Biometry applied to facial recognition of four portraits presumed to be of Leonardo da Vinci

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Our original aim for this project was to use artificial-intelligence tolls to measure objectively similarities observed subjectively by human eye between faces in graphic works using different pictorial techniques. We submit images that are presumed to be portraits of Leonardo da Vinci for identification by facial-recognition software. Algorithmic identification allowed us to compare each portrait to the whole database, pair by pair. However, our experimental method led us to reverse our approach. In the end we had to authenticate the results from facial-recognition technology using 'one-to-one' visual comparison. So that we double-checked by submitting the portraits to a panel of nonexpert volunteers, thus verifying our hypothesis. We proved that artificial intelligence is an invaluable addition to the toolkit of today's art expert. Reinforced by the natural abilities of the human eye, it will be essential to recognizing and verifying the identity of subjects in works of art.

Biometry (shortened from anthropobiometry, the study of 'the measurement of the living human body') is the 'automatic recognition of a person using distinctive features' [1]. Physical features are automatically measurable and so unique that they can be used to identify individuals or to verify their alleged identity [2]. Other properties of biometric characteristics are that they are universal and unique. That is, they are present in everyone and no one has exactly the same characteristics as anyone else. They also are permanent, meaning that they do not change over time or they change very little [3]. Humans have a natural ability, more or less developed according to the individual, to identify faces. The most discerning are called 'physiognomists' ('spotters' in the vernacular). In the art world, such experts are said to have an 'absolute eye' in much the same way as we speak of the 'absolute ear' ('perfect pitch' in the vernacular) of virtuoso musicians.

A computerized system of facial recognition

This ability to recognize faces does not exist naturally, of course, in the information technology (IT) of a computer. Hence, the need to simulate recognition by means of autonomous intelligent systems. Just as our brain stores images of faces we have seen and observed throughout our lives, facial-recognition computer software requires the prior establishment of a database of well-known faces. A facial recognition system must be able to automatically identify faces within a picture or a video. The image of the face to be recognized is normalized before being sent to the recognition system that will process it, using an algorithm to extract a signature. A classifier then compares this signature with the rest of the signatures in the database, in order to identify the face to be recognized [1] (Fig. 1).

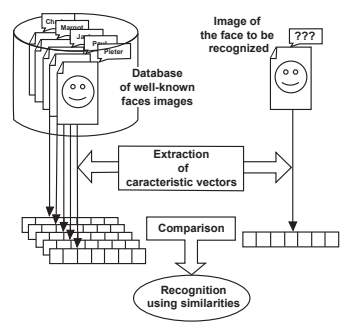

Figure 1 | The different phases of facial recognition tools using artificial-intelligence system [1].

The biometric system can operate in these following two modes [2, 4]:

- Verification (authentication), where the user inputs the image of a face alleged to be that of Person X, and the biometric system tries to answer the question: 'Is this Person X?' Using the characteristic data of the face in the image, the system formulates a mathematical signature for the face and searches the database for signature that corresponds to the alleged identity. This is a 'one-to-one' comparison, (1:1). The system verifies that the two faces match, and that this is indeed Person X. This procedure is commonly used in applications such as access control, border security and in payment authentication.
- Identification, where the biometric system is used to establish

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the identity of a person from a database and tries to answer the question : 'Who is Person X?' This time, the system compares the signature obtained from the input information with all others signatures in its database. This is a 'one-to-all' comparison, (1:N). The system gives each pair of images a score based on their degree of resemblance and ranks all the images in the database according to the paired scores obtained by these N 'one-to-one' comparisons, (1:1) x N. This procedure is commonly use in commercial applications to identify regulars customers and VIP or shoplifters and fraudsters, but also in forensic investigations to identify criminals and even corpses.

