Pattern recognition after image processing of low-contrast images, the case of the Shroud of Turin

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Abstract. We discuss the potentially misleading effect of software techniques for elaborating low-contrast images. In particular, we present the example of the stains embedded into one of the most studied archaeological objects in history, the Shroud of Turin. We show for the first time that image processing of both old and recent photographs of the Shroud may lead some researchers to perceive inscriptions and patterns that do not actually exist, confirming that there is a narrow boundary between image enhancement and manipulation.

Keywords: *Digital image processing; Pattern recognition; Perception; Turin Shroud; Pareidolia*

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1. INTRODUCTION

Human visual perception is a complex process which involves the eyes and the brain. The eyes behave as electronic devices that collect the data, while the brain performs real-time information processing. The result of this mind-related process is called "perception" and it may transform the objective image into a subjective sensation [1]. In fact, both shape and color of objects can be modified by our brain, depending on our past experience, state of mind and the context where objects are located.

In this paper, starting from the basic concepts of "dynamic" and "static" contrast, we show how our visual perception can be deceived after image processing of low-contrast images, like the case of invisible letters and patterns perceived on the Shroud of Turin.

2. HUMAN VISION, BACK TO BASICS

The human eye is an excellent detector [2], and in spite of the impressive development of detector technology, it works better than the most advanced CCD cameras available today [3].

The light-sensitive region of the eye is the retina, a complex layered structure where the crystalline lens focuses the light rays to form an image. Unlike electronic devices, where there are three detectors per pixel (one for each primary color), on the retina there are two distinct photoreceptors, the cones and the rods. There are about 6 million cones concentrated in the central region of retina, while the rods are distributed around the peripheral region and their number is greater than 100 million. This large number of micro-detectors and the mechanical movement of the iris allow us to adapt our vision within a very broad range of light levels. The resulting "dynamic contrast" is the ability to distinguish different luminosity levels, and it is of the order of some million to one. As a consequence, we are able to recognize objects in a dark room illuminated by just a single candle (i.e. an illumination level of about 10^{-3} lux) and we can see perfectly on a bright sunny day (up to 10^{5} lux). However, when the light level is fixed, our ability decreases down to about 100:1. In this case we speak of "static contrast" and in Sections 4 and 5 we will discuss the effects of the limited static contrast on the perception of low-contrast images.

Despite the fact that the eye is an excellent detecting system and the information sent to the brain is the result of reproducible physical-chemical processes, the data elaborated by the brain do not always give a correct perception of the object seen. In fact, our brain adds, removes, reorganizes and codifies the sensorial data it receives in real time, in order to construe a coherent picture of the external world [1]. This complex and rapid processing work may occasionally lead to an incorrect perception of both the shape and color of an object, as discussed in the following.

3. THE PERCEPTION OF SHAPES AND COLORS

The paper of Kanizsa [4] describes our ability to assemble a coherent picture from ambiguous fragments in an image. The brain seeks the correct interpretation of the incomplete image by using built-in knowledge the data accumulated form our previous experience to eliminate improbable solutions. According to Kanizsa "*Certain combinations of incomplete figures give rise to clearly visible contours even when the contours do not actually exist. It appears that such contours are supplied by the visual system*" [4]. This happens because our brain chooses the best interpretation of the data following the Gestalt theory [5] and fills in the missing information accordingly. The

Gestalt theory states that visual perception is not a simple addition of the elements we see, but it is the result of the relations among the observed objects.

Not only patterns, but even colors may be perceived in a subjective way. What we perceive as a definite color, in fact, is the consequence of the comparison between the object and the context where it is inserted. This can lead to our eye-brain system being fooled as shown in Fig. 1, which shows the "checker shadow illusion" [6] where two identical shade of gray squares appear different just because they are surrounded by different square colors, and the presence of a shadow enhances the illusory effect.

