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Holistic Facial Composite Systems: Implementation and Evaluation

When there is no suspect for a crime, the police may ask an eyewitness to construct a facial composite of the offender from memory. Composites often provide the only possibility of solving the case. Early systems regularly produced poor suspect likenesses that were of little investigatory use. Some may have led to innocent suspect identifications. Many issues have been overcome with the recent development of systems such as the E-FIT series of holistic systems (e.g. EigenFIT, EFIT-V, EFIT6), designed to best match human face processing. In conjunction with a variety of post-construction techniques, the likelihood of correct suspect identification has been substantially improved.

Police artists were first drawing sketches of suspects from witness's descriptions in the 19th century. In the 1970's the first 'mechanical' facial composite systems were developed (Identikit, Photofit). These required witnesses to assemble facial features (printed on cards or transparencies) with police assistance. These systems often produced poor likenesses that rarely assisted police investigations (Kitson, Darnbrough, & Shields, 1978), partly a consequence of limited feature choices (Davies, 1983), and lines separating the features hindering composite recognition (Ellis, Davies, & Shepherd, 1978).

The first *computerised* feature-based systems were developed in the 1980's (e.g., E-FIT, FACES, PRO-fit). Functionality varies, with some allowing enhancement via photo editing software. High suspect-likeness composites are possible, although empirical research (Frowd, Carson, Ness *et al*., 2005), and police trials (e.g., Frowd, Hancock, Bruce *et al*., 2011) have often found that recognition rates of feature-based system composites are low, partly because these systems weakly match human face processing mechanisms (for reviews see Davies & Valentine, 2007; Frowd, 2015). These systems also require witnesses to provide a pre-construction verbal description of the suspect in order to reduce feature choice to manageable levels. However, witnesses find providing facial descriptions hard, and often, no individuating vocabulary exists. Moreover, although construction of, for instance, a feature-based E-FIT is assembled within the context of a whole face, which can enhance *feature* recognition (Tanaka & Farah, 1993; Tanaka & Sengco, 1997); effective *face* recognition is mainly driven by holistic or whole face processing, and is not feature-by-feature dependent (e.g., Davies, Ellis, & Shepherd, 1978; Tanaka & Farah, 1993).

The solution has been the development of the holistic system such as those in the EFIT series (EigenFIT, EFIT-V, EFIT6; see also EvoFIT: Frowd this volume; ID: Tredoux, Nunex, Oxtoby, & Prag, 2006), which require *recognition* and selection of *whole* face images from a series of arrays (see Davis, Maigut, Jolliffe, Gibson, & Solomon, 2015 for a video depicting EFIT-V construction). Interfaces differ (EFIT-V arrays contain nine colour images; EvoFIT - 15 in black-and-white), although with all, featural (e.g., positioning, resizing) and holistic mechanisms (e.g., ageing, healthiness) allow witness-directed enhancement of individual faces, or to all array faces. Importantly, the EFIT holistic composite systems require only a basic pre-creation suspect description (ethnicity, gender, age), assisting witnesses most likely to struggle with vocabulary (e.g., children: Davis, Thorniley, Gibson, & Solomon, 2016; see Figure 1; older adults: Davis, Maigut, Gibson, & Solomon, in preparation).

Construction of holistic EFITs tends to be quicker than those produced using the older feature-based composite systems (Davis, Gibson, & Solomon, 2014), and when guided by an experienced operator, holistic EFITs are the equal of, or better likenesses than feature-based system composites (Davis *et al*., 2014; Davis, Sulley, Solomon, & Gibson, 2010). Some are exceptional. The vast majority of UK police forces, and many worldwide now employ one of the holistic EFIT systems. Their implementation has increased suspect identification rates. Indeed, the suspect naming rates (40% - 53%) of over 1,000 EFIT-Vs constructed by West Yorkshire Police from 2008-2011 exceeded previous feature-based system statistics (Solomon, Gibson, & Maylin, 2012).

Figure 1: Previously unpublished holistic EFIT composite (EFIT-V) (right) produced from memory of the actor (left) by a child aged seven-years (see Davis, Thorniley et al., 2016).

Technical Description of Holistic Facial Composite Systems

Holistic composite systems typically rely upon a principal components analysis (PCA) model, affording a compact representation of human facial appearance from which new examples of face images can be generated. Although, with the exception of sufferers of *prosopagnosia* (face blindness), humans are adept at differentiating faces, even though faces are statistically remarkably similar in appearance, specifically with respect to the hue of skin colour, shape of facial features, and the spatial relationships between features. This high degree of similarity, or correlation, allows the majority of the facial variance, associated with the training set, to be represented by a relatively small number of principal components. [1] The first description of encoding faces using PCA was presented by Sirovich and Kirby (1986), whereas Turk and Pentland (1991) introduced the term *eigenfaces* when referring to principal components generated from face images. Subsequent work in this area included pre-processing face images by warping them to the mean face shape. This non-rigid alignment process improves facial feature registration, thereby reducing image blurring. These shape normalised images have been called *texture maps* (Edwards, Taylor, & Cootes, 1998).