Problems specific to the facial recognition of portraits

'Using artificial-intelligence tools, is it possible to measure objectively similarities observed subjectively by human eye between faces in graphic works using different pictorial techniques?' That is the question we attempted to answer in this study. As our facial-recognition software we choose *NeoFace © Watch* developped by NEC Corporation. Due to its first-place finish in vendor testing conducted in 2013 by the US National Institute of Standards and Technology (NIST), with only 4.1% failure for facial recognition in a database of 1.6 million images, this software is still considered the most accurate on the market, especially for its success with low-quality images. It provides the most rapid comparison and the best resistance to orientation variables (up to 30 ° differential deviation relative to front face) and aging (up to 10 years' age differential relative to database face). It attempts to conceal identity by wearing a hat, a cap, a beard, mustaches, or a simple change of hairstyle. The facial-recognition software *NeoFace © Watch* is based on a generalized learning vector quantization (GLVQ) algorithm type [5].
In the art domain, identification by an expert eye of the drawn or painted face is in fact synonymous with authentication. The scope of assessment of the portrait to be identified will be differ, depending on whether or not the artist is known:
- If the author of the portrait is known, the expert eye will give a name to the depicted subject based on the similarities between his face and other identified portraits done by the same artist.
- However, if the author is unknown, but the work relatively well dated, the expert eye will give priority to attributing the portrait to a specific artist. The similarities in the rendering will enable the expert eye to attribute the portrait to a particular known artist. The search for the subject's name moves down the priority list.
At this stage, it was certainly tempting to use facial-recognition algorithms originally developed for forensic investigations to identify criminals and now often used in commercial applications. But we had reservations about applying such technology to the expert evaluation of pictures of faces [6]. If the identification is based on facial recognition that 'crystallizes the individual identity' [7], the problem of recognizing a drawn or painted face is based on the rendering differential specific to each artist: the pictorial technique (sketch, drawing or painting), the style (the artist's 'creative hand' and the coarseness or fineness of its 'touch') and the format used, with its pictorial constraints. Indeed, regarding the fineness of the features and the processing details, consider the obvious rendering differences between a subject's face pictured in a miniature work done under a magnifying glass, and the same subject's face pictured in a giant mural or fresco work.

Some responses provided by early studies

Several scientific studies had already broached the topic seriously. One that should be mentioned is the biometric study conducted in 2005 by Raoul Perrot, director of the Anthropology and Anatomical Paleopathology Laboratory at the Claude Bernard University of Lyon 1, on behalf of the Design Department of the Cosimo Di Medici Laboratory of Paris [6]. Perrot used mathematical facial-recognition tools to assess the degree of resemblance between three painted or carved faces presumed to be of Benvenuto Cellini. The known and authenticated face of the Benvenuto Cellini 's portrait by Giorgio Vasari served as a reference. In the end, two of the three faces to be recognized were identified as Benvenuto Cellini's self-portraits. In 2012, a team of art historians from the California State University of Riverside led by Conrad Rudolph began work on a research project entitled a project entitled 'Faces, Art and Computerized Evaluation Systems' (FACES) [8]. The known and authenticated face of the three-dimensional Laurenzo di Medici 's death mask served as a reference. They began to develop a facial-recognition software that could identify his two-dimensional face in drawn or painted works of artists that were his contemporaries. One member of the team, Amit Roy-Chowdhury, has since used the software he helped to develop to identify Anne Boleyn, second and hapless wife of Henry VIII, in a portrait which until then had been considered that of Henri VIII's next wife, Jane Seymour. The same study enable him to unmask a falsely alleged portrait of Anne Boleyn exhibited at the National Portrait Gallery of London.

The implemented double experimental system

Faced with this delicate conundrum, we decided to approach it from two angles : The artificial-intelligence of the *NeoFace © Watch* algorithm, complemented by the discernment of the human ocular and cerebral neural network. Regarding facial recognition by means of software, scores established by comparing faces with those of a database are only numerical values based on confidence level and must be considered as such. The higher the score, the more the two faces are alike. Usually, a score around 0.550 for a pair of 'real faces' (photographed) would indicate that the two faces are potentially alike. In our particular case, namely the recognition of 'interpreted faces' (drawn or painted), we considered a score around 0.450 significant. However, we had to keep in mind that this score did not represent a probability coefficient. Computerized facial-recognition systems are not foolproof magic tools and final verification by the human eye will always be an invaluable adjunct. Moreover, in addition to the score value set by the software, it is also interesting to consider the comparative ranking images as selected by the database. Faces sorted by descending score up to rank 10 should be considered potentially similar, leaving the human eye ultimately exercise its critical and discriminatory potential. Hence the interest in this study to propose to

