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Research report

The role of skin texture and facial shape in representations of age and identity

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ABSTRACT

Faces have both shape and skin texture, but the relative importance of the two in face representations is unclear. Our goals were first, to determine the contribution of shape versus texture to aftereffects for facial age and identity and second, to assess whether adaptation transferred between shape and texture, suggesting integration in a single representation. In our first experiment we examined age aftereffects. We obtained young and old images of two celebrities and created hybrid images, one combining the structure of the old face with the skin texture of the young face, the other combining the young structure with the old skin texture. This allowed us to create adaptation contrasts where the two adapting faces had the same facial structure but different skin texture, and vice versa. In the second experiment, we performed a similar study but this time examining identity aftereffects between two people of a similar age. We found that both skin texture and facial shape generated significant age aftereffects, but the contribution was greater from texture than from shape. Both texture and shape also generated significant identity aftereffects, but the contribution was greater from shape than from texture. In the last experiment, we used the normal and hybrid images to determine if adaptation to one property (i.e., texture) could create aftereffects in the perception of age in the other property (i.e., shape). While there was significant within-component adaptation for texture and shape, there was no evidence of cross-component adaptation. We conclude that shape and texture contribute differently to different face representations, with texture dominating for age. The lack of cross-component adaptation transfer suggests independent encoding of shape and texture, at least for age representations.

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Humans can deduce a large variety of information from faces, including properties such as identity, gender, ethnicity, age, emotional state, and attractiveness. How these are represented in the visual system is important for our understanding of face processing. One interesting question regarding face representations is whether different aspects of the face contribute differently to different perceptual judgements. For example, in the older literature a substantial body of work focused on determining which facial regions were more important for recognizing identity (Shepherd et al., 1981). More

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recently the 'Bubbles' technique has shown that which facial regions are critical depends on the type of judgement demanded, differing between identity and expression and even between different expressions (Gosselin and Schyns, 2001; Schyns et al., 2002; Smith et al., 2005). These regional differences may also be reflected in ocular fixation patterns, which are skewed to the eye region and upper face during identity judgements (Barton et al., 2006), but shifted to the lower face for certain facial expressions (Malcolm et al., 2008).

Beyond regional variations, other work has compared the roles of the shape of the face versus its surface properties. This has been facilitated particularly by the use of laser-scanning of heads to generate separate maps of three-dimensional shape versus surface reflectance (Vetter and Troje, 1997). Reflectance, sometimes referred to as pigmentation (Russell et al., 2006; Bruce and Langton, 1994), is most explicitly defined as the "complete light transfer function of a surface" (Russell and Sinha, 2007b), which includes properties like albedo, the fraction of light of all wavelengths reflected by the surface; hue, the differential reflectance of different wavelengths; texture, the spatial variation in light reflection across the surface; as well as specularity and translucence, more complex functions of how light is scattered by the surface (Russell and Sinha, 2007b; Russell et al., 2006). Several studies have used facial stimuli made from these maps to vary shape or reflectance independently, and have found that both shape and reflectance can support judgements of facial identity (Bruce and Langton, 1994; Vuong et al., 2005; Russell et al., 2006; Caharel et al., 2009; Jiang et al., 2006; Russell and Sinha, 2007b; Russell et al., 2007a; Jiang et al., 2009).

As with the data on regional variation, findings regarding the role of reflectance and shape in identifying faces cannot be assumed to hold for other types of face perception. Nevertheless, there are reasonable *a priori* grounds for believing that reflectance and shape may both contain diagnostic clues for certain properties. The age of a face may be a particularly good candidate. Ageing imparts many changes to the face in both shape and reflectance. Bony remodelling is obvious during the transition from childhood to adulthood, but also continues throughout adult life (Behrents, 1985a), with increasing cardioidal strain causing a vertical raising of features, increased facial width, reduced maxillary height, and a more protuberant jaw (Bartlett et al., 1992; O'Toole et al., 1997b). These bony changes to shape are augmented by soft tissue changes: softening of cartilage causes the nose and ears to lengthen, decreased facial muscle tone leads to jowls, and reduced fatty tissue causes features to appear more angular. The eyes appear smaller and the eyebrows coarsen or thin. Beyond these changes to facial shape and features, there are also alterations to skin texture, with loss of elasticity causing coarsening and wrinkling (Behrents, 1985b; Berry and McArthur, 1986; O'Toole et al., 1997b), prominent cues to age that drive the profitable industry of cosmetic use of botulinum toxin.

Even if age and identity representations both incorporate information from both shape and reflectance, it is not necessarily the case that the proportional contribution of these two facial cues is the same for both facial judgements. However, few have studied the balance between shape and reflectance in face perception. For identity processing the existing results are mixed. One group suggested equal proficiency of subjects with the use of shape versus reflectance (Caharel et al., 2009), another reported better recognition of familiar faces from reflectance than from shape (Russell and Sinha, 2007b), which was also supported by a study using a principle components analysis of images (Calder et al., 2001), while others found similar (Russell et al., 2007a) or greater (Jiang et al., 2009) face inversion effects –a putative marker of face expert mechanisms – for shape than for reflectance. For age estimations, there is a suggestion that colour may play a greater role than shape, but only for certain age ranges (Burt and Perrett, 1995); otherwise, nothing is known. Nevertheless, if the relative importance of shape versus reflectance is found to vary with the facial property being decoded, this would indicate significant flexibility in the way the brain assembles or uses face representations, presumably in the service of optimizing the accuracy of different perceptual judgements.

In this report, our chief goal was to determine the proportional role of shape and skin texture in facial representations of age and identity. We focused on the component of skin texture rather than all of facial reflectance because reflectance also captures some feature properties, such as those of the mouth, eyes and eyebrows, which could also be seen as contributing to perception of local feature geometry, which we wished to keep distinct from the properties of the skin surface (Kwon and de Vitoria Lobo, 1999). To measure the relative balance between facial shape (including local features) and skin texture information in face representations, we turned to a relatively new behavioural technique: face adaptation. Adaptation has proved to be a useful probe of the nature of face representations, with aftereffects shown for many facial properties, including identity (Leopold et al., 2001; Fox et al., 2008), expression (Fox and Barton, 2007; Vida and Mondloch, 2009), gender (Oruc et al., 2011), ethnicity (Webster et al., 2004) and most recently age (Lai et al., 2010; Schweinberger et al., 2010). Our strategy was to use hybrid faces, much as has been done in the work on reflectance, to determine the magnitude of aftereffects that could be generated when skin texture alone varied between adapting stimuli, and when facial shape alone varied. We examined this first for age aftereffects, and second for identity aftereffects. Our hypothesis was that the proportion of total adaptation accounted for by skin texture would be greater for age than for identity representations. Finally we performed a third experiment to determine whether adaptation to one aspect (e.g., facial shape) generated aftereffects in the second (e.g., skin texture). If so, this would indicate that adaptation to texture and shape was occurring at a level where they were integrated in a common representation.

1. Experiment 1

1.1. Methods

1.1.1. Subjects

14 subjects participated, 11 of whom were right-handed and 7 of whom were male, with a mean age of 22 years (range 18–31). For this and the following experiments, protocols were approved by the institutional review boards of Vancouver General Hospital and the University of British Columbia, and all subjects gave informed consent in accordance with the declaration of Helsinki.

