2015

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Susan Hayes
University of Wollongong, suehayes@uow.edu.au

Publication Details

Hayes, S. (2016). Faces in the museum: revising the methods of facial reconstructions. Museum Management and Curatorship, 31 (3), 218-245.

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Disciplines

Medicine and Health Sciences | Social and Behavioral Sciences

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http://www.tandfonline.com/eprint/vh5JWsQ3DKJnSruayvBD/full
Museum Management and Curatorship, DOI:10.1080/09647775.2015.1054417

Published online: 15 Sep 2015.

Title: Faces in the Museum: Revising the Methods of Facial Reconstructions

Susan Hayes [a,b*]

[a]Centre for Archaeological Science, Faculty of Science, Medicine and Health, University of Wollongong, Wollongong, Australia; [b]Museum Geologi, Bandung, Jawa Barat, Indonesia
(Received 27 November 2014; accepted 12 May 2015)

Abstract

Museum displays of faces derived from skeletal remains – typically referred to as facial reconstructions – are extraordinarily popular, and frequently function as iconic representations of a much broader engagement with collections from a particular people, time and place. Their actual ability to meaningfully represent either an individual or a museum collection is questionable, as facial reconstructions created for display and published within academic journals show an enduring preference for applying invalidated methods. Since 2002 there has been an increase in verified skull-soft tissue relationships, and these, together with research findings from related academic fields, can be incorporated within an evidence-based estimation of facial appearance. By illustration, a face given to an individual from the Museo de la Plata collection is critically revised to show how validated relationships result in a different face, and furthermore a face that is more closely aligned to what constitutes knowledge and display within the contemporary museum.

Key words

Facial approximation, reconstruction, methods, validity, museum display

Every species of pre-modern human, a handful of ancient *Homo sapiens*, and a large number of Holocene skulls have been the subject of a facial reconstruction (e.g. Anderson (2011) identified 192 facial reconstructions in a cross-section of European and Australian museums (n=55), 88.5% of which were of modern humans). It is due to their powerful and continuing popularity that so many faces have been created for public display, and many are sourced from existing museum collections. Within the context of the museum a facial reconstruction is largely iconic: a face given to an individual from a particular time and place becomes representative of collections relating to a people, time and place, and along with this, all of the curatorial, archaeological, anthropological and historical research that has been undertaken to better understand, document and preserve them (Berman 1999, 2003, Moser 1992a, b, 2010).

For the purposes of this paper a 'facial reconstruction' is taken to encompass a broadly biological anthropological approach, where the face and each of its features (eyes, nose, mouth, ears) are estimated from what can be determined from the remains of the skull. Sometimes, but not always, facial reconstructions in the museum are supported by a peer reviewed research publication, though these publications do not include the more familiar faces displayed in the museum and the media. Unsupported facial reconstructions include Bach, 'Bouchra', 'Jesus', Richard III, St. Nicholas, Tutankhamun, all Pleistocene and early-mid Holocene *Homo sapiens*, all *H. neanderthalensis*, nearly all archaic humans such as *H. habilis*, *H. heidelbergensis*, *H. rudolfensis* and *H. ergaster*, and all *Australopithecines*. However, publications relating to the facial reconstructions of at least 67 individuals have appeared in European, Asian and American academic journals between 1912 and 2014. Two of these concern pre-modern humans (Baba, Aziz, and Narasaki 1998, Hayes, Sutikna, and Morwood 2013), while the remaining are of people who died relatively recently (circa 4000-100 years ago). These facial reconstructions of 65 modern humans involve men, women and children from a range of social strata, and represent excavations, exhumations and collections from all over the world.

Up until recently the methods applied in a facial reconstruction have of necessity been reliant on a large number of unverified 'forensic' recommendations to create the faces. As a consequence the field has long attracted a great deal of scepticism from the scientific community, and is considered by many to be an artistic interpretation of dubious merit (e.g. Haglund 1998, Kemp 2004, Montagu 1947, Stephan 2003a). Such scepticism has not, however, had a discernible impact on international museums both great and small. As is claimed within a number of research papers (though not based on actual studies), depicting an individual's facial appearance for museum display provides the museum visitor with an immediate and personal communication about the past, and as such is thought to offer the non-specialist a more familiar and understandable view of human remains, archaeology, history, associated artefacts and related research endeavours (Balueva, Veselovskaya, and Rasskazova 2010, Boutin et al. 2012, Cesarani et al. 2004, Gill-Robinson et al. 2006, Musgrave et al. 1995, Neave 1979a, Needham, Wilkinson, and Knüsel 2003, Poynter 1915).