a 85-person panel the subjective assessment of the degree of resemblance between the images of faces we submitted in parallel to the software *NeoFace © Watch*. Usually, a visually set score around 0.650 for a pair of 'real faces' (photographed) would indicate that the two faces are potentially alike. In our particular case, namely the recognition of 'interpreted faces' (drawn or painted) by a nonexpert panel, we also considered a score around 0.450 significant.

Figure 2 | The four apparently similar faces which were the subject of the present study. 1, Presumed 'Self-portrait of Leonardo da Vinci' (Turin - Italy). **2,** The Apostle Thaddeus from the 'Last Supper' (Luxembourg). **3,** Saint-Anthony from the 'Temptation of Saint Anthony' **(**France). **4,** Presumed 'Portrait of Leonardo da Vinci' (Winsor Castle - UK).

Four faces with apparent features and extracted from separate graphic works (made of different pictorial techniques and realized in different formats) were the subject of the present study (Fig. 2). The first one [1] in Figure 2, is a portrait drawn with red chalk commonly attributed to Leonardo da Vinci (kept at the Turin Royal Library) ; this three-quarters face, about fifteen centimetres high, is generally presented as being that of Leonardo da Vinci, about sixty years old. The second one [2], is extracted from a painting on a large canvas representing the 'Last Supper' (kept in a Luxembourg private collection); this three-quarters face, also about fifteen centimetres high, is that of the Apostle Thaddeus, whose features are presumed to be those of Leonardo da Vinci in his prime, i.e., about fifty years old (in terms of the 'Last Supper' fresco in Milan). The third one [3], is extracted from a painting on a small panel of wood representing the 'Temptation of Saint Anthony', in the alchemical mode of the 'Great Work' (kept in a French private collection) ; this front face, only a few millimetres high, represents Saint-Anthony, 'the Great', alias 'the Egyptian'. Finally, the fourth one [4], is extracted from a catalogue at the Windsor Castle Royal Library (RL 12300v ref.). This three-quarters face, only a few centimetres high, is a pencil-and-ink drawing generally presented as being that of Leonardo da Vinci, about fifty years old, most likely executed by one of his studio students.

Our database was extracted from the basic free image data rights 'Google's license Creative Commons 3.0 Attribution'. Including 51 drawn or painted faces, selected from almost twenty centuries of profane and sacred art, it broke down as follows:

- 12 portraits of diverse and varied men, mostly self-portraits extracted from known profane works and absolutely authenticated as to the author,
- 23 portraits of men with beards, mainly extracted from sacred iconography,
- 13 portraits of diverse and varied women extracted from known profane works and absolutely authenticated as to the author.

The two images of 'unrecognized' faces to be identified [2] and [3], and the two well-known presumed portraits of Leonardo da Vinci [1] and [4], were as expected added to complement this database. At each test match, the image to be recognized was of course been removed from the database, except to set an expected score of 1.000.