1.1.2. *Stimuli*

We selected from the Internet photographs of Deborah Harry and Henry Winkler, a young and an old image that were closely matched in facial expression and viewpoint, so that variations in these properties would not inadvertently confound age judgements in our measures of age adaptation. Celebrities were chosen not because of any desired familiarity effects, but because they are more likely than anonymous faces to have a wealth of available images of comparable high quality that span a significant range of years, and that stand a chance of having similar poses. Using Adobe Photoshop CS 8.0 (www.adobe.com), we converted all images to greyscale, adjusted them to match for mean contrast and mean brightness. All of the faces were cropped to eliminate the background, but the external contours of the lateral and lower face were retained. These images were then set against a homogenous white background. We placed the images of the same person in separate layers of the same document and moved and sized them so that the inter-pupillary distance of all images of the same person was identical and superimposed: this ensured that the two faces were the same size and occupied the same spatial position in the display.

For our adapting stimuli, we generated four different images for each of the two celebrities. Two were the unaltered original young face ('*young texture/young shape*') and original old face ('*old texture/old shape*'). Two were hybrid faces, with either '*young texture/old shape*' or the '*old texture/young shape*' (Fig. 1A). In other studies, a variety of techniques have been used to create hybrids. These include three-dimensional methods such as the proprietary techniques of FaceGen Modeler (Russell et al., 2006) or the use of laser-scanning maps (Vetter and Troje, 1997; O'Toole et al., 1997a), and two-dimensional transforms that rely on composites using image blends (Burt and Perrett, 1995). Because we wished to focus on skin texture rather than facial reflectance, we used a two-dimensional transfer technique that allowed us to select regions corresponding to skin for the texture map. This involved the "Clone Stamp Tool" function in Photoshop to transfer the skin texture from one image to the other. The two images are first set to be identical in size and position as separate layers in the same Photoshop document. The clone stamp tool then allows one to specify an area to be sampled in one image for transfer as an overlay to the second image. The size of the area to be transferred and the hardness of its edge are determined by brush-tip choice, and the opacity of the overlay can be varied. By repeatedly choosing and transferring small regions selected to fit the contours of the face and its features, we carefully overlaid the texture of one face on top of another, without altering feature and external contour. The opacity was set at 100% and the hardness of the edge was kept to a minimum to avoid introducing artificial edges into the images. Use of this tool requires care, patience and judgement to ensure that texture is selected from relatively featureless regions of the face, and that featural components are not selected or their contours distorted by the process. The success of this procedure can be judged in the images in Fig. 1A.

The cropped original old and young face images were also used as the start and end images to create morphed test stimuli with Fantamorph 3.0 (www.fantamorph.com). From each pair of young and old faces of the same person, we first created a morph continuum of 41 images, each a 2.5% increment in morphing degree from the previous image. We then selected the 13 images ranging from 35% young/65% old to 65% young/35% old to be used as test stimuli (Fig. 1B).

The end result was two sets of four adapting stimuli with 13 morphed test stimuli, one for a Deborah Harry series and one for a Henry Winkler series.

1.1.3. *Procedure*

All three experiments were created and run using SuperLab 4.0 (www.cedrus.com) on a Toshiba laptop computer with a 19" screen. All subjects sat 33 cm away from the presentation screen in a darkened room.

On each trial an adapting stimulus was presented for 5 sec, followed by a mask of random black and white pixels lasting 50 msec, a blank screen for 150 msec, then a fixation cross spanning 1.41° at screen centre for 150 msec (Fig. 1C). A test stimulus then appeared for 300 msec, followed by a final choice screen, which had an old face on the left and a young face on the right. Subjects were told that they were to make a judgement about the apparent age of the test stimulus, and to indicate with a keypress whether the test stimulus most resembled the young or the old choice image. The adapting image was 483 × 516 pixels (12.5 cm × 13.5 cm, which at a viewing distance of 33 cm equals 20.7° × 22.3°) and the test images were half the size of the adapting images (242 × 258 pixels, or 10.3° × 11.1°) to minimize any contribution from low-level retinotopic aftereffects, as done in previous studies (Anderson and Wilson, 2005; Jenkins et al., 2006; Guo et al., 2009; Jeffery et al., 2006; Oruc and Barton, 2010; Zhao and Chubb, 2001). Choice images were presented at a size halfway between the adapting and test images (363 × 387 pixels).

With two different adaptation series (Harry and Winkler), each with 13 morphed test stimuli and four different adaptors, there were 104 trials, given in random order in a single block. Before the experiment, we gave subjects 5 practice trials, using stimuli created from images of Hilary Clinton, which were not used in the actual experiment.

1.1.4. *Analysis*

In each subject and for each of the four adapting conditions, we calculated the frequency of the subject's responses that were "old". We then ran two statistical analyses.

First, we averaged responses across all morph levels for each subject: this gives us a measure in which inter-subject variance determines statistical significance. To calculate the magnitude of the total aftereffect – that is, the aftereffect generated from both texture and shape combined – we subtracted the "old" response frequency for the adapting condition with *old texture/old shape* from that for the adapting condition with *young texture/young shape*. The aftereffect due to texture alone was derived from two subtractions: first, between the original image *old texture/old shape* and the hybrid adaptor *young texture/old shape*, and second, between the other hybrid adaptor *old texture/young shape*, and the original image *young texture/young shape*. In both of these subtractions, the shape is constant in the two adaptors being contrasted, and