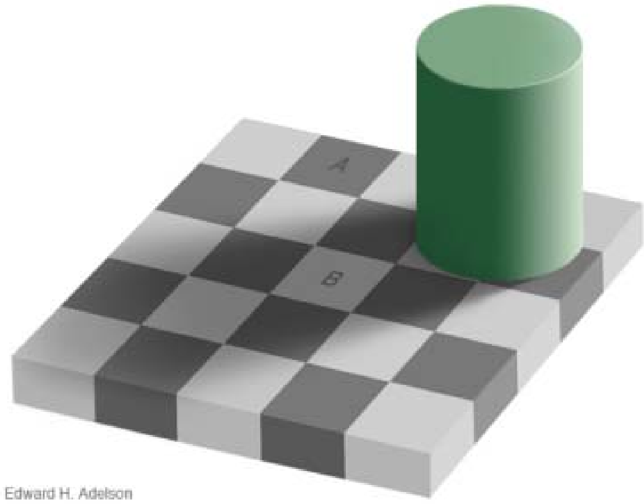

Figure 1. *An amazing incorrect perception of colors. Despite the appearance, the two squares marked by "A" and "B" have the same shade of gray. To convince us it is necessary to hide the picture observing only the marked squares, using, e.g., a screen with two holes. From [6].*

To some extent, our brain "bleaches" the color of square B to "compensate" for the shadow and to "accommodate" the fact that square B borders on four black squares. In the case of Fig. 1 the incorrect perception of reality is independent of our will, and the response of our eye-brain system is almost the same for all humans having similar experiences. When this happens we speak of "optical illusions" [7].

In other cases, the interpretation of an image is more subjective and the next section describes how the digital image processing of low-contrast images can introduce misleading elements which may lead to an incorrect perception of an image.

4. IMAGE PROCESSING OF THE SHROUD OF TURIN

In section 2 we pointed out that human eyes have a limited static contrast, and at a fixed light level we can distinguish differences in terms of brightness only in a range of about 1 to 100. A low-contrast image seen on the computer monitor may hide many details that we can see only if we adjust the brightness and contrast levels. In this case, it is difficult to establish if the original image has or has not the embedded information that we reveal only after manipulation. Apparently this is a philosophical doubt, but in the case of, e.g., latent fingerprints, radiological images and archaeological objects, the possibility to disclose hidden patterns may have important consequences.

As a meaningful example, let us consider the low-contrast stains barely visible on the linen cloth of the Shroud of Turin. The Shroud is considered one of the most studied archaeological objects in the world [8, 9, 10]. Several image processing techniques (which reduce noise and enhance contours of the image) were used to render the Shroud in order to make certain features more obvious to the human analyst [11, 12]. However, in the following we will show that in some cases the perceived results of image processing techniques may render more information than that actually embedded in the Shroud.

4.1 Letters on the Shroud?

Several years ago a paper [13] claimed the discovery of invisible Latin and Greek inscriptions around the image of the face on the Shroud. Figure 2 shows the hidden inscriptions "reconstructed" after digital image processing of photographs and prints of Enrie negatives (1931) and those of Miller (1978).

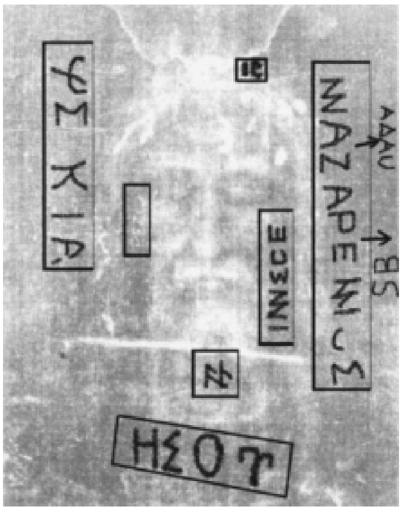

Figure 2. *Presumed inscriptions reconstructed on the basis of barely visible pixels that appear only after a deep digital image processing of the photographs of the Shroud by Enrie and Miller. Inscriptions are overlapped on the negative image of the face. From [13].*

Photographs were digitized by a scanner and a microdensitometer to enhance the contrast. The image processing of the digitized images included convolution and frequency filters to eliminate the herringbone pattern of the cloth, the extraction of pertinent information, and the fusion of all this information in a single image. Finally, convolution, nonlinear and morphological filters were applied directly on this single image and others in its frequency domain (Fourier filters).