Since 2002 a number of investigations have been undertaken to redress the erroneous recommendations applied in traditional facial reconstructions, and/or to provide robust, validated methods to estimate different aspects of the face from the skull. It is evident from the research publications that recent facial reconstructions are beginning to include verified findings, but it is also clear that this is yet to be widespread. Since 2002, 26 research papers concerning a facial reconstruction have been published, but only 10 refer to at least one valid methodological finding, and most often this is applied within a much greater reliance on invalidated, traditional methods published in various popular 'forensic' how-to books (see Table 1).

Although only a very small number of facial reconstructions displayed in museums are also published as an academic paper, these publications are taken to be representative of the range of individuals selected for museum display as well as the methods typically used to produce the faces. Following a summary of whose face has been reconstructed and an evaluation of how this has been undertaken, an illustration is provided showing how verified relationships can be more inclusively applied to estimate facial appearance. The example used for this illustration is a previous facial depiction of an individual in the Museum de la Plata collection in Argentina (Hayes 2011), revised to better reflect current understandings.

A. Who's Who in Facial Reconstruction: The Remains

Facial reconstructions of past humans have appeared in English language academic journals since as early as 1912 (Wilder 1912), though the majority have been published since 2002 (only 12 publications appeared 1912-2001, see Table 2). The largest group of facial reconstructions by population affinity involves the remains of Ancient Greeks (12), followed by Egyptian mummies (10 individuals, wrapped and unwrapped). Nobles, or similarly elevated personages, are the subject of 21 publications (30), many of whom were mummified (12), and a number of facial reconstructions have been undertaken with an individual bearing skeletal evidence of antemortem abnormalities: facial injuries (2), pathology (3), and artificial cranial distortion (2). Estimated time since death is, not surprisingly, the highest for the Egyptian mummy collections (up to approximately 4000 years ago); 31 individuals died less than 1000 years ago, and five within the past 200 years. The geographical location of the remains is fairly varied, and following the macro geographical regions as defined by the Statistics Division of the United Nations (2013), it can be seen that reconstructed individuals have been exhumed, excavated or collected from the Americas (11 individuals), Europe (33), Africa (10), Asia (3), and Oceania (8). There is a high number of males (43), young to mid-age adults (34), and high status individuals (30), but this is in agreement with patterns of skeletal preservation which favour young to mid-age adults, and individuals (mostly male) whose burial methods have enhanced preservation (Bello et al. 2006).

Overall the facial reconstruction research publications contain, and represent, a range of people from different geographic locations, time periods and social strata. In addition, they can be seen as fairly representative of the popularity of Egyptian mummy exhibitions, the diversity of international collections sourced outside of Egypt and Greece, and the patterns of skeletal preservation that is typical within museum collections.

B. Preferred Methods of Facial Reconstruction: A Critical Review

Most facial reconstructions, published or otherwise, involve sculpting the face and its features in clay over a cast of the skull, and this approach has been applied to 41 of the 65 individuals represented within the research papers. Clay modelling requires a high level of skill and experience, and clay obscures all of the skeletal and dental information that it covers. Checks are in place with soft tissue depths (see below), but these collectively occupy only a very small region of the face, and clay does not easily facilitate metric assessments as the work progresses. It is for this reason that Gerasimov (1955) and George (1987) recommend a 2D 'blue-print' is achieved before a clay facial reconstruction is undertaken. Only two of the clay reconstructions include reference to a graphic plan within their methods (Klepáček and Malá 2012, Poynter 1915).

Traditional 2D drawing has an advantage over clay sculpting in that it involves greater transparency – each aspect of the process can be drawn as a separate layer, and the work can be constantly checked throughout. With minor variations, a 2D approach has been applied to 24 individuals in the research publications, and while not nearly as popular as working in clay, manual drafting has been an established approach for over a century. More recent methods include computer graphics: in one instance this involves virtual clay over a CT scan, which essentially follows the traditional 3D approach, and 2D computer graphics, which similarly follows the traditional 2D approach, has been applied to both digital photographs and CT scans.

Regardless of whether a facial reconstruction is achieved in reference to a skull, skull cast, photograph, 3D print or scan, all of the following aspects are able to be embraced by traditional methods as well as those incorporating verified relationships:

- estimation of repairs to the skull and teeth when poorly preserved
- application of soft tissue depths
- estimation of an underlying anatomy
- approximation of the face and its facial features.