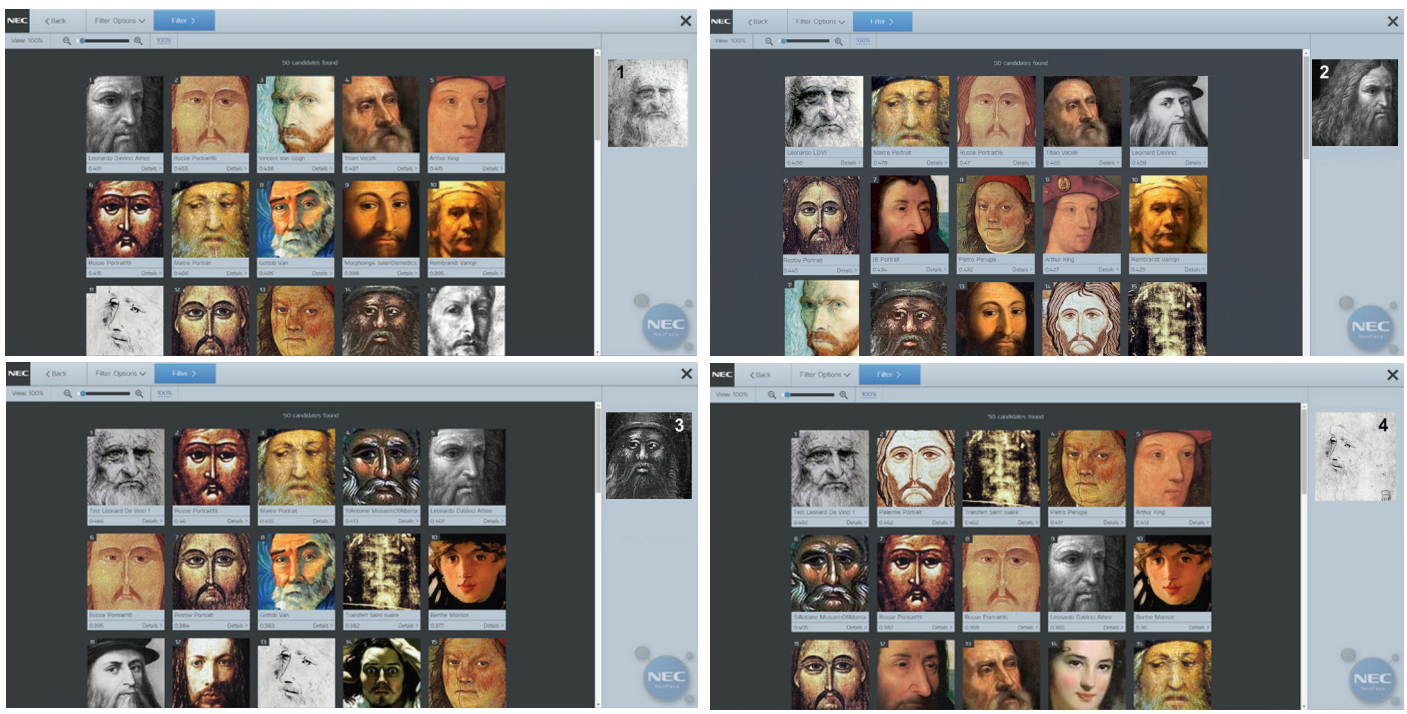

Figure 3 | The four grids of test matches results (1:51) ranked in descending order of scores, from up to bottom and from left to right, by *NeoFace © Watch* software. On the light blue sidelines, top and right of each of the four grids, the face to be recognized. In the top left of each grid, the leading candidate of the test match ranked by the software.

Results of artificial-intelligence and visual test matches

The first test match carried out with artificial-intelligence software compared to the database (1:51) face image [1] of the red-chalk portrait commonly attributed to Leonardo da Vinci (Fig.3). The biometric system tried to answer to the question: 'Who is represented on the face image [1]?'. This was a 'one-to-all' test match (1:51), comparing the signature obtained from the characteristic data input for image [1] with those of the other 51 face images in its database. The system then ranked in descending order all the paired scores obtained by these 51 'one to one' comparisons, (1:1) x 51 (Fig. 3). The first position was occupied by face image [2] of the Apostle Thaddeus painted portrait, whose features are presumed to be those of Leonardo da Vinci (Fig. 3 and 4).

Figure 4 | Result of the first artificial-intelligence test match (Fig. 3), comparing face image [1] to the rest of the database (1:51). On the right, the leading candidate [2] ranked by the *NeoFace © Watch* software.