Independent of the controversial meaning of these inscriptions [14], here we are interested in the reliability of the discovery of letters that appear after the deep image processing described in [13]. The first problem concerns the use of the orthochromatic films used by Enrie in 1931, which record a quasi-binary image, only black and white without mid-tone grays, thus discarding much data and altering the rest. According to [15] "*The orthochromatic film used by Enrie, coupled with the extreme raking light he used when making the photographs, created an infinite number of patterns* *and shapes everywhere on the Shroud. (…) The grain structure of orthochromatic film is not homogenous and consists of clumps and clusters of grain of different sizes that appear as an infinite myriad of shapes when magnified. It is easy to find anything you are looking for if you magnify and further duplicate the image onto additional generations of orthochromatic film, thus creating even more of these shapes. Although Enrie's images are superb for general views of the Shroud, they contain only a small part of the data that is actually on the Shroud so they are much less reliable for imaging research purposes and have a tendency to lead to 'I think I see' statements*".

These considerations make clear that inscriptions, coins, flowers and other patterns "discovered" on the Enrie films may be not very reliable. However, in the paper [13] high-resolution photographs of Miller (made in 1978) were also used, and to date, no one has been able to show if image processing of the information hidden in the modern photographs may lead to unreliable results, as in the Enrie's images. To check this, we digitally processed a modern photograph of the Shroud as described in the following. Figure 3a shows the photo of the hands of the Turin Shroud made in 1978 with high resolution. We see the image of hands and blood stains. Figure 3b is a zoomed region of Fig. 3a where we cannot see any pattern that makes sense. Then, by using the Paint Shop Pro X4 image processing software, we reduced the image to 256 gray levels and adjusted both brightness (-55) and contrast (+95). As a consequence, some black pixels emerge, see Fig. 3c. The last (and most dangerous) operation is the interpretation of these pixels to form letters. Figure 3d represents the reconstruction of the hidden writing influenced by the pareidolia effect [16, 17].

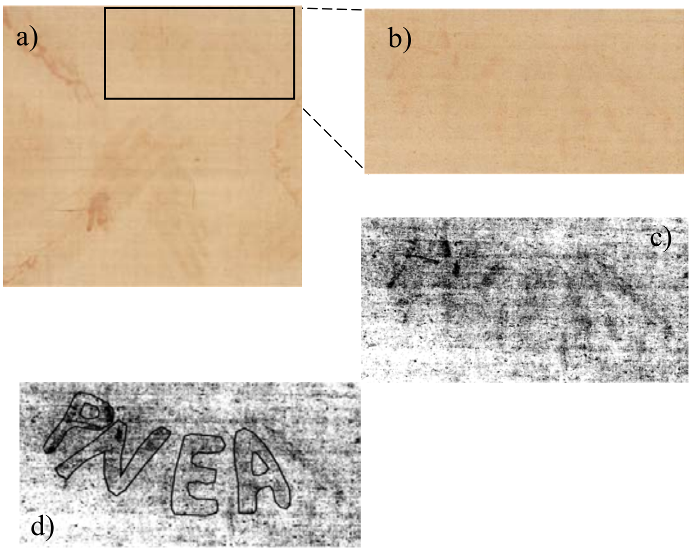

Figure 3. *A test to reveal an inscription on the Shroud that does not exist. Although the photo does not seem to hide anything, image processing software allows some "letters" to become visible.*

a) Photo of the hands on the Turin Shroud (© B. Schwortz, 1978). b) Zooming a detail of a) c) What happens after applying software filters and contrast enhancement. d) The pareidolia effect helps the "interpretation" of the hidden pixels.