Poor preservation is a feature of most collections of human skeletal material. Facial reconstruction research publications, however, rarely include how damaged, distorted or absent facial bones (e.g. the orbital rims, maxilla, nasal and zygomatic bones), and loss of the anterior teeth, were dealt with in order to estimate the relevant facial features, even though this is apparent for at least 38 individuals. Indeed, one 3500 year-old cranium is described displaying a 'gaping chasm' where the facial bones once were (Musgrave et al. 1995), and it can only be assumed, as it is not discussed in the research paper, that a complete absence of facial bones would have presented somewhat of a challenge during the facial reconstruction. Research papers that do describe estimations due to poor preservation include the use of geometric morphometrics to virtually repair a damaged left condyle (Benazzi et al. 2010), experimentation with cremation to identify patterns in the resultant warping (Prag, Musgrave, and Neave 1984), and the use of mirroring to estimate a paired feature (e.g. Boutin et al. 2012). A few of the published facial reconstructions have relied on previously undertaken bone estimations and repairs, though unfortunately for one individual this was seen to have contributed to an excessively retroussé nose (Harrison 1966).

Average facial soft tissue depths (fSTDs) are, almost without exception, applied in a facial reconstruction, and a skull dotted with depth markers typifies *science at work* in the popular media. There are a number of different fSTD collections that can be applied to a skull, though traditional facial reconstructions show an enduring preference for average data collected from relatively small numbers of cadavers (His 1895, Kollmann and Büchly 1898, Rhine, Moore, and Weston 1982, Rhine and Campbell 1980, Rhine and Moore 1984). Helmer's ultrasound fSTD measures, which were taken from the living (Helmer 1984, Rohrer-Ertl and Helmer 1984), and a much larger and more recent ultrasound collection (De Greef et al. 2006), are applied within the relatively recent research publications, and a few individuals have been reconstructed in reference to fSTDs that are specific to their population affinity. Many population specific fSTDs, however, are the average of a small number of individuals, and some cadaveric collections do not constitute a viable dataset (e.g. for Papuans the 'average' is from two males, Fischer 1905).

Many of the preferred facial soft tissue depth collections are reproduced in forensic handbooks (Krogman and Iscan 1986, Taylor 2001, Wilkinson 2004), and cited accordingly. Unfortunately, these reproductions of fSTD data has been found to occur with varying degrees of accuracy (Stephan and Simpson 2008), and of a related concern is that most facial reconstructions, and the forensic handbooks, locate all of the fSTD markers 'perpendicular' to the bone. This is possibly a misunderstanding of an abbreviation instigated (and clearly explained) by Aulsebrook and colleagues, as such a bisection of the curvature of the bone is relevant for only five fSTDs on the skull. The majority (~20, depending on the dataset) have a different angulation (Aulsebrook 1996, George 1987, Stephan and Simpson 2008).

A layer of underlying anatomical features is not always included in a facial reconstruction, though outside of North America it is the far more popular approach. In a traditional facial reconstruction how the muscles, glands and facial fat were applied is often attributed to the late Russian anatomist, Mikhail Gerasimov, and referenced accordingly (Gerasimov 1971). However, this information is not described within the cited source, and such a reference to Gerasimov is in any event an overstatement. Gerasimov's methods include modelling the temporalis and masseter muscles, which together inform the shape of the outer face, but not the remaining 14 or so facial muscles, parotid glands or fatty tissue more typically included in an 'anatomical' facial reconstruction (Stephan 2006).

Traditional facial reconstructions tend to refer to two well-known publications to estimate the shapes of the facial features, though neither was intended for this purpose. *The Face Finder* (Gerasimov 1971) is an English translation of a German translation of a Russian popular text, and while it contains very little practical information, it transpires that somewhere in the iterative process it became a much cited mistranslation regarding how to estimate the nose (Ullrich and Stephan 2011). *Making Faces: Using Forensic and Archaeological Evidence* (Prag and Neave 1997) is also a popular resource, and is often cited in conjunction with *The Face Finder*. *Making Faces* similarly contains little information for undertaking a facial reconstruction (estimated at 4% of the overall contents, Stephan 2003a), and, while most of the recommendations that it does contain were acceptable at the time, many have since been found to be invalid (e.g. Guyomarc'h and Stephan 2012, Stephan and Davidson 2008, Stephan 2003b, 2002b). More recent publications that are cited (Taylor 2001, Wilkinson 2004) include a few verified relationships, but most of the recommendations they contain have since been invalidated, and it is evident that many facial reconstructions that depend on these publications do not discriminate between them.

C. Facial Approximation: Verified Methods for a Man from San Juan

The main aim of this paper is to show that applying verified findings can result in a face that is more in accord with museum collections and the broader research that it represents, and that the methods themselves can be, as with other research endeavours in the museum, more transparently approximate and open to revision. It is in part for this reason that some researchers prefer the term 'facial approximation' when describing both the methods and the results (e.g. Decker et al. 2013, Reichs and Craig 1998, Stephan 2003a, Taylor and Angel 1998). Facial reconstruction is, however, by far the most common term in research publications, museums and the media, even though it is often confused with a far larger number of publications reporting craniofacial surgical procedures and estimated repairs to damaged skulls within archaeology and palaeoanthropology.