The score was 0.491. The face image occupying the second position on the grid scored only 0.453. This consolidated the position of face image [2] as the leading candidate to keep. It should also be noted that faces images [4] and [3] respectively ranked 11th and 14th, with 0.392 and 0.375 scores, clearly less significant. This result was exactly corroborated by the visual test match. Indeed, when our 85-person panel compared 'one to one' (1: 1) the four apparently similar faces which were the subject of the present study (Fig. 2), the classification set by eye also ranked the [1-2] pair at the first place, tied at 0.500 median score with the [1-3] pair .The [1-4] pair came in third with its 0.400 median score.

The second test match carried out with artificial-intelligence software compared to the database (1:51) face image [2] of the Apostle Thaddeus, whose features are presumed to be those of Leonardo da Vinci. The system ranked in descending order all the paired scores obtained by these 51 'one to one' comparisons, (1:1) x 51. The first position was logically occupied by face image [1] of the red-chalk portrait commonly attributed to Leonardo da Vinci (Fig. 3). The score was 0.488. The face image occupying the second position on the grid scored only 0.479. This consolidated the position of face image [1] as the leading candidate to keep. It should also be noted that face images [3] and [4] respectively ranked 12th and 19th, with 0.402 and 0.366 scores, clearly less significant. This result was not exactly corroborated by the visual test match. Indeed, when our 85-person panel compared 'one to one' (1: 1) the four apparently similar faces which were the subject of the present study (Fig. 2), the classification set by eye ranked this time the [2-4] pair at the first place with a 0.600 median score. The [2-1] and [2-3] pairs occupied ranks 2 and 3 with respective 0,500 and 0,400 median scores.

The third test match carried out with artificial-intelligence software compared to the database (1:51) the face image [3] that was represented Saint-Anthony, 'the Great' alias 'the Egyptian'. The system then ranked in descending order all the paired scores obtained by these 51 'one to one' comparisons, (1:1) x 51 (Fig. 3). The first position was logically occupied by face image [1] of the red-chalk portrait commonly attributed to Leonardo da Vinci (Fig. 3 and 5).

Figure 5 | Result of the third artificial-intelligence test match (Fig. 3), comparing face image [3] to the rest of the database (1:51). On the right, the leading candidate [1] ranked by the *NeoFace © Watch* software.

The score was 0.466. The face image occupying the second position on the grid scored only 0.460. This consolidates face image [1] as the leading candidate to keep. It should also be noted that face image [2], which ranked 5th in the classification (Fig. 3), was a potential candidate too, but to a lesser extent in view of its 0.407 score. Face image [4] ranked 13th with a 0.373 score even less significant. This result was exactly corroborated by the visual test match. Indeed, when our 85-person panel compared 'one to one' (1: 1) the four apparently similar faces which were the subject of the present study (Fig. 2), the classification set by eye also ranked the [3-1] pair at the first place with a 0.500 median score. The [3-2] pair came in second, tied at 0.400 median score with the [3-4] pair.

The fourth and last test match carried out with artificial-intelligence software compared to the database (1:51) face image [4] of the pencil-and-ink portrait generally presented as being that of Leonardo da Vinci. The system ranked in descending order all the paired scores obtained by these 51 'one to one' comparisons, (1:1) x 51. The first position was occupied by face image [1] of the red-chalk portrait commonly attributed to Leonardo da Vinci (Fig.3). The score was 0.492. The face image occupying the second position on the grid scored only 0.462. This consolidates the face image [1] as the leading candidate to keep. It should also be noted that face image [2], which ranked 9th in the classification (Fig. 3), was a potential candidate too, but to a lesser extent in view of its 0.365 score. Face image [3] ranked 16th with a 0.343 score even less significant. This result was not exactly corroborated by the visual test match. Indeed, when our 85-person panel compared 'one to one' (1: 1) the four apparently similar faces which were the subject of the present study (Fig. 2), the classification set by eye ranked this time the [4-2] pair at the first place with a 0,600 median score. The [4-1] pair came in second, tied at 0.400 median score with the [4-3] pair.