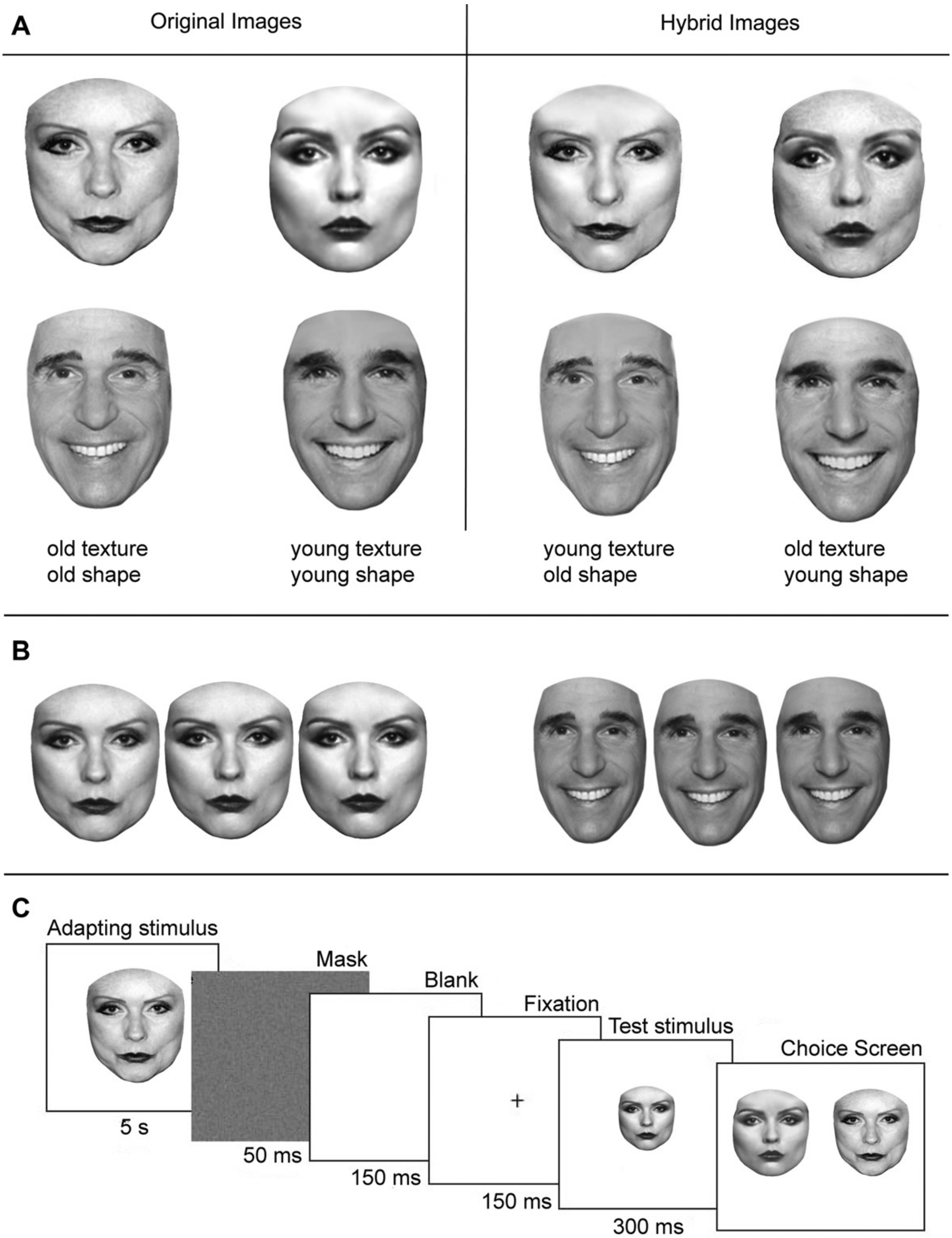

Fig. 1 – (A) Examples of adapting and choice stimuli in Experiment 1. The original young and old faces of Debbie Harry and Henry Winkler are shown on the left, the hybrid faces with texture of one age and shape from the other age of the same person are shown on the right. (B) Examples of morphed stimuli used as test images from the series morphing between old and young images of Debbie Harry (left), and of Henry Winkler (right). Each triplet shows from left to right the 65% old/35% young, the 50% old/50% young, and the 35% old/65% young morphs. (C) Example of a trial sequence. Each trial began with a 5-sec view of an adapting face, which was one of the four classes of faces shown in A. This was followed by a 50 msec mask, a 150 msec blank interval and a fixation cross shown for 150 msec, followed by a 300 msec view of a smaller test face, which was an ambiguous image, which was chosen from a morph series where only either shape or texture changed. A choice screen was presented and the observer indicated which of the two the test face had most resembled.

therefore the aftereffect generated by shape is nullified in the subtraction. The mean of these two subtractions was taken as the magnitude of the texture aftereffect. Similarly, to determine the aftereffect due to shape alone, we averaged the results of the subtractions between *old texture/old shape* and the hybrid *old texture/young shape*, and second, between the hybrid *young texture/old shape*, and *young texture/young shape*. By the nature of these subtractions, the total aftereffect equals the sum of the texture aftereffect and the shape aftereffect.

These three resulting aftereffect measures (total, texture, and shape aftereffects) were then averaged across all subjects. To determine if each condition generated a significant aftereffect, we used *t*-tests for the null hypothesis that the aftereffect was zero. We compared the shape-based and texture-based aftereffects with a paired *t*-test.

Second, we averaged responses across all subjects for each morph level, to allow us to plot the psychometric curves for response as a function of stimulus content. We fitted curves to these group mean data, using least-squares linear regression of normalized (z-transformed) frequency-of-response data (Simpson, 1995): the goodness of fit of these lines we report as regression coefficients in the figures. From these fitted curves we calculated the point of equivalence, the morph level at which subjects respond "old" 50% of the time – i.e., where they were equally likely to state that the image was young or old. The distance in morph level between the points of equivalence for the original faces can be considered a measure of total aftereffect, in that it reflects the lateral shift in the response curve induced by adapting to a young versus an old face. Points of equivalence for adapting to hybrid images lie at positions intermediate to those for the original faces. By measuring the proportion of the total aftereffect lying to the right versus left of each of the two hybrid images' points of equivalence, we can assess the relative contribution of shape and texture, which we average across the two hybrid conditions. We can also use the data to determine whether the psychometric curves in the two hybrid adapting conditions significantly differ from each other: if so, this would confirm statistically that the relative contributions of texture and shape are different. Because these data are reasonably fit by linear functions in z-transformed space, we can compare the mean slope-adjusted y-value of the linear regressions for the different curves (http://department.obg.cuhk.edu.hk/researchsupport/Compare_2_regressions.asp) (Armitage, 1971), to determine if the psychometric curves are shifted differently by adapting to one type of hybrid image versus adapting to the other.

1.1.5. *Perceptual age estimates*

Finally, we were interested in comparing our adaptation results to the estimates of age given by subjects for our stimuli. We had an independent sample of 14 subjects, 10 of whom were right-handed and 6 of whom were male, with mean age of 26 years (range 21–38), view the four different images of Harry and Winkler, namely the two original images (young and old), and the two hybrid images (*young texture/old shape* and *old texture/young shape*). These images were shown one at a time on the screen in random order and we asked the subjects to estimate the age of the person in each image. We examined the variable of perceived age using a repeated-measures analysis of variance (ANOVA), with the main factors of image (Harry, Winkler), texture (young, old), and shape (young, old), with subjects as a random effect.

1.2. *Results*

There was a large total age aftereffect (19.78%, SD 2.41, $t_{13} = 8.72$, $p < .0001$) (Fig. 2A). The contrasts between adapting conditions in which texture but not shape varied showed significant texture-based age aftereffects (15.25%, SD 1.47, $t_{13} = 10.97$, $p < .0001$). The contrasts between adapting conditions in which shape but not texture varied showed smaller but still significant shape-based age aftereffects (4.53%, SD 2.21, $t_{13} = 2.42$, $p < .031$). The difference between shape-based and texture-based aftereffects was significant ($t_{13} = 3.71$, $p < .003$). These results suggest that texture contributes about 77% (i.e., 15.25/19.78) of the total age aftereffect, with 23% (i.e., 4.53/19.78) from shape.

The analysis based on group psychophysical curves yielded similar results (Fig. 2B). The curves for the hybrid images were nearer to those for original images that shared similar texture rather than similar shape with the hybrids. In terms of proportionate deviation of the equivalent point, this suggested that 79% of age aftereffects were generated by texture and 21% by shape, highly similar results to those from the above analysis of total aftereffect magnitude. The slope-adjusted differences between the mean for the two hybrid adapting conditions were significant [$t_{(23)} = 3.11$, $p < .005$].

Regarding perceptual estimates of age (Fig. 3), the ANOVA showed that there were main effects of shape [$F_{(1,91)} = 72.5$, $p < .0001$] and texture [$F_{(1,91)} = 54.5$, $p < .0001$] and an interaction between shape and texture [$F_{(1,91)} = 6.51$, $p < .013$]: Tukey's HSD test showed that all condition differed from each other with the exception that there was no significant difference in the perception of age for the two hybrid images.

1.3. *Comment*

These results show that both skin texture and facial shape can generate age aftereffects, but that texture is the main source of age aftereffects. The age estimation data showed similarities and differences with the adaptation results. First, both hybrid images were judged to be from an age intermediate between and different from the perceived ages of the young and old original images. Thus the estimation data support the conclusion from the adaptation data that both texture and shape contribute to age perception. On the other hand, the perceptual estimates for the two hybrid images were similar to each other, and thus do not parallel the asymmetric contribution of shape and texture to age aftereffects. Given the adaptation results, one might have predicted that the *young texture/old shape* hybrid would appear younger than the *old texture/young shape* hybrid, but this was not the case. The reason for this discrepancy is unclear. It may be that subjects can weight the unequal contributions of shape and texture in age representations that are suggested by our adaptation data, to generate more equivalent explicit estimations of intermediate age from either cue. Alternatively, it may be that the age estimates given by most subjects when faced with a stimuli with intermediate or conflicting age information, as with our