The more traditional, and more popular, approach to undertaking a facial reconstruction is typically presented as a 'one size fits all' series of repeatable steps resulting in a definitive realisation of how an individual appeared in life. In contrast, a research-based approach is both specific to the individual and far from definitive. By illustration, in 2010 a Huarpe farmer from San Juan, Argentina, who died approximately 500-800 years ago, was given an approximate face. Only a few years later this face has changed. This is because, as with other research with museum collections, variation occurs in what is known, what is applied, and how both the skull and the methods are interpreted at the time. There is also an issue of experience – the original face given to the *Man from San Juan* was undertaken after a shift from manual drawing to computer graphics, and therefore displays a distinctly imperfect control of the complexity of Adobe Photoshop (see Figure 1). This new face is therefore a revision of some of the visual, as well as methodological, wrinkles.

This individual was selected from the Museo de la Plata collection (collection reference E1807) primarily because the remains displayed an excellent level of preservation, and therefore the analyses could be undertaken over a period of 10 days – at the time the costs of CT scans were prohibitive. Somewhat unusually the anterior nasal spine was still intact and nearly all of the teeth were preserved – so a more typical stage of estimating and reflecting missing or damaged elements of the bones and teeth was not required (see Figure 2). In addition, because the Museo de La Plata's collection included the post-cranial skeleton, sex and age had been determined (Gonzalez 2008), which was an important factor given sex determination from the skull alone is made more difficult with rugose individuals (Bernal, Perez, and Gonzalez 2006). A more detailed explanation of the socio-historical and biological anthropological context of the Huarpe people from San Juan and north-west Argentina (e.g. Sardi, Novellino, and Pucciarelli 2006, Fabra, Laguens, and Demarchi 2007, Perez 2006), how their cultural and physical environment impacted on their skulls and teeth (e.g. Gonzalez, Perez, and Bernal 2010, Del Papa and Perez 2007, Gonzalez-Jose et al. 2005, Bernal et al. 2007, Bernal, Perez, and Gonzalez 2006, Sardi and Beguelin 2010), what was undertaken with this individual at the time and why it was undertaken, can be found in the original publication (Hayes 2011).

Once the skull had been visually assessed and measured, the mandible was articulated to the cranium following the traditional facial reconstruction recommendation of allowing a 2mm freeway space between the maxillary and mandibular molars (e.g. Taylor 2001). Subsequent literature reviews have indicated that freeway space is not calculated as an inter-molar distance, the range and average is larger (Johnson, Wildgoose, and Wood 2002), and studies of living individuals suggest the impact of extreme tooth wear has a complex, variable, and not necessarily discernible, impact on overall facial height (e.g. Crothers 1992). Unfortunately, this aspect of the original facial approximation has not been able to be revised as the work was undertaken in reference to digital photographs, but it seems reasonable to assume that this individual had a slightly longer lower face than illustrated here.

All photographs involve a degree of distortion (parallax) which has been found to decrease the greater the lens-subject distance (e.g. Eliášová and Krsek 2007). The articulated skull was photographed from a distance of 2m (any closer and distortions are manifest) with the nasion as the focal point, and because the ambient conditions in the Museo de la Plata were good, it took only one day to achieve closely matching frontal and lateral views of the skull. However, in comparison to even low resolution medical CT scans, photographs will always be less than perfectly orthogonal, do not provide as much information regarding the cavities of the skull, cannot be reliably altered post-production, and often take many, many hours to achieve satisfactory results. This is important as this particular approach to estimating facial appearance is essentially a 'hands-off' technique. That is, it does not involve the manual application of rods representing the soft tissue depths (fSTDs) with sticky wax (or similar) directly onto the skull. Facial STDs can be much more accurately positioned and angled using computer software, and virtual application removes the need for bone contamination (which is not popular with geneticists, archaeologists or museum curators). However, virtual application does require the images to be as close to orthogonal as possible. For this individual a subset (coronal and sagittal) of the weighted means derived from a large number of the more robust extant fSTD collections was applied, as these have been found to be independent of sex, adult age, biomass and population affinity given the standard errors within fSTD collections are in excess of any discernible group related differences (Stephan and Simpson 2008).

In the original estimation the underlying anatomy followed the traditional facial reconstruction recommendations and illustrations. Another, later, literature review indicated there is individual variation in the number, and shape, of facial muscles (e.g. Pessa et al. 1998) and that many of the facial reconstruction recommendations and illustrations do not agree with more authoritative texts (e.g. nearly all editions of *Gray's Anatomy*). Research has also been undertaken regarding the inaccuracy of traditional facial reconstruction methods with regards to the lateral view of the temporalis muscle , and the relationship of masseter muscle size to the skull (Stephan 2010). To this can be added the location of the depressor labii inferioris muscles, which in this revised version of the *Man from San Juan* is now in closer agreement with its more typical anatomical placement (Standring 2008).