Obviously, this writing has no meaning, except (as a joke) for authors working at "ENEA", but it demonstrates that the results of image processing techniques may lead some to perceive letters which do not exist, even in a modern, high-resolution photograph.

How can we explain the wrong perception of letters in Fig. 3? The ability to recognize letters or shapes in unusual contexts can be referred to as "pareidolia" [16, 17]. Pareidolia is the experience of seeing patterns or connections in random or meaningless data, a subconscious illusion involving a vague and random stimulus being perceived as significant. Common examples include animals or faces in clouds or the "man in the moon". Generally, we are able to distinguish between a genuine image and a subjective perception. However, as in the case of optical illusions, the state of mind and previous experience may fool our perception. This is because our mind tends to see what it expects and/or wants to see.

Therefore, we can summarize the incorrect perception in Fig. 3 as a two-step process. As a first step, when incrementing the contrast we create a binary image, arbitrarily stretching the color of mid-gray pixels towards white or black. Thus, new "image" pixels appear. As a second step, the pareidolia effect tries to make sense out of patterns obtained interpolating new and old image pixels in different paths, till a letter or a shape is "formed", which matches letters or shapes in our memory. The brain's ability to supply the missing contours [4] and to find a coherent relation among the observed objects by the statistics of the previous experience [5] plays an important role in this process, reinforcing pareidolia. In addition, the increment of the contrast and sharpness in visual response due to lateral neural inhibition [18] may help the vision of letters and shapes that pareidolia and Gestalt create from random pattern of dots. Note that both pareidolia and "filling information ability" are non-conscious mechanisms, are automatically triggered and therefore are independent of our will [4, 5, 17, 19]. It is likely that the above described two-step perception process plays an important role in the "discovery" of the invisible inscriptions reported in [13].

4.2 A face on the reverse side of the Shroud?

In 2004 a paper claimed the discovery of a facial image on the reverse side of the Shroud [20]. The face emerged after deep image processing of a screened halftone photographic reproduction taken from a book [21]. Image processing tools included convolution with Gaussian filters, summation of images, gamma correction and filtering in spatial frequency by direct and inverse bidimensional Fourier transforms. Figure 4a shows the "hidden face" revealed after digital image processing.

The first concern on the reliability of the results in [20] questions the quality of the original information. The acquisition and digital processing of a photograph printed in a book and convoluted by a complex photomechanical reproduction process may easily lead to uncertain and debatable results. A confirmation of this doubt came from the results of the Fourier transform of a high-resolution image directly obtained by in-depth scanning of the reverse side of the Shroud, which did not show any face or any other image [22].

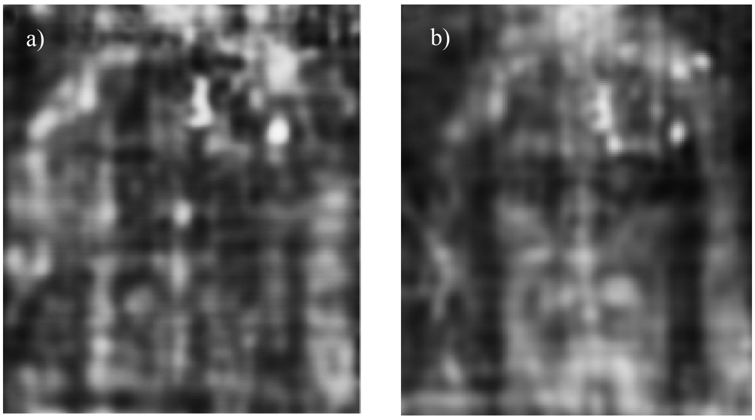

Figure 4. *a) Presumed hidden image of a face on the reverse side of the Shroud made visible by deep image processing of a photograph printed in a book. The image is inverted right-left. b) Negative image of the face visible on the frontal part of the Shroud, elaborated as well as a). From [20].*