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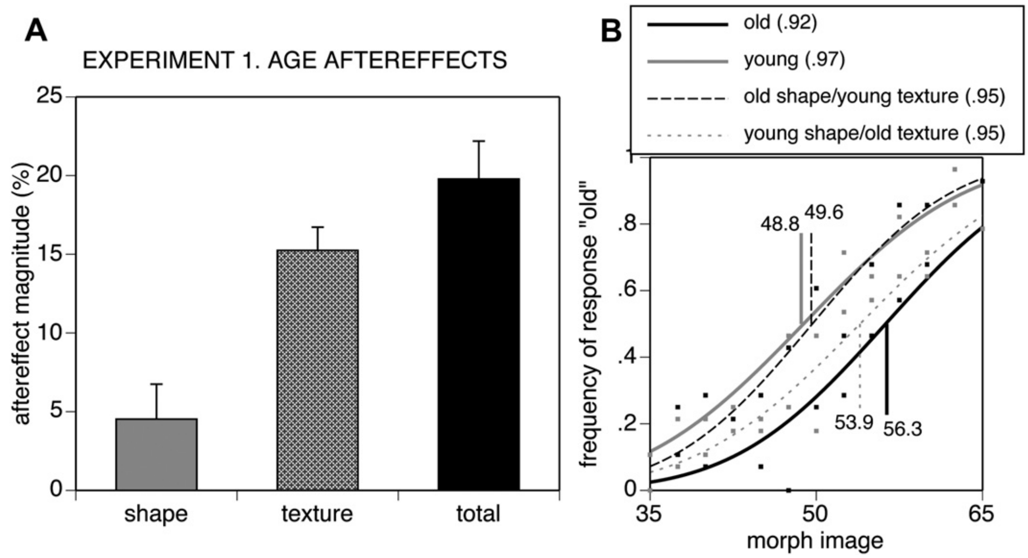

Fig. 2 – Results, Experiment 1. (A) Age aftereffect magnitude is depicted for total age aftereffect, which contrasts adaptation between the young and old original faces, which differ in both texture and shape; shape alone, in which the texture of the two contrasting adapting faces is the same; and texture alone, in which the shape of the two contrasting adapting faces is the same. Error bars indicate one standard error. (B) Psychometric curves for all four adapting conditions are plotted for the group data as a function of the morph content of the test images, where the number indicates the percent of the young image in the morph (e.g., 35 = 35% young/65% old). Vertical lines corresponding to each psychometric curve indicate the equivalence points (where the curves cross the 50% response level), which are also given as the numerical values shown. In the box legend above the plot, the regression coefficients for the fit of each of the 4 psychometric curves are given.

hybrid faces, are simply some default intermediate age value (e.g., around 50 years, Fig. 3) and therefore lack any real precision: if so, the adaptation data may more accurately reflect the relative contribution of texture and shape. Regardless, the fact that adaptation and estimation do not yield equivalent findings places limits on comparisons between our work and studies that used age estimates as a dependent variable (Burt and Perrett, 1995).

Whether textural cues are as important in judgements about other facial properties can be questioned. We next performed a similar experiment, but this time involving judgements about the identity of the face.

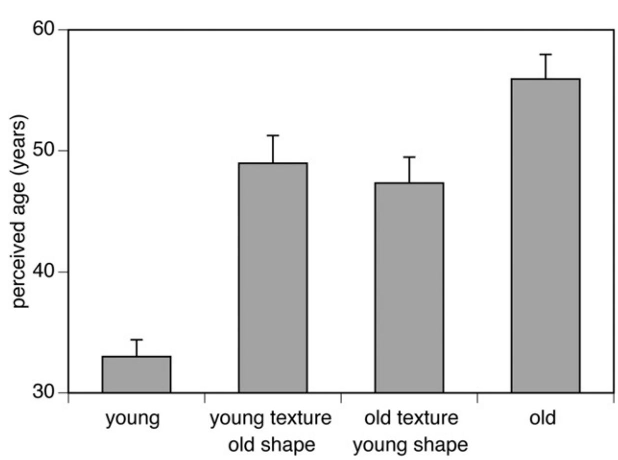

Fig. 3 – Perceptual estimates, Experiment 1. Mean age estimates given by subjects for the original and hybrid images used. Error bars indicate one standard error.

2. Experiment 2

2.1. Methods

2.1.1. Subjects

14 subjects participated, 10 of whom were right-handed and 5 of whom were male, with mean age of 29 years (range 22–53).

2.1.2. Stimuli

From the Internet we obtained young and old photos of Julie Andrews and Jane Fonda in which the facial expression and viewpoint were highly similar. Using the same method as in Experiment 1, we created adapting images for each of these two celebrities, two being the original faces (‘*Fonda texture/Fonda shape*’ and ‘*Andrews texture/Andrews shape*’), and two being hybrid faces, but now hybrid for identity not age, being either ‘*Fonda texture/Andrews shape*’ or ‘*Andrews texture/Fonda shape*’ (Fig. 4A). This was done first for the pair of young faces, and then for the pair of old faces. Likewise, since the goal of this experiment was to examine identity adaptation, we created test stimuli by morphing between the two celebrities, rather than between the two ages. Thus one series of morphed stimuli were generated from the young Julie Andrews and the young Jane Fonda, and the other series of morphed stimuli were generated between the older Julie Andrews and the older Jane Fonda.