The facial features (eyes, nose, mouth, ears) were originally estimated applying a combination of published but yet to be tested relationships, tested and verified relationships, and traditional recommendations. Eyeball projection followed verified findings (Stephan 2002b, Wilkinson and Mautner 2003) (Stephan 2002b, Wilkinson and Mautner 2003), but the eyes were located centrally in the orbits, and this traditional recommendation for placement has now been corrected (see Figures 2 and 3). Wolff (1954) has long stated that the eyeball is displaced from the centre, and this has been further verified through dissections (Stephan, Huang, and Davidson 2009, Stephan and Davidson 2008), and validated by a recent large-scale examination of CT scans (Guyomarc'h et al. 2012). Furthermore, these dissection studies add verification for the anatomical locations of the corners of the eyelids, and usefully add methods for determining these when the orbital rims are poorly preserved. Iris diameter was originally estimated referring to surgical recommendations (Larrabee and Makielski 1993), which fortuitously agree with the research-based findings (Driessen, Vuyk, and Borgstein 2011).

Nasal projection, while it was originally estimated referring to a verified recommendation (Rynn, Wilkinson, and Peters 2010), still requires revision. Rynn and colleagues' verified recommendation incorporates mistranslations from Gerasimov (Ullrich and Stephan 2011), and unfortunately correction for this mistake requires knowledge of the nasal cavity base, which is not possible to determine from photographs. Mouth width originally followed two early verified recommendations (Stephan 2003b, Wilkinson, Motwani, and Chaing 2003), and these have since been both refined and elaborated from cadaveric studies (Stephan and Murphy 2008) to include research findings from anaesthesia, and now more usefully include the relationship of the mouth to the infraorbital and mental foramina (Song et al. 2007). For this revision the results of two verified methods were applied. One method was found to correlate with the revised eyeball placement (Stephan 2003b), and the other with the infraorbital foramina (Stephan and Henneberg 2003), so an average of the two results was applied here.

A verified method for calculating an estimation of lip height (Wilkinson, Motwani, and Chaing 2003) is only relevant for teeth displaying little or no tooth wear. As with most collections, the *Man from San Juan* displays significant dental wear, so in this revision the maximum lower lip still refers to George's facial triangle (George 1993, 2007), but adjusted to agree with the revised eyeball placement. Ear shape has no statistically verified correlates with the skull, other than the location of the external auditory meatus and that non-adherent lobes are more frequent in non-European populations (Guyomarc'h and Stephan 2012). All traditional facial reconstruction recommendations for estimating the dimensions, angle and projection of the ear are therefore void. Ear height is, however, related to the soft tissue distance between the base of the nose and lower chin (Farkas 1994). Therefore of necessity ear morphology is a very subjective addition to the face – though it has been found that ears, unless they are outstanding in shape or size, attract minimal viewer attention (Shepherd, Davies, and Ellis 1981).

This revised face for the *Man from San Juan*, as with the original estimation, still contains soft tissue recommendations that are yet to be tested, and these occur mostly with aspects of the surface appearance. A naso-labial fold is retained as indicated by the depth of the canine fossa and the location of the second molar, and the eyebrows are shaped and positioned in reference to the morphology of the superior orbital rim and brow ridge (Fedosyutkin and Nainys 1993, Gerasimov 1955). Eyebrow peak is located lateral to the medial border of the iris, a position that was only able to be very generally determined from statistical testing of the traditional recommendations (Stephan 2002a). Some features of adult male facial aging have been reviewed (Albert, Ricanek, and Patterson 2007) and averaged (Burt and Perrett 1995), and although patterns of facial aging can be highly variable (Cunha et al. 2009), lip thinning is a frequently reported change in anthropometric and geometric morphometric measures of the adult face (e.g. Sforza et al. 2010). In this revision, indications of surface weathering and aging were only applied after a more neutral, age-average adult face was achieved (Figures 4 and 5).

The shape, texture and location of scalp hair cannot currently be estimated from the skull, though recent DNA analyses can determine an >86% probability of black hair (and not so surprisingly, brown eyes) from modern non-European samples (Walsh et al. 2013). In the original facial approximation of this Huarpe individual, as with previous applications to museum collections (e.g. Hayes et al. 2012, Hayes and Connell 2007, Hayes et al. 2009), head hair is represented minimally, if at all. A consequence of this adherence to methodological purity is that a 'bald' face is typically assumed to be a male face (which impacts deleteriously on approximations involving women), and most research collaborators, which include ancestral custodians as well as museum curators, would much rather the results include terminal scalp hair. A more recent compromise of *wet hair, off the face* has been applied (Hayes, Sutikna, and Morwood 2013) which to some extent evades, but not entirely avoids, subjective assumptions such as hair texture and length, and additionally reduces the visibility of upper ear shape. The historical records describe the Huarpe people as having dark and long hair (Canals Frau 1946), and this is included in the revised results.