In the remainder of this section we provide an overview of the mechanisms by which faces can be generated and optimised to produce a likeness of a suspect in holistic composite systems (for detailed descriptions see, Gibson, Solomon, & Bejarano, 2003; Solomon, Gibson, & Mist, 2013). An appearance model, capable of synthesising realistic faces, is constructed from a training set of images that are firstly annotated with land mark points to delineate the facial features. The position coordinates of the land marks are recorded in a shape vector. The principal components of a training set of all such vectors (i.e. for all training examples) are then calculated and these model the variation in face shape contained within the training set. To represent the variation in texture, the training images are first warped to the mean face shape. PCA on these shape-normalised images yields principal components that model the variations in skin tone and shading.

[1] Compared with the number of training images and far less than the number of image pixels.

Correlations between shape and texture also exist (also exploited in shape from shading work in computer vision), and therefore shape and texture models can be combined with an additional, third, principal component analysis. We refer to the resulting principal components as appearance components since they simultaneously model both shape and texture. Appearance components form the 'building blocks' from which previously unseen facial images can be approximated. This is achieved by firstly weighting and then adding each of the appearance components, and then working 'backwards' to obtain the corresponding shape and texture. Finally, the textures are warped to the desired shape (see Figure 2 for a schematic representation).

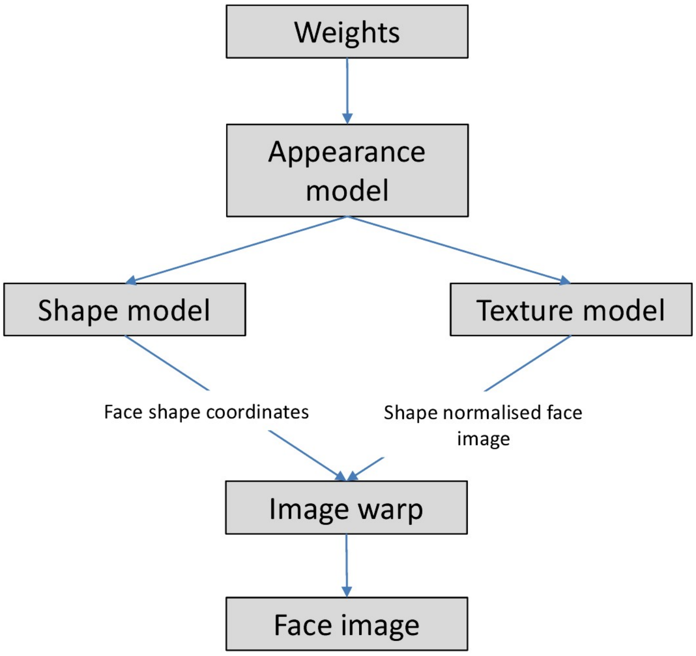

Figure 2: Generating a face image from an appearance model. The appearance, and hence the identity, is determined by the weights. Separation of shape and texture improves feature alignment and hence reduces blurring.

Given that the appearance model has been constructed from a comprehensive sample of faces, representing the demographic from which a suspect originates, a pictorial representation of the suspect's face can be obtained by choosing optimal weights for each of the appearance components. Since the correct weights are not known in advance, these are determined through an iterative optimisation process in which the witness assesses the similarity between faces generated from the appearance model and their memory of the suspect's face. Evolutionary algorithms allow iterative optimisation of weights. In contrast to feature-based composite construction, in which individual features are chosen from databases, here a whole face image is refined (i.e. 'evolved') at each iterative step. Weights are initialised using pseudo-random number generation, possibly with the addition of constraints based on the preliminary description of the suspect provided by the witness. This includes, for example, the gender, ethnicity and approximate age of the suspect. In the holistic EFIT systems, at each step in the process the witness is presented with an array of nine faces from which they simply select the face that is closest in appearance to the suspect. The weights corresponding to the selected face are then varied randomly to produce a new nine face array, with the intention that one or more face(s) in the set will be an improved likeness. The witness then selects a face from the new set and the process is repeated until an acceptable likeness has been attained (see Figure 3).