Discussion

The first test match carried out with artificial-intelligence software, comparing to the database (1:51) face image [1] of the red-chalk portrait commonly attributed to Leonardo da Vinci, designates as leading candidate face image [2] of the Apostle Thaddeus painted portrait, whose features are presumed to be those of Leonardo da Vinci (Fig. 3 and 4). It is corroborated by

the visual test match (1: 1) that ranks the [1, 2] pair at the first place. Finally, it is consolidated by the second test match carried out with artificial-intelligence software, which compared to the database (1:51) face image [2] of the Apostle Thaddeus, that logically designates as leading candidate the above mentioned face image [1] of the red-chalk portrait commonly attributed to Leonardo da Vinci (Fig. 3). The inversion in the classification for 2 and 3 ranks between the artificial-intelligence software and the visual test matches may be explained by a large difference of processing and finishing, which is superimposed that of an age gate of about ten years, between the two face images [1] and [4]. The nonexpert eye of everyone is not necessarily able to integrate these parameters, unlike the intrinsic performances of the facial-recognition software. If tried that the red-chalk portrait kept at the Turin Royal Library [1] would be a self-portrait of Leonardo da Vinci, this study supports the hypothesis that the face of the Apostle Thaddeus character depicted in this version of the 'Last Supper' would also be that of Leonardo da Vinci. Anyway, it significantly confirms that face image [1] and [2] would be portraits of the same personality. Furthermore, the present study opens the debate on whether the face image [2] of the Apostle Thaddeus extracted from this painting on large canvas representing the 'Last Supper' could be the hand of Leonardo da Vinci himself, or that of one of his studio students, after a lost original of his Florentine master.

The fourth test match carried out with software artificial-intelligence, comparing to the database (1:51) face image [4] of the pencil-and-ink portrait generally presented as being that of Leonardo da Vinci, designates as leading candidate face image [1] of the red-chalk portrait commonly attributed to Leonardo da Vinci. The ranking shift between artificial-intelligence software and visual test matches may again be explained by a large difference of processing and finishing, which is superimposed that of an age gate of about ten years, between the two faces images [1] and [4]. As mentioned above, everyone nonexpert eye is not necessarily able to integrate these parameters, unlike the intrinsic performances of the facial recognition software. If tried that the red-chalk portrait kept at the Turin Royal Library [1] would be a self-portrait of Leonardo da Vinci, this study confirms the hypothesis that the pencil-and-ink face of the character extracted from a catalogue at the Windsor Castle Royal Library (RL 12300v ref.) would also be that of Leonardo da Vinci. Anyway, it significantly confirms that face image [1] and [4] would be portraits of the same personality.

The result of the third test match carried out with artificial-intelligence software, comparing to the database (1:51) face image [3] of the Saint-Anthony character extracted from a painting representing the 'Temptation of Saint Anthony', is paradoxically not the most surprising, although the perspectives it offers are the most incredible and even more dizzying in their layout and possible reading. Nothing in this painted face, only a few millimetres high, would at first glance let the average viewer glimpse or even imagine any resemblance with that of any presumed portrait of Leonardo da Vinci. Neither at first glance, nor the following. Even the more discerning eye cannot distinguish this 'Saint-Anthony-like' miniature portrait from its archetypal 'father of hermits' representation, as it typically appears in profane or sacred iconography. Only an 'absolute eye' might notice that the features of this 'Saint-Anthony-like' face have nothing to do with the emaciated one's we would expect to find on the face of a hermit ; rather, much more with those of the face of a healthy monk, somewhat chubby. It takes more than 20 x magnification to realize, not only the actual account dexterity of the artist and the extreme precision of his touch, but also the resemblance of this face with that of presumed portraits of Leonardo da Vinci. The result of the third test match carried out with artificial-intelligence software, comparing to the database (1:51) to face image [3], designates as the leading candidate the face image [1] of the red-chalk portrait commonly attributed to Leonardo da Vinci. It is corroborated by the visual test match (1: 1) that ranks the [3, 1] pair at the first place. If tried that the red-chalk portrait kept at the Turin Royal Library [1] would be a self-portrait of Leonardo da Vinci, this study allows to emit the incredible assumption that Leonardo da Vinci himself would be portrayed in the guise of the famous 'father of hermits' in this painting representing the 'Temptation of Saint Anthony', in the alchemical mode of the 'Great Work'. The hypothesis is also supported by another pictorial detail of that this painting : an 'anthropomorphic landscape' whose profile recalls precisely the features of the same red-chalk portrait [1] commonly attributed to Leonardo da Vinci (Fig. 6). Anyway, the results of the present study significantly shows that face image [3] and [1] would be portraits of the same personality.