Overall, with regards to surface appearance, a less-is-more approach is consistent with what can be reliably estimated from the skull. For computer graphic images this can be achieved by minimising the appearance of what is not known, and rendering the overall facial surface 'fuzzy' by using grain filters in Adobe CS Photoshop. In a 2D image this does not necessarily detract from the result, as studies show that visual perception of the face is well adapted to degraded photographic information (Bruce et al. 2001). Furthermore, and in keeping with these findings, it is mass, rather than edge information (Bruce et al. 1992, Goffaux et al. 2005), and the spatial configuration of the features (e.g. Karavaka, Halazonetis, and Spyropoulos 2008, Rakover 2002) that are more relevant to how faces are perceived and recognised.

In summary, in addition to a revised surface appearance, this new estimation of a man from the late Agriculturalist period of San Juan, Argentina, includes a more accurate average placement of the eyeball within the orbits, and a refined mouth both in average width and average age related dimensions. Much of the information used in the original facial approximation is essentially the same, but it is interesting to note that this more inclusive application of verified research findings impacts on feature configuration (see Figure 3, left), which is, as noted above, a key factor in face perception and recognition.

D. Conclusion

A facial reconstruction is most often presented as a *fait accompli*. This holds for most of the facial reconstructions displayed in museums, magazines, web pages, and to a slightly lesser extent, facial reconstructions in both popular fiction and documentary archaeology. Although the research literature shows these faces represent a wide, and diverse, range of international collections of past populations, they also show a marked tendency to continue to rely on invalidated recommendations to produce a face from the skull. Very little can be claimed by a sample of one, but this illustration of a fresh face for the *Man from San Juan* does indicate that a different facial configuration emerges when a larger number of validated findings are applied to estimate the features.

The advantages of a research based approach to facial approximation is that each aspect of the process can be illustrated, described, justified and subsequently modified in reference to relevant findings. Ideally such methodological transparency would help to demythologise the definitive *face to face with the living past* most often presented to the museum public, and in so doing, deflate what has been called the 'wow' factor of facial reconstructions (Stephan 2003a). In the museum, as with a facial approximation, what we currently know about peoples from the past is mostly predicated on a limited knowledge of statistical averages of human variation. Definitive answers are rarely part of contemporary museum narratives, and an evidence-based estimation enables each face to be more closely aligned to the raft of research and understandings it unavoidably, and powerfully, represents. Furthermore, although this is also not a verified finding, personal experience indicates most members of a non-specialist postmodern museum public, sub-adult to senescent, are quite happy with facial approximations displaying a much greater level of methodological transparency, and a lot less certainty.

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Table 1: Facial reconstruction research papers, 2002-2014 (n=26)

TSD = Time Since Death in years, fSTD = facial Soft Tissue Depths

Research Paper	Burial or Location of the Remains	Excavation, Exhumation or Collection	Max. TSD	Biological Age and Sex (where given)						Medium	Methodological References (where cited)	
				<12	12-20	20-35	35-50	>50	Sex		fSTD Dataset	Face and Facial Features
(Manley et al. 2002)	Egypt	Egyptian Mummy	3500			1			1 F	3D clay		(Gerasimov 1971, Prag and Neave 1997)
(Prokopec and Ubelaker 2002)	Czech Republic	Cemetery, Rajhrad	1200			2	2		2 M 2 F	2D drawing	(Gerasimov 1940)	(Balueva and Lebedinskaya 1991, Caldwell 1981, Ubelaker and O'Donnell 1992)
(Wilkinson 2002b)	Egypt	Egyptian Mummy	1900			1			1 M	3D clay	(Phillips and Smuts 1996)	(Gerasimov 1971, Prag and Neave 1997)
(Needham, Wilkinson, and Knüsel 2003)	UK	Cemetery, Sussex Hospital	900				1	1	2 M	2D drawing	(Helmer 1984)	(Prag and Neave 1997, Taylor 2001)
(Wilkinson and Neave 2003)	UK	Towton Battle Collection	550				1		1 M	3D clay	(Helmer 1984)	(Krogman and Iscan 1986, Fedosyutkin and Nainys 1993, George 1987, Gatliff 1984)
(Cesarani et al. 2004)	Egypt	Egyptian Mummy	2900			1			1 M	3D clay		(Prag and Neave 1997)
(Kustar 2004)	Hungary	Dominican Church, Vác	200				1		1 M	3D clay	(Rohrer-Ertl and Helmer 1984)	(Kollmann and Büchly 1898, Krogman and Iscan 1986, Gerasimov 1955, Gerasimov 1968, Snow, Gatliff, and McWilliams 1970, Gatliff 1984, George 1993, Ubelaker and O'Donnell 1992, Macho 1986, Kustar 1999, Kustár and Gy 1996, Kustár 1997, Macho 1989)
(Liston and Papadopoulos 2004)	Greece	Ancient Greek Tomb	2500			1			1 F	2D drawing	(Taylor 2001, Rhine and Campbell 1980)	(Taylor 2001, Glassman, Gatliff, and McGregor 1989, Gatliff and Snow 1979)