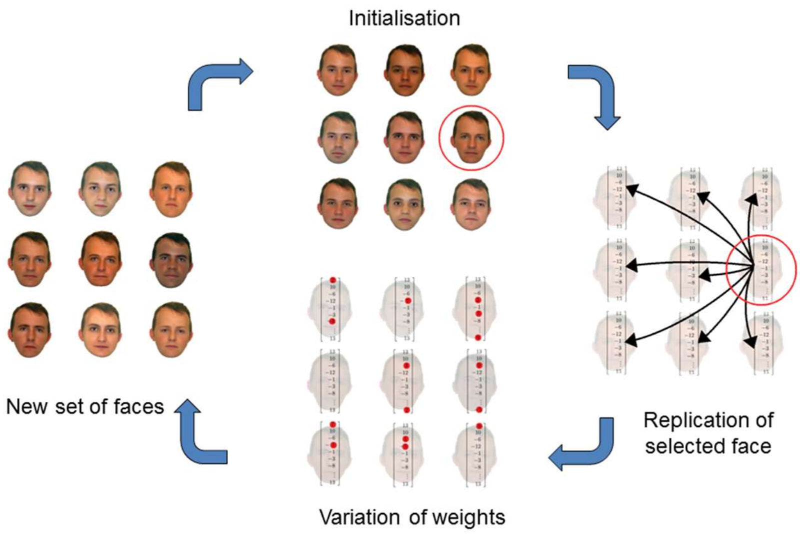

Figure 3: Schematic diagram illustrating the optimisation of weights, and hence facial appearance, using an evolutionary algorithm. The process is repeated until an acceptable likeness is achieved.

Holistic systems are also amenable to whole face transformations such as increasing or decreasing the perceived age of the composite image (see Figure 4). This is difficult to achieve with feature-based systems and would typically require skilled and lengthy work in image editing software. However, hair, clothing and accessories cannot be modelled adequately using PCA. Therefore, in holistic EFIT systems, hair, clothing and other accessories are chosen from databases and added as image layers to the facial composite.

Figure 4: The perceived age is easily controlled with sliders in the EFIT6 user interface.

Post-production enhancement of EFIT-Vs and other composites

Regardless of the system employed to construct a composite, a composite-creating witness will be previously unfamiliar with the suspect. The aim is that someone familiar with the suspect recognises that composite. Different cognitive (e.g., Bruce & Young, 1986; Megreya & Burton, 2006) and neurological (e.g., Quiroga, Reddy, Kreiman, Koch, & Fried, 2005) mechanisms are involved in familiar and unfamiliar face processing (for a review see Johnston & Edmonds, 2009). Familiar faces are mainly recognised using internal features (eyes, nose, mouth), whereas external feature extraction drives unfamiliar face memory - particularly hairstyle (e.g., Ellis, Shepherd, & Davies, 1979; Young, Hay, McWeeny, Flude, & Ellis, 1985). Therefore, hairstyle is often well produced in facial composites, while internal aspects can be more erroneous. And yet, accurately constructed internal features will facilitate familiar face recognition, and thus facial composite recognition likelihood. Post-construction enhancement methods provide a solution (e.g., displaying multiple composites: Frowd, Bruce, Plenderleith, & Hancock, 2006; dynamic animated caricatures: Frowd, Atherton, Skelton, *et al*., 2012). Two additional techniques used in police investigations have also been tested with feature-based (e.g. E-FITs) and holistic EFITs (e.g. EFIT-Vs).

Morphing or merging two or more composites together increases accuracy as measured by improved composite naming rates, and ratings of composite-target similarity (e.g., Bruce, Ness, Hancock, Newman, & Rarity, 2002; Davis *et al*., 2010; Hasel & Wells, 2007; Valentine, Davis, Thorner, Solomon, & Gibson, 2010). There is also a positive correlation between ratings of morph quality, and increasing the number of composites that contribute to that morph (2, 4, 8, or 16; Davis, Simmons, Sulley, Gibson, & Solomon, 2015). The technique is included in UK police best practice guidance (Association of Chief Police Officers (ACPO), 2009), and is often used in investigations.

Valentine *et al.* (2010) demonstrated that morphing improves the internal features of a composite more than the external features, and this enhances composite recognition, although the combined impact positively influences whole images even more. Morphing also works with composites created by the same witness (see also Davis *et al*., 2010), although effects are strongest when constructed by different witnesses. This is because errors in composites constricted by different witnesses are less likely to correlate than multiple single-witness creations. The merging process enhances the consistent, mainly correct aspects of multiple composites, while *averaging* out random incorrect internal inconsistencies. Nevertheless, Hasel and Wells (2007) warned that averaging might sometimes have the adverse effect of making composites appear more similar to non-targets, potentially increasing risks of innocent suspect identification. However, in a series of four experiments, Davis, Simmons, *et al.* (2015) found that although morphing reduced EFIT-V distinctiveness, there was no evidence for any increases in rates of incorrect identifications.