However, once established by a direct, high resolution image acquisition and processing that there are no images on the reverse side of the Shroud [22], the problem still remains to understand how the face we perceive in Fig. 4a came out. In general, a high-contrast image like that in Fig. 4a suffers from the same problems mentioned in §4.1, and it is possible that the previously discussed two-step perception process of the letters in Fig. 3 plays a role in the perception of the face in Fig. 4a as well. However, according to [20], Fig. 4a shows some degree of spatial correlation of selected zones of the face (nose, eyes, mustache, hair) with the corresponding zones of the face on the frontal side of the Shroud shown in Fig.4b. The spatial correlation values of the single zones reported in [20] ranged between 0.6 and 0.9. This degree of spatial correlation led authors to conjecture that the formation mechanism of the face image on the frontal side of the Shroud acted on the reverse side of the Shroud as well. The spatial correlation reported in [20] was obtained by template matching based on a cross-correlation algorithm that calculates the Pearson product-moment correlation coefficient S according to the following equation:

$$S = \frac{\sum_{ij}\left[\left(A_{ij} - <A>\right)\cdot\left(B_{ij} - <B>\right)\right]}{\sqrt{\sum_{ij}\left(A_{ij} - <A>\right)^2 \sum_{ij}\left(B_{ij} - <B>\right)^2}} \qquad (1)$$

where *A*ij (*B*ij) is the gray level of the single pixel (i,j) of the image *A* (*B*), and <*A*> (<*B*>) is the mean value of the gray level of the image *A* (*B*).

Is this spatial correlation of small zones a valid argument against the possibility that the face we see in Fig. 4a is a wrong perception due to pareidolia and Gestalt? To answer this question we have checked the real spatial correlation of the two images in Fig. 4, performing two tests as described in the following.

1) We applied the Eq. (1) used in [20] on the whole images in Figs. 4a and 4b, obtaining S = 0.4. To make it clear how much poor is this spatial correlation value, we compared two completely different objects shown in Fig. 5, obtaining the same S = 0.4. The result that the two images in Fig. 5 have a

S ≠ 0 infers S in Eq. (1) is not the most reliable parameter to measure the true spatial correlation of two figures. In any case, S = 0.4 means a very poor spatial correlation.

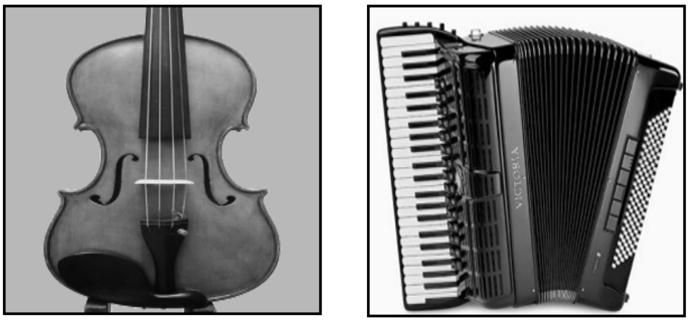

Figure 5. *Photographic images of a violin and an accordion. Despite the two images have nothing in common, they have the same spatial correlation S = 0.4 of figures 4a and 4b. The S value is calculated by template matching based on Eq. (1).*

2) We checked Figs. 4a and 4b and both have the same histogram of "number of pixels" vs. "gray levels". As a consequence, after the best spatial overlap of the two figures (using bloodstains as a reference), the absolute value of the difference of gray levels between Figs. 4a and 4b should give an almost black figure when the two figures are perfectly correlated, or a noisy figure when they have a partial degree of correlation, or a still recognizable face when the correlation is very poor. The result of this pixel-by-pixel calculation is shown in Fig. 6, where a Shroud-like face can be still recognized, thus confirming the poor degree of spatial correlation as a whole of Figs. 4a and 4b.

Figure 6. *Image resulting from digital subtraction of the values of the gray levels of figures 4a and 4b.*

In summary, the above results indicate the spatial correlation of Figs. 4a and 4b is very poor, if there at all. To some extent, this is a surprising result, because our perception suggests that there is a certain resemblance between Fig. 4a and Fig. 4b. In the next Section we illustrate the psychological processes that may explain why we perceive a face in Fig. 4a.