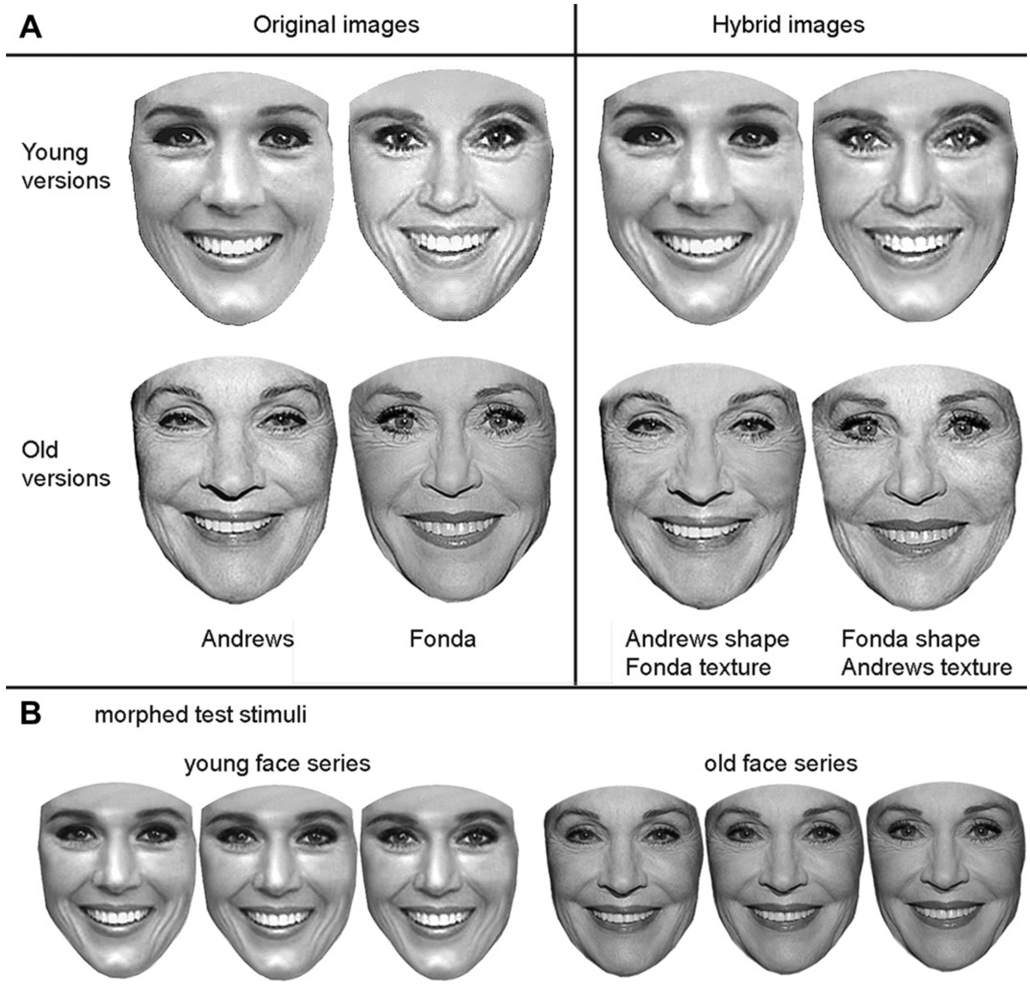

Fig. 4 – (A) Adapting and choice stimuli in Experiment 2. The original young and old faces of Julie Andrews and Jane Fonda are shown on the left, the hybrid faces with texture of one person and shape of the other at the same age are shown on the right. (B) Examples of morphed stimuli used as test images from the series morphing between images of the young Andrews and young Fonda (left), and from the series morphing between images of the old Andrews and old Fonda (right). Each triplet shows from left to right the 65% Andrews/35% Fonda, the 50% Andrews/50% Fonda, and the 35% Andrews/65% Fonda morphs.

Again, for test stimuli we used the 13 images in the range from 35% Andrews/65% Fonda to 65% Andrews/35% Fonda (Fig. 4B).

The end result was two sets of four adapting stimuli and 13 test stimuli, one for a younger-face series and one for an older-face series.

2.1.3. *Procedure*

The trial parameters were highly similar to Experiment 1. In each trial, subjects saw one of the four different adapting faces for 5 sec, followed by the mask, the blank and the fixation screen, then one of the morphed test stimuli for 300 msec, and finally a choice screen with Julie Andrews on the left and Jane Fonda on the right. Subjects were told that they were to make a judgement about which celebrity the test stimulus most resembled, and thus that they were to indicate with a keypress whether the morphed test stimulus looked more like Julie Andrews or more like Jane Fonda.

With two different adaptation series (young and old), each with 13 morphed test stimuli and four different adaptors, there were 104 trials, given in random order. Before the experiment, we gave subjects 5 practice trials, using stimuli created from images of Helen Mirren and Meryl Streep.

2.1.4. *Analysis*

In each subject and for each of the four adapting conditions, we calculated the frequency of the subject's responses that were "Andrews".

Again, first to calculate the magnitude of the total aftereffect – that is, the aftereffect generated from both texture and shape combined – we subtracted the "Andrews" response frequency for the adapting condition with *Andrews texture/Andrews shape* from that for the adapting condition with *Fonda texture/Fonda shape*. The aftereffect due to texture alone was the average of two subtractions, first between *Fonda texture/*

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Fonda shape and the hybrid adaptor *Andrews texture/Fonda shape*, and second between *Fonda texture/Andrews shape* and *Andrews texture/Andrews shape*. To determine the aftereffect due to shape alone, we average the results of the subtractions between *Fonda texture/Fonda shape* and the hybrid *Fonda texture/Andrews shape*, and between the hybrid *Andrews texture/Fonda shape* and *Andrews texture/Andrews shape*.

These three resulting aftereffect measures (total aftereffect, texture aftereffect, and shape aftereffect) were then averaged across all subjects. To determine if each condition generated a significant aftereffect, we used *t*-tests for the null hypothesis that the aftereffect was zero. We compared the shape-based and texture-based aftereffects with a paired *t*-test.

Second, we averaged responses across all subjects and across both young and old face sets for each morph level, to plot the psychophysical curves for response as a function of stimulus content. We fitted curves to these group mean data, as in Experiment 1, and calculated the point of equivalence, the morph level at which subjects respond "Andrews" 50% of the time – i.e., where they were equally likely to state that the image was Andrews or Fonda. The distance in morph level between the points of equivalence for the original faces was the total aftereffect, and we measured the proportion of the total aftereffect lying to the right versus left of each of the two hybrid image's points of equivalence, to assess the relative contribution of shape and texture to the identity aftereffect. Again we tested for the equivalence of the mean slope-adjusted *y*-value for the *z*-transformed data of the two hybrid adapting conditions, to assess for equivalence of the contributions of texture and shape.

2.2. Results

There was a large total identity aftereffect (19.23%, SD 23.66, $t_{13} = 3.04$, $p < .009$) (Fig. 5A). The contrasts between adapting conditions in which texture but not shape varied showed significant texture-based identity aftereffects (6.18%, SD 6.92, $t_{13} = 3.34$, $p < .006$). The contrasts between adapting conditions in which shape but not texture varied also showed significant shape-based identity aftereffects (13.05%, SD 19.87, $t_{13} = 2.46$, $p < .029$). These results thus suggest that texture contributes about 32% (i.e., 6.18/19.23) of the total age aftereffect, with 68% (i.e., 13.05/19.23) from shape. However, the difference between shape-based and texture-based aftereffects did not reach significance by this method of analysis ($t_{13} = 1.42$, $p < .18$).

The analysis based on group psychophysical curves showed that the curves for the hybrid images were nearer to those for original images that shared similar shape rather than similar texture with the hybrids (Fig. 5B), opposite to the results of Experiment 1, and in keeping with the analysis above based on aftereffect magnitude. In terms of proportionate deviation of the equivalent point of these curves, this suggested that 88% of these identity aftereffects were generated by shape and only 12% by texture. The slope-adjusted differences between the mean for the two hybrid adapting conditions were significant [$t_{(23)} = 2.83$, $p < .01$].

2.3. Comment

The magnitude of the total identity aftereffect in this experiment was nearly identical to the magnitude of the total age

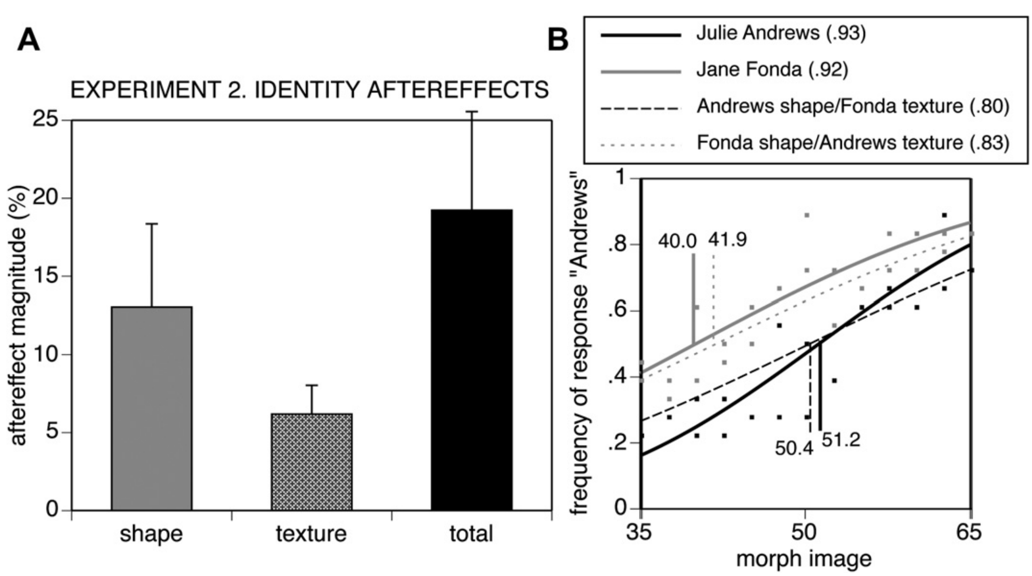

Fig. 5 – Results, Experiment 2. (A) Identity aftereffect magnitude is depicted for total identity aftereffect, which contrasts adaptation between the Fonda and Andrews original faces, which differ in both texture and shape; shape alone, in which the texture of the two contrasting adapting faces is from the same person; and texture alone, in which the shape of the two contrasting adapting faces is from the same person. Error bars indicate one standard error. (B) Psychometric curves for all four adapting conditions are plotted for the group as a function of the morph content of the images, where the number indicates the percent of the Andrews image in the morph (e.g., 35 = 35% Andrews/65% Fonda). Vertical lines corresponding to each psychometric curve indicate the equivalence points (where the curves cross the 50% response level), which are also given as the numerical values shown. In the box legend above the plot, the regression coefficients for the fit of each of the 4 psychometric curves are given.