(Tiesler, Cucina, and Pacheco 2004)	Mexico	Mayan Tomb	1300					1	1 F	2D drawing	Rhine (1983) cited in (Taylor, 2001)	(George 1987, Stephan, Henneberg, and Sampson 2003, Wilkinson and Mautner 2003)
(Gill-Robinson et al. 2006)	Egypt	Egyptian Mummy	2230			1			1 F	3D clay	(Rhine, Moore, and Weston 1982, Rhine and Campbell 1980)	
(Nunn et al. 2007)	Fiji	Lapita Burial, Naitabale	2950					1	1 F	3D clay		(Prag and Neave 1997)
(Benazzi et al. 2009)	Italy	Partial cast, measures, photographs (c. 1921)	700					1	1 M	3D clay		(Wilkinson 2004, Prag and Neave 1997)
(Gaytán et al. 2009)	Mexico	Museum Collection	100			1			1 F	3D clay	(Escorcia and Valencia 2003)	(Wilkinson 2004, Stephan and Davidson 2008, George 1987, Krogman and Iscan 1986)
(Hayes et al. 2009)	Vanuatu	Lapita Burial, Teouma	3100						2 M 2 F	2D drawing		(Gerasimov 1955, Wilkinson 2004, Prag and Neave 1997, Taylor 2001, Fedosyutkin and Nainys 1993, Hrdlicka 1939, Rynn and Wilkinson 2006, Gerasimov 1971, Wilkinson 2006)
(Papazoglou-Manioudaki et al. 2009)	Greece	Ancient Greek Grave Circle	3500			2			2 M	3D clay		(Prag and Neave 1997)
(Balueva, Veselovskaya, and Rasskazova 2010)	Russia	Cemetery, Novgorod	700						3 M 3 F	3D clay 2D drawing	(Veselovskaya 1997)	(Balueva and Veselovskaya 2004)
(Benazzi et al. 2010)	Italy	Cathedral, Mantua	450					1	1 M	3D clay		(Prag and Neave 1997, Taylor 2001, Wilkinson 2004, Quatrehomme et al. 2007)
(Wescott et al. 2010)	USA	Cemetery, Missouri	160			1			1 F	2D drawing		(Taylor 2001)

(Mays et al. 2011)	UK	Memorial, Arctic Expedition	170				1		1 M	3D clay	Helmer (1984) in (Wilkinson 2004)	(Mitchell 2007, Prag and Neave 1997, Wilkinson 2004)
(Hayes 2011)	Argentina	Amerindian Burial	800			1			1 M	2D drawing Virtual 2D	(Stephan and Simpson 2008, Stephan, Norris, and Henneberg 2005)	(Gerasimov 1955, Prag and Neave 1997, Taylor 2001, Stephan 2002b, Fedosyutkin and Nainys 1993, Stephan and Davidson 2008, Wilkinson 2004, Larrabee and Makielski 1993, Rynn, Wilkinson, and Peters 2010, Gerasimov 1971, Ullrich and Stephan 2011, Woo 1931, Stephan 2003b, Wilkinson, Motwani, and Chaing 2003, George 1993, 2007, Farkas 1987)
(Papagrigorakis et al. 2011)	Greece	Ancient Greek Mass Grave	2500	1					1 F	3D clay	(Wilkinson 2002a)	(Gerasimov 1971, Prag and Neave 1997, Wilkinson 2004)
(Boutin et al. 2012)	Bahrain	Burial Mound	4000		1				1 M	3D clay 2D drawing	(Manhein et al. 2000, Rhine and Campbell 1980, Rhine, Moore, and Weston 1982)	(Nusse 2007)
(Hayes et al. 2012)	New Zealand	Maori Burial	600			1	2		2 M 1 F	Virtual 2D	(Stephan and Simpson 2008)	(Gerasimov 1955, Taylor 2001, Prag and Neave 1997, Stephan 2002b, Fedosyutkin and Nainys 1993, Stephan and Davidson 2008, Wilkinson 2004, Larrabee and Makielski 1993, Rynn, Wilkinson, and Peters 2010, Gerasimov 1971, Woo 1931, Stephan 2003b, Wilkinson, Motwani, and Chaing 2003, George 1993, 2007, Farkas 1987)
(Klepáček and Malá 2012)	Czech Republic	Museum Collection	300		1				1 F	3D clay	(De Greef et al. 2006)	(Wilkinson and Mautner 2003, Stephan and Davidson 2008, Stephan, Huang, and Davidson 2009, Whitnall 1921, 1932, Fedosyutkin and Nainys 1993, George 1987, Stephan, Henneberg, and Sampson 2003, Gerasimov 1955, Prag and Neave 1997, Rynn, Wilkinson, and Peters 2010, Lebedinskaya 1998, Stephan and Murphy 2008, Stephan and Henneberg 2003)
(Erolin et al. 2013)	Iran	Lateral photograph (c. 1950)	980					1	1 M	2D drawing		(Rynn, Wilkinson, and Peters 2010)