5. 8R41N' 5K1LL 70 5UPPLY M1551NG 1NF0RM4710N

The title of this Section is "Brain' skill to supply missing information" and it is written using numbers and letters. Nevertheless, most of us can read it without problems. This is another example of our capability of retrieving information from incomplete patterns. In the previous Section we have shown that our ability to retrieve incomplete information acts in synergy with the pareidolia effect to interpret false image pixels emerging after image processing, to finally perceive patterns that do not exist in the original low-contrast image. Here we show the pareidolia effect is so powerful that we do not need any image processing to "see" a figure which does not exist: in fact, our mind successfully tries to make sense out of any pattern we can see. As an example, let us consider the frontal body image on the Turin Shroud, see Fig. 7a. This is a real body image; it is not an optical illusion or a pareidolia effect. When zooming into a detail of the belly as shown in Fig. 7b, we cannot see any pattern that makes sense. However, simply by adding a detail of the forehead and hairs from Fig. 7a to the top of Fig. 7b we can obtain an image that looks like a face, see Fig. 8.

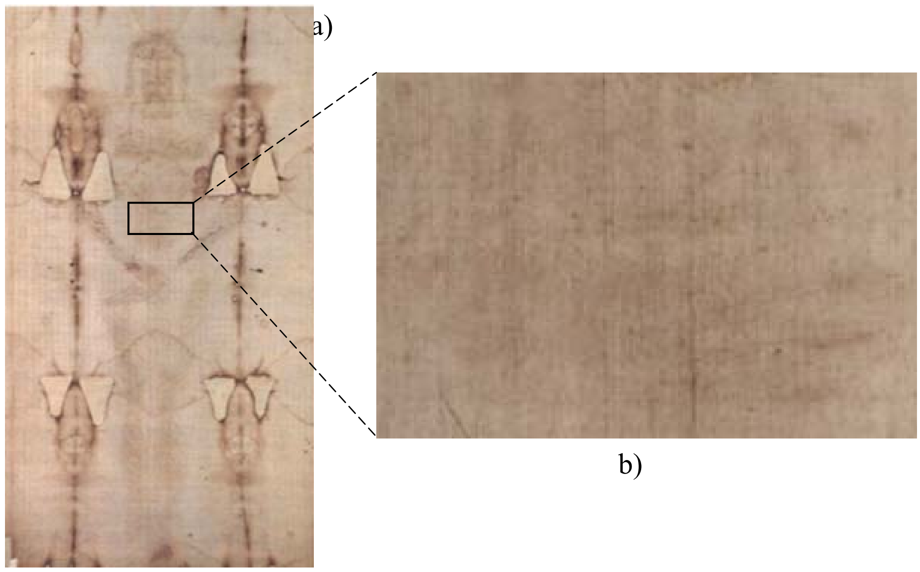

Figure 7. *a) Body image on the Shroud of Turin. b) Enlarged image of the belly of a)*

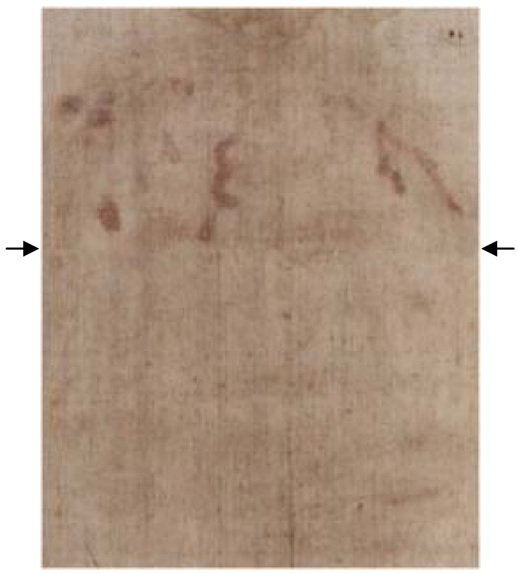

Figure 8. *Pareidolia and Gestalt help to perceive a face when adding the forehead of Fig. 7a to the top of the belly of Fig. 7b. The arrows show where the two figures are joined.*