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aftereffect in Experiment 1. Notably though, the balance between texture-based and shape-based aftereffects differed. While the majority of the total age aftereffect derived from texture in Experiment 1, Experiment 2 suggests that identify aftereffects are mostly shape-based. In the first analysis of aftereffect magnitude, the difference between shape-based and texture-based identity aftereffects did not reach significance, in part due to higher variability of identity aftereffects. However, the analysis based on psychophysical curves suggested even more strongly a greater reliance of identity adaptation on shape information, which was significant. The difference between the two analyses likely reflects the fact that identity discrimination was less accurate in this Experiment than the age discrimination in Experiment 2, as reflected in shallower slopes of the psychophysical curves in Fig. 5B compared to Fig. 2B, as well as more variability in the slopes of the curves between the four conditions.

Hence, even though both Experiments 1 and 2 suggest that both texture and shape play a role in both identity and age adaptation, the relative contributions of texture and shape differ significantly between identity and age representations, with texture playing a more dominant role for age.

While the above experiments provide evidence that both texture and shape have a role in identity and age representations, they do not clarify whether texture and shape are integrated into a common representation. In Experiment 3 we use a technique recently developed in our laboratory to study integration of different sources of perceptual information in representations – 'cross-component transfer of adaptation'. In this technique, the ability of each of two facial components (in the current case, texture and shape) to generate adaptation for itself is assessed and then compared to its ability to adapt the other component. If adaptation is occurring at a level where the component information is combined in an indivisible holistic representation of the face, then cross-component adaptation should be found and in fact should be equivalent to same-component adaptation.

3. Experiment 3

3.1. *Methods*

3.1.1. *Subjects*

12 subjects participated, 10 of whom were right-handed and 5 of whom were male, with mean age of 28 years (range 21–53).

3.1.2. *Stimuli*

We used the same adapting stimuli as in Experiment 1. The key difference in this experiment is that we generated different morphed test stimuli in which (1) only texture varied in the morph between young and old, with shape age fixed as a constant at one age extreme across all test stimuli and all choice stimuli, or in which (2) only shape varied between young and old, with texture age fixed as a constant at one age extreme. We used these in separate blocks, one to examine skin texture adaptation and one to examine facial shape adaptation.

Thus, in the block examining adaptation effects on perception of age in texture, one series had test images generated by morphing between a *young texture/young shape* face and an *old texture/young shape* hybrid face. These two 'morph endpoint' faces were also shown in the choice screen: hence, like the test stimuli, the two choices also did not differ in shape. The second test series had test images generated by morphing between a *young texture/old shape* hybrid face and an *old texture/old shape*, and these two were shown in the choice screen for this series. In both, the subject's task would be to indicate which of the two choice faces the test stimulus most resembled. Because the facial shape is a constant in all test and choice stimuli for each of the two series, adaptation effects would be due to changes in the perception of texture age alone.

Conversely, in the block examining adaptation effects on perception of age in shape, the first series had test images generated by morphing between a *young texture/young shape* face and a *young texture/old shape* face, and these two 'morph endpoint' faces were shown in the choice screen. The second test series had test images generated by morphing between an *old texture/young shape* face and an *old texture/old shape* face, and these two faces were shown in the choice screen. Because facial texture is a constant in all test and choice stimuli for each of the two series, adaptation effects would be due to changes in the perception of shape age alone.

As in Experiment 1, test images were the 13 images ranging from 35% young/65% old to 65% young/35% old.

3.1.3. *Procedure*

The sequence of adapting, test and choice displays was identical to those used in Experiments 1 and 2. There were two blocks of trials (Fig. 6). Block 1 examined adaptation effects on texture age perception, and block 2 examining adaptation effects on shape age perception. For each block, there were trials for two different celebrities (Deborah Harry and Henry Winkler): with 13 morphed test stimuli for the four different trial types shown in Fig. 6, there were 104 trials per block. Half of the subjects began with block 1 and half with block 2.

Before each block of the experiment, we gave subjects 5 practice trials, using stimuli created from images of Hilary Clinton, which were not used in the actual experimental blocks.

3.1.4. *Analysis*

As before, the frequency of choosing the "old" rather than the young image on the choice screen was the outcome measure. The key to assessing *within-component* and *cross-component* adaptation is the nature of the subtractions between different trial types, which we will explain in some detail (Fig. 6).

For *within-component* adaptation this is straightforward. By comparing two conditions in which the first component is held constant across adapting, test and choice stimuli, one can measure *within-component* adaptation for the second component by subtracting results of trials with old versus young versions of this second component, which is also probed by the morph test stimuli and depicted in the choice stimuli. For example, one way to assess *within-component* adaptation for texture is to use trials that have (i) test stimuli with morphed texture but young shapes and (ii) an answer screen with a choice between faces with young versus old texture, but both sharing young shapes (trials A and B in Fig. 6). A subtraction between trials of this type with young