(Lee et al. 2014)	Korea	Tomb, Gangneung	400					1	1 M	Virtual 3D	(Lebedinskaya, Balueva, and Veselovskaya 1993)	(Lee, Wilkinson, and Hwang 2012)

Table 2: Facial reconstruction research papers, 1912-2001 (n=12)

TSD = Time Since Death in years, fSTD = facial Soft Tissue Depths

Research Paper	**Burial or Location of the Remains**	**Excavation, Exhumation or Collection**	**Max. TSD**	**Biological Age and Sex (where given)**						**Medium**	**Methodological References (where cited)**	
				<12	12-20	20-35	35-50	>50	Sex		**fSTD Dataset**	**Face and Facial Features**
(Wilder 1912)	USA	Amerindian Burials	350						3 M 1 F	3D clay	(His 1895, Kollmann and Büchly 1898)	(Welcker 1883, Whitnall 1911, Merkel 1900, Kollmann and Büchly 1898)
(Poynter 1915)	USA	Amerindian Burials	350						2 M	3D clay	(Wilder, 1912)	(Wilder, 1912)
(Harrison 1966)	Egypt	Egyptian Mummy	3300			1			1 M	2D drawing	(His 1895, Kollmann and Büchly 1898)	(Wolff 1954, Kollmann and Büchly 1898)
(Neave 1979a)	Egypt	Egyptian Mummy	4000		1		1	1	2 M 1 F	3D clay	(Harrison 1966, Kollmann and Büchly 1898)	(Krogman 1962, Gerasimov 1971, Kollmann and Büchly 1898)
(Prag, Musgrave, and Neave 1984)	Greece	Ancient Greek Tomb	2350				1		1 M	3D clay	(Rhine, Moore, and Weston 1982)	(Neave 1979a, Krogman 1962, Neave 1979b)
(Maples et al. 1989)	Peru	Crypt, Lima	470					1	1 M	3D clay		(Snow, Gatliff, and McWilliams 1970, Gatliff 1984)
(Hill, Macleod, and Watson 1993)	Egypt	Egyptian Mummy	3500			1			1 F	3D clay	(Kollmann and Buchly, 1898, cited in Krogman and Iscan, 1986)	(Krogman and Iscan 1986, Gerasimov 1971)
(Musgrave et al. 1995)	Greece	Ancient Greek Grave Circle	3500			5	1	1	6 M 1 F	3D clay	(Prag, Musgrave, and Neave 1984)	(Prag, Musgrave, and Neave 1984, Prag 1990)
(Hill, Macleod,	UK	Museum	450					1	1 M	3D clay	(Moore 1981)	(Krogman and Iscan 1986)

and Crothers 1996)		Collection										
(Puech 1995)	France	Cemetery, Sainte-Marguerite	200		1				1 M	2D drawing	(Howells 1973, Dumont 1986)	(Gatliff 1984, Rogers 1987, Ubelaker and O'Donnell 1992)
(Kustar 1999)	Hungary	Cemetery, Mosz	1700			1			1 F	3D clay	(Rohrer-Ertl and Helmer 1984)	(Kollmann and Büchly 1898, Gerasimov 1955, Gerasimov 1968, Kustár and Gy 1996)
(Macleod et al. 2000)	Egypt	Egyptian Mummy	1900			1			1 M	3D clay		

FIGURE CAPTIONS

Figure 1: The original facial approximation (Hayes 2011)

Figure 2: Revised estimation of the facial features of the Man from San Juan

Figure 3: Revised anatomy and surface appearance – left, overlay and comparison of the original and revised estimations, centre, underlying anatomy, and right, surface appearance

Figure 4: Revised facial approximation showing a neutral age

Figure 5: Revised facial approximation showing an older adult