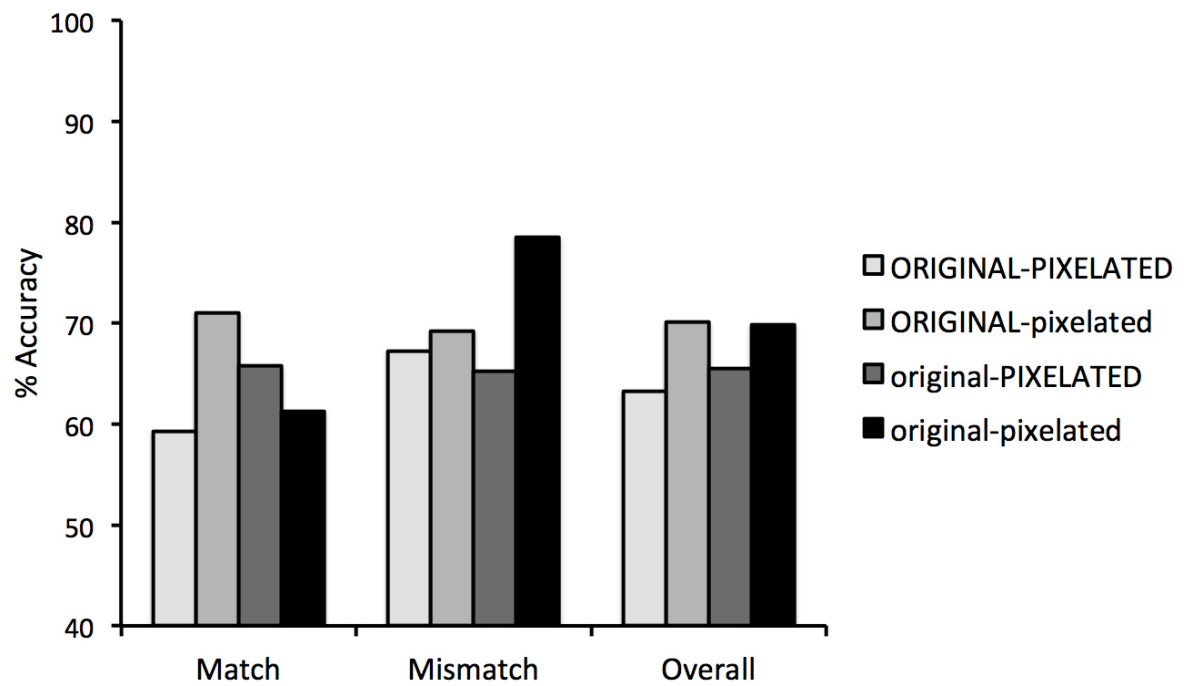


FIGURE 8. Example stimuli from Experiment 4, depicting an identity mismatch in the frontal-original (top left), frontal-pixelated (top right), profile-original (bottom left), and profile-pixelated (bottom right) conditions.

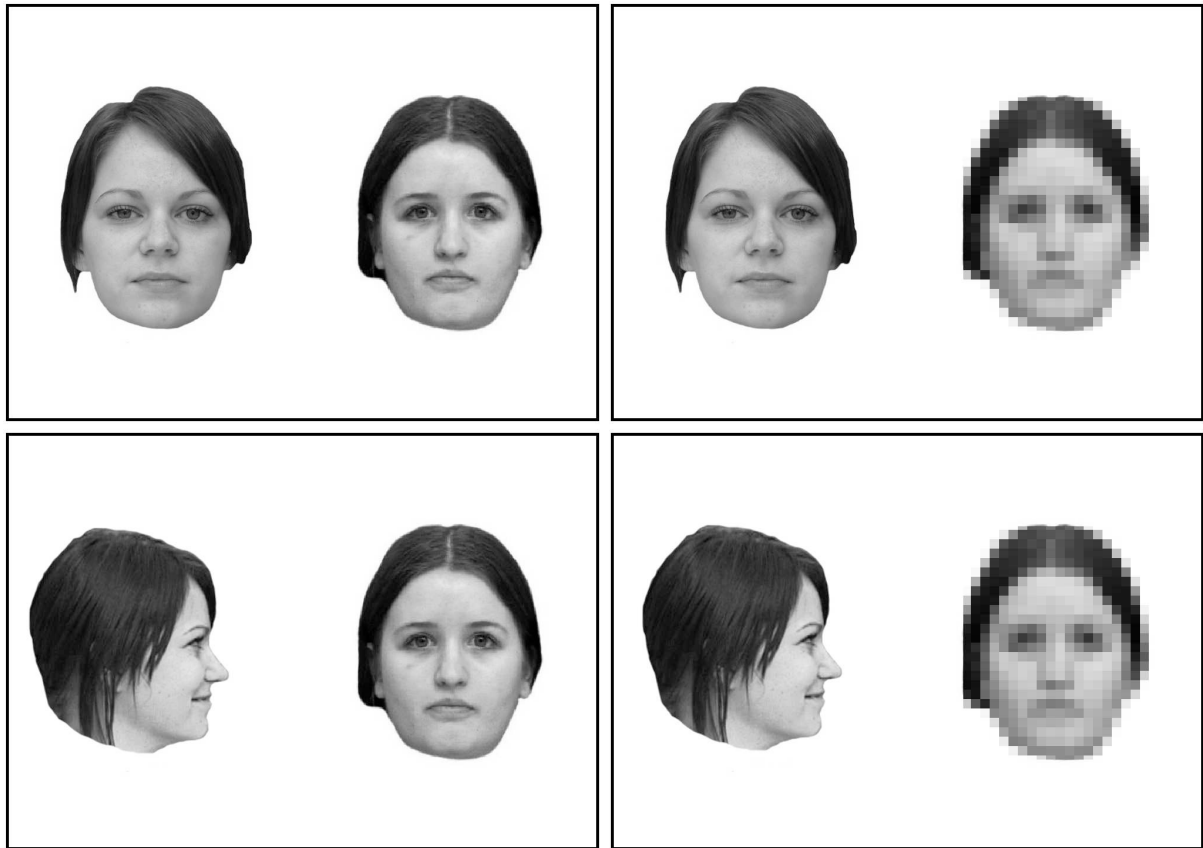


FIGURE 9. Percentage accuracy for match and mismatch trials, and overall accuracy, for the experimental conditions in Experiment 4.