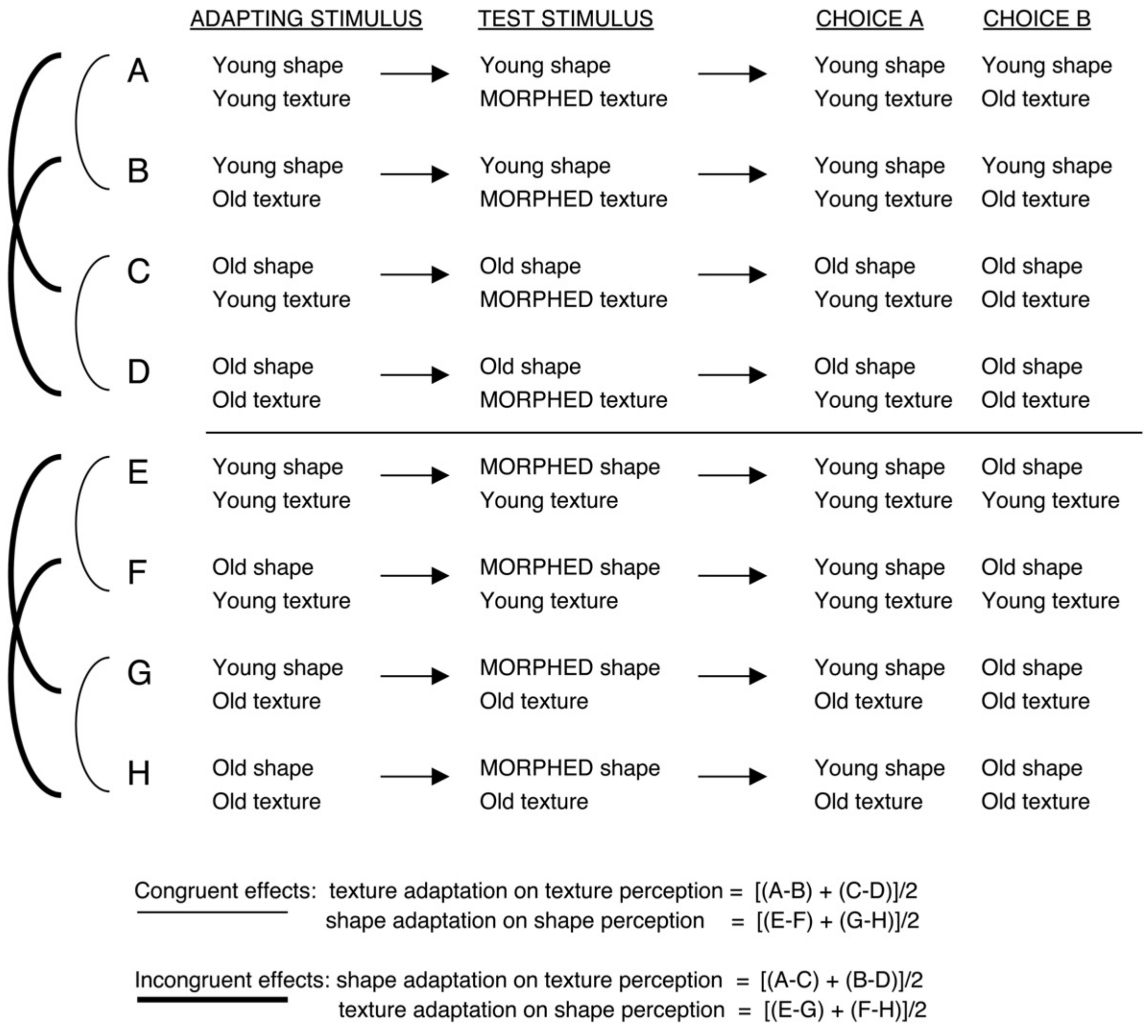

Fig. 6 – Trial types for Experiment 3. Adapting, test and choice screen stimulus properties are shown for trials A to H. Trials A to D are from block 1, in which the test stimuli are ambiguous to texture age only, to test effects on texture perception alone. Trials E to H are from block 2, in which the test stimuli are ambiguous to shape age only, to test effects on shape perception alone. Bottom shows the subtractive contrasts that yield measures of within-component and cross-component adaptation, which are also illustrated as thin curved lines (within-component contrast) and thick curved lines (cross-component contrast).

shape and young texture as adapting faces (A), and trials with young shape and old texture as adapting faces (B) will yield the effect of texture adaptation of texture perception. A similar contrast can be made for trials in which all adapting, test and choice images contain the old shape (trials C, D in Fig. 6). The average of (A − B) and (C − D) is our final measure of *within-component* adaptation for texture. Likewise, comparisons using trials with texture held constant across all stimuli in a trial and with test stimuli morphed in shape alone yields the *within-component* adaptation for shape.

Cross-component adaptation can be assessed using the same trials and the same stimuli, but with different subtractive contrasts (Fig. 6). This method thus has the advantage of controlling for the adaptive potency of the various stimuli: since they are identical for the measures of within-component and cross-component adaptation, differences between these two measures cannot be attributed to variable efficacy of the adapting stimuli. The logic here is to compare adaptation between two adapting images that differ in the age of the first component but are identical in that of the second, on test stimuli that vary in the age of the second component but are constant in that of the first, with choice screens whose two displayed options are also contrasts in the age of the first component.

We can consider the example of testing whether texture adapts shape perception. In trial A (Fig. 6), the adapting face has young shape and young texture, the test stimulus has young shape but variable texture, and the answer screen presents faces with young shape but differing in old versus young texture. In trial C, the adapting face has old shape and young texture, the test stimulus has old shape but variable texture, and the answer screen presents faces with old shape but differing in old versus young texture. In both A and C, as discussed for *within-component* adaptation, there is no adaptation effect from shape on shape perception, since the test stimulus is not ambiguous as to age from shape, and the

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answer screen does not present a choice between young and old shape. Also, the effects of texture adaptation of texture perception are cancelled by the subtraction between A and C, since the adapting images in both A and C contain young texture. Hence all that remains in the subtraction (A − C) is a contrast between old and young shape adaptation upon the perception of age in stimuli with ambiguous texture, with answer screens that differ only in the age of the textural component. The contrast (B − D) yields a similar result.

To summarize, using the trial labels in Fig. 6, for texture perception we can measure the within-component adaptation from texture as {(A − B)+(C − D)}/2 and the cross-component adaptation from shape on texture as {(A − C)+(B − D)}/2. For shape perception, the within-component adaptation from shape is {(E − F)−(G − H)}/2 and the cross-component adaptation from texture on shape is {(E − G)+(F − H)}/2. As in Experiments 2 and 3, we determined if each contrast represented a significant aftereffect by using *t*-tests for the null hypothesis that the aftereffect was zero.

Finally, as in Experiments 1 and 2, we could fit psychometric functions to the z-transformed data to derive equivalence points for all eight adapting/test conditions, and substituted these values for the mean aftereffect magnitude values in the above equations of Fig. 6, to see if this parallel analysis yielded a similar pattern of findings.

3.2. *Results*

Both of the within-component adaptation measures showed significant aftereffects (Fig. 7). Facial age-related texture adapted the perception of texture in age (mean 13.03%, SD 9.62, $t_{11} = 4.69$, $p < .0007$) and age-related shape adapted the perception of shape in age (mean 14.10%, SD 20.8, $t_{11} = 2.35$, $p < .04$). However, neither of the cross-component measures showed any significant aftereffect, either from texture to shape or from shape to texture. The analysis of the psychometric functions showed that, for within-component effects, texture generated a lateral shift of 5.50% morph level in equivalence point for texture perception, and shape a 5.51% shift in equivalence point for shape perception. However, for cross-component effects, the lateral shifts were actually slightly negative, with a shift of −3.2% from shape to texture perception and −1.4% from texture to shape perception, similar to the results for aftereffect magnitude depicted in Fig. 7.

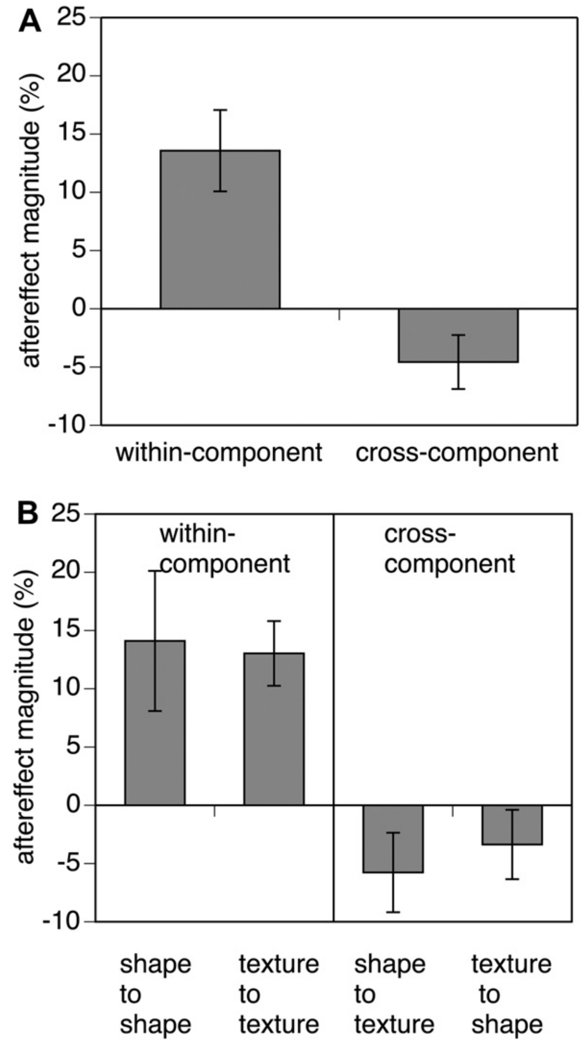

Fig. 7 – Results, Experiment 3. Aftereffect magnitude for within-component and cross-component adaptation. (A) Overall results. (B) Results shown separately for texture and shape perception. Error bars show one standard error.