Holistic EFIT (e.g. EFIT-V) composite identification rates can also be enhanced by *physical linear* or *perceptual stretch*, in which a printed composite can be turned with the instructions, “viewing the composite sideways may help you to recognise the face” (Frowd, Jones, Fodarella *et al*., 2013). They can also be artificially rotated on a computer monitor, so as to appear from an angle of about 45^0 (Davis, Simmons, *et al*., 2015; Frowd *et al*., 2013a). Like morphing, stretch averages out errors. However, there are upper limits to enhancements using averaging techniques. Applying both techniques to EFIT-Vs, Davis, Simmons, *et al.* (2015) found that a combination of morphing and stretch had no additional benefit over the application of morphing or stretch alone.

Influence of composite creation on subsequent eyewitness identification

In some cases, the original composite-creating witness may view a line-up containing a suspect bearing a close resemblance to the composite, as someone else, viewing that composite, perhaps in a media appeal may suggest a name to the police. Facial composites were constructed in the investigations of 30% of US DNA-exonerated individuals, and many witnesses misidentified the subsequently imprisoned, but innocent suspect from a line-up (Innocence Project, 2016). The Innocence Project therefore criticised the use of composites in US investigations suggesting they can, "contaminate a witness' memory so that the witness can no longer discern, or has a very difficult time discerning, between their memory of the perpetrator and the likeness that they helped to create". Some research with old-fashioned feature-based composites which are more prevalent in the USA supports this position (e.g., Davies *et al*., 1978; Kempen & Tredoux, 2012; Wells, Charman, & Olson, 2005), whereas in contrast, research with the more recently developed holistic systems has mainly found *positive* effects from composite creation on line-up accuracy (Davis *et al*., 2014; Davis, Thorniley *et al*., 2016; see also Davis, Maigut *et al*., 2015).

Wells *et al.* (2005, Experiment 1) found that only 10% of participants recognised a facial photograph from a six-person target-present line-up two days after creating a feature-based FACES composite of that photograph. In contrast, 84% of non-composite-creating controls correctly identified the photograph. These negative effects were strongest when composites possessed a poor likeness to a target. A second experiment replicated these negative findings in target-present trials, although the authors also introduced a target-absent line-up condition with the 'culprit' replaced by a foil, and found no differences between composite creators and controls. Nevertheless, FACES software employs a feature-by-feature construction method, and instead of an operator guiding the witness, composites were self-created. It is clear FACES composites in this study were not constructed in optimum conditions and indeed, opposite positive effects have been found in studies using other feature-by-feature systems (for a meta-analysis see Meissner & Brigham, 2001a).

These inconsistent findings beg the question as to whether the advantages of using a holistic composite system carry over to identification accuracy from a line-up. Two studies by Davis and colleagues (Davis *et al.*, 2014; Davis, Thorniley *et al.*, 2015; for a review see Davis, Maigut, *et al.*, 2015) demonstrated that under varying conditions, including forensically-valid delays of a few days between stages, adult identification accuracy from a subsequent video line-up – the standard line-up type used in the UK - was either enhanced or unaffected by EFIT-V construction (see Figure 6). However, children (aged 6-11 years) were more likely than adults to select a line-up foil after constructing an EFIT-V, suggesting that care may need to be taken in police investigations with young children. Nevertheless, consistent with Wells et al. (2005), there was no evidence that composite creation increased innocent suspect or foil identification rates, if the correct target was not included in a line-up. This suggests that the 'blame' in DNA-exoneration cases should not be directed at facial composites, but instead, highlights the likelihood that there may have been other subsequent more serious errors in these investigations. Indeed, these findings suggest that any such risks may be reduced if a composite is constructed using a holistic system.

Figure 6: Suspect still from 'crime scene video' (left), EFIT-V created by a naïve witness with the assistance of a police-course trained operator (centre), and still from a nine-member video PROMAT line-up (right) prepared in a Metropolitan Police Service identification suite a few weeks later (see Davis, Maigut et al., 2015).

Conclusions

Eyewitness identification accuracy and composite quality depends on many factors outside the control of police, including the witness' memory, the event (e.g. how long the offender was viewed), and the offender (e.g., ethnicity, suspect distinctiveness, see Frowd *et al*., 2005). In addition, EFIT-Vs have been constructed at least six years after the witness viewed a suspect (e.g., Lohr, 2013). However, human memory is affected by delay (for a review see Deffenbacher, Bornstein, McGorty, & Penrod, 2008), and holistic EFIT (e.g. EFIT-V) quality is reduced if constructed after two days instead of on the same day (Davis *et al*., 2010). It is important that composite creation should occur as quickly as possible.

More research is still required on the utility of facial composite systems, such as the influence of the cross-ethnicity effect (e.g., Meissner & Brigham, 2001b) and the face recognition ability of the witness (see Davis, Lander, Evans, & Jansari, 2016) on holistic composite quality, as these factors can adversely influence eyewitness identification accuracy. However, it is clear that with the development of holistic systems such as the EFIT holistic series, in conjunction with effective post-construction enhancement techniques, the correct identification and conviction of the perpetrator from a holistic facial composite is more likely than ever.

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