Figure 6 | Anthropomorphic landscape : On the right, the 'Leonardo-like' profile of the 'Temptation of Saint Anthony', from which is also extracted face image [3] of this study (Fig. 2). On the left, the red-shark portrait commonly attributed to Leonardo da Vinci [1].

Ultimately, this study was able to affirmatively answer to the original question, namely : 'Using artificial-intelligence tools, is it possible to measure objectively similarities observed subjectively by human eye between faces in graphic works using different pictorial techniques?' The consistency of the test-matches results obtained using the *NeoFace* © *Watch* artificial-intelligence software and those obtained using the human ocular and brain neural network can position this software as a necessary tool for facial recognition applied to separate graphic works made of different pictorial techniques. Beyond this scientific aspect, if tried that the red-chalk portrait kept at the Turin Royal Library [1] would be a self-portrait of Leonardo da Vinci, as regards the two 'unrecognized' face images [2, 3], this study can allow to affirm that they would also be that of Leonardo da Vinci. Anyway, the results of the present study significantly shows that these two face images would be portraits of the same personality as that shown in the red-chalk portrait kept at the

Turin Royal Library. The result that raised the most questions was undoubtedly one obtained for the face image [3] extracted from a painting on a small panel of wood representing the 'Temptation of Saint Anthony', in the alchemical mode of the 'Great Work'. If tried that the red-chalk portrait kept at the Turin Royal Library [1] would be a self-portrait of Leonardo da Vinci, why was the Florentine master this time represented in these amazing appearances and staged in such a theatrical manner? Perhaps, to agree with Giorgio Vasari when he wrote in the first version of his 'Life of painters' that Leonardo da Vinci had 'developed in his mind such an heretical doctrine that he was no longer dependent of any religion, maybe more preferring to be a philosopher rather than a Christian'. Finally, in the case of authentication, who could have created such an explicit esoteric alchemical 'manifesto'? Leonardo da Vinci himself? Or a disciple from his near or distant surroundings? Someone who wanted - through this painted panel of the 'Great Work' - to pay tribute in the form of posterity testimony to Leonardo da Vinci's sacred way for 'insiders', that is a heretical way for the others? The controversy is reopened.

SUMMARY OF METHOD

The four apparently similar faces extracted from separate graphic works which were the subject of the present study, were submitted to the identification test (1:N) of the *NeoFace © Watch* facial-recognition software developed by NEC corporation. Performing at a rate of only 4.1% failure for facial recognition in a database of 1.6 million images, this software is currently considered the most accurate of its type on the market, especially for its success with low-quality images. The facial-recognition software *NeoFace © Watch* is based on a generalized learning vector quantization (GLVQ) algorithm type [5]. We established a database of 51 drawn or painted faces, selected from almost twenty centuries of profane and sacred art (extracted from the basic free image data rights 'Google's license Creative Commons 3.0 Attribution'), to enable the biometric system to identify (1:N) the four apparently similar faces which were the subject of the present study. For drawn or painted portraits (these being 'interpreted faces', opposed to - strictly speaking - 'real faces' of photographed portraits), a score of about 0.450 can be considered significant. To validate the results of these identification tests (1:51), we submitted the same four faces in parallel to control tests (1:1) by an 85-person panel. For drawn or painted portraits (these being 'interpreted faces', opposed to - strictly speaking - 'real faces' of photographed portraits), moreover being identified by nonexpert eyes, a score around 0.450 was also considered significant.

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