4. Discussion

Our results suggest that about 78% of the facial age aftereffect in the stimuli we used was generated by skin texture, with only 22% by facial shape. In contrast, only between 12 and 32% of our face-identity aftereffect was due to skin texture, with 68–88% generated by facial shape. Hence we conclude that the visual system shows flexibility in its reliance on different facial cues for representations of different facial properties like age and identity. Our final result showed that there was no significant cross-component transfer of adaptation between skin texture and facial shape in the perception of age. While this does not necessarily imply that there is no age representation that combines both of these facial cues in a unitary percept, it does suggest at least that adaptation effects may arise at a level of age representation where they are not combined.

Previous work has established that both shape and reflectance contribute to identity processing. Studies with match-to-sample tasks or identification of recently seen faces have shown that the detrimental impact of photo-negation is found predominantly in stimuli containing reflectance information (Bruce and Langton, 1994; Vuong et al., 2005; Russell et al., 2006). Since recognition of faces is impaired by photo-negation (Galper, 1970; Galper and Hochberg, 1971), the inference is that reflectance contributes to identity recognition. Others have shown that subjects are equally proficient at discriminating faces based on differences in reflectance alone or shape alone (Caharel et al., 2009), or can learn to recognize new faces with either reflectance or shape information alone (O'Toole et al., 1999). Inverted faces are more difficult to recognize than upright faces: because this effect of orientation is greater

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than that seen with other objects, the face inversion effect is considered a marker of a face-expertise mechanism (Farah et al., 1995; Rossion, 2009). Some have shown similar inversion effects for both reflectance information and shape information (Russell et al., 2007a), though others with similar experiments assert that the inversion effect derives principally from shape information (Jiang et al., 2009). Finally, and most relevant to our work, one previous study has shown that identity adaptation can occur for both shape-only and reflectance-only images (Jiang et al., 2006).

It is not clear how much skin surface texture contributes to the role of reflectance in identity processing found in these studies, though. Inspection of reflectance maps shows that these contain significant featural information about hair, eyes and eyebrows, and even some shape-related shadows in regions with acute surface deflections like the nostrils and ears (O'Toole et al., 1997a). Also, reflectance effects may be dominated by hue, since one study found that they were significantly attenuated when greyscale images were used (Russell et al., 2007a). Indeed, a specific role for colour alone in face identity is suggested by improved recognition of famous faces when colour contrast is enhanced, the "colour caricature effect" (Lee and Perrett, 1997; Lee and Perrett, 2000). Though comparisons with greyscale stimuli indicate that colour may play only a modest part when shape information is available (Kemp et al., 1996; Lee and Perrett, 1997), colour can contribute more to recognition when shape information is degraded, as with Gaussian blur (Yip and Sinha, 2002). Hence it is possible that colour is a major determinant of effects in studies using reflectance maps of faces, which minimize shape information. By using greyscale images rather than colour images and by limiting featural shapes from our texture transfers, our study shows that the skin texture component of reflectance as well as facial shape makes contributions to identity representations.

Less is known about the role of shape and reflectance for ageing judgements. A contribution of facial shape is indicated by the finding that shape caricatures create an impression of advancing age (O'Toole et al., 1997b). A study using facial composites of old and young faces based on either shape or colour information – where the term 'colour' encompassed skin colour, hair colour, and skin wrinkles – reported that subjects could use both shape and colour to estimate facial age (Burt and Perrett, 1995). Although the manipulations are not quite comparable to our study, the results are consistent with our finding that both facial shape and skin texture contribute to age representations.

The relative proportion of shape and texture information in face representations was a main focus of our study. There are limited existing data on this point, most concerning identity processing. In one study, reaction times were equivalent for discriminating facial identity in reflectance images and shape images (Caharel et al., 2009). In another, familiar faces were recognized more accurately from reflectance images than shape images (Russell and Sinha, 2007b). Facial shape images may show equivalent (Russell et al., 2007a) or greater (Russell et al., 2007a; Jiang et al., 2009) inversion effects than reflectance images. One study found that face similarity ratings depend more on shape than reflectance (Jiang et al., 2009), but since a pixel-based analysis also found an asymmetry in the physical similarity of the images, the implications of the behavioural result are not clear. For age perception, one study found that colour changes had a greater impact than shape transformations on age estimates, but only for younger faces (Burt and Perrett, 1995).

Again, our study focused on skin texture rather than hue or overall facial reflectance, and used a paradigm that determined the proportion of the total face aftereffect that was due to skin texture and that due to facial shape. This showed that skin texture is responsible for about three-quarters of the representation of facial age, compared with one-third of the representation of facial identity. Thus skin properties like wrinkles appear to play a dominant role in age representations. Their reduced importance for face identity may stem from several factors. First, this may imply that shape differences are more important sources of variation in human face identity than skin texture. Second, face identity is to some degree age-invariant, given that individuals can be recognized even after a span of many years (Sergent and Poncet, 1990; Bahrick et al., 1975). This capability may be aided by minimizing the inclusion in identity representations of the factor that contains the dominant cues to age.

Our final experiment did not find evidence of integration of facial shape and skin texture in face representations. Studies of general texture and shape processing with functional magnetic resonance imaging (fMRI) and in visual agnosic patients suggest independent processing streams, with texture processed in the collateral sulcus and shape in the lateral occipital cortex (Cavina-Pratesi et al., 2010a, 2010b). For faces, an adaptation study with event-related potentials showed sensitivity to shape but not reflectance in the right N170 potential, an electrophysiological signature of face processing (Caharel et al., 2009), and an fMRI-adaptation study showed that the same was true of the right fusiform and occipital face areas (Jiang et al., 2009). Hence these reports provide some support for independent processing of shape and texture for faces. However, they also suggest potential substrates for integration of reflectance and shape, with adaptation to both shape and reflectance in the N250 potential (Caharel et al., 2009) and on fMRI in left-hemisphere face-sensitive areas (Jiang et al., 2009). Also, the study of texture and shape in general reported responses to both cues in the fusiform gyri (Cavina-Pratesi et al., 2010a). As a behavioural study, our work cannot speak to the anatomic basis of the effects we observed: nevertheless, a lack of cross-component transfer between shape and identity indicates a relative segregation of shape and texture in age representations. Whether this would also be true for identity representations remains to be determined.

A number of limitations should be mentioned in closing. First, given that we used a small set of faces, it is possible that the results we obtained would vary in magnitude if other identities were used. In fact, it is implausible that these effects would be uniform for all faces: some idiosyncratic faces may have particularly distinctive textural or shape properties that dominate their specific representations in an anomalous manner. Second, our greyscale images do not allow us to comment on a putative role of colour in face adaptation, which is possible given the evidence that colour can contribute to face perception under certain conditions (Russell et al., 2007a; Lee and Perrett, 1997; Lee and Perrett, 2000; Yip and Sinha, 2002). Third, because we wished to group local feature 'shapes' (whether derived from three-dimensional structure or reflectance) with overall facial shape, it may be that our shape-based adaptation effects are greater than those that would be generated from the three-dimensional shape data of laser-scanned faces, which do not include feature shapes based on reflectance (e.g., eyes, eyebrows). Nevertheless, with these reservations in mind, our results do suggest a differential contribution of skin texture and facial shape to representations of facial age and facial identity, with texture contributing more than shape to facial age, and that at least for age representations, these contributions of shape and texture are relatively independent. Given some evidence that reflectance and shape may also contribute differently to expression and gender categorizations (Calder et al., 2001; O'Toole et al., 1997a), investigations of texture and shape adaptation for other types of facial representations may be of interest in future work.

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