In the case of Fig. 8, the forehead and its typical bloodstains (in particular the “ε”-shaped bloodstain) may “guide” our brain to select the face of the man of the Shroud as the most similar image we find in our memory. Then, the previously discussed pareidolia and ability to supply the missing information “create” the illusion of nose, mouth chin and long hairs that we perceive in Fig. 8. If we look again at Fig. 7b, we see only stains and cannot identify any nose, mouth or chin. The reason is that we cannot find images similar to Fig. 7b in our memory, and then our brain is forced to spend more time than usual to objectively recognize they are just random stains, whose patterns do not make sense, or better, do not resemble any image memorized in our previous experience.

More in general, the “face” we perceive in Fig. 8 can be explained by the well known fact that our brains are hard-wired to detect the presence of a face as quickly as possible. We have experienced this process since the very beginning of our life, as face-recognition processes are already present in human newborns [23, 24]. As a matter of fact, our visual system has the propensity to rapidly interpret stimuli as faces based on minimal cues, so that many patterns can be perceived as faces [19, 23, 24]. This propensity is clearly shown not only in Fig. 8 but also in Fig. 4a: in fact, at least three faces can be perceived in Fig. 4a, as pointed out in Fig. 9.

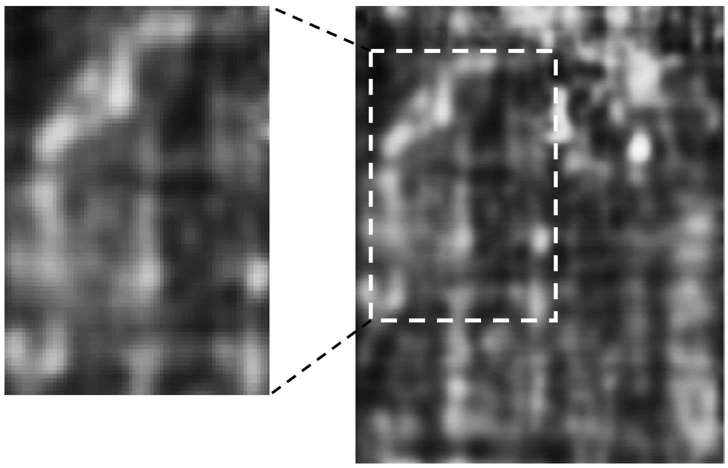

Figure 9. *Right: enlarged view of Fig. 4a. Left: a Shroud-like face we perceive in the top-left part of Fig. 4a (as shown in the right). Another face we can perceive is in the bottom left part of Fig. 4a. Pareidolia and Gestalt produce false positives, allowing to see faces in Fig. 4a that do not exist.*

The above described perception mechanisms that allow to see one “face” in Fig. 8 and more than one “face” in Fig. 4a, together with the poor degree of spatial correlation of Figs. 4a and 4b (see §4.2) suggest the “discovery” of the hidden image of a face-like pattern on the reverse side of the Shroud reported in [20] is due to a combined effect of Gestalt [5], pareidolia [16, 17], and to the fact we have gotten so used to seeing faces everywhere that sensitivity to them is high enough to often produce false positives [19, 23, 24].

6. CONCLUSION

When observing an object, we trigger a complex process involving our eye-brain system. The result of this process is what we call “perception”. Our perception may be subjective in that it is filtered by our experience [1], depends on the relations among the framed objects [4, 5], and it is influenced by our mood and state of mind. Even when the answer to a stimulus is the same for almost all, we cannot be sure that our perception is correct, like in the cases illustrated in Figs. 1, 3, 4a, 8 and 9. In fact, our eye-brain system is very efficient in supplying the missing information in order to make sense out of any pattern we can see [4, 5], thus enhancing pareidolia effects [16]. It should be pointed out that many aspects of perception, including pareidolia, are "automatic", in that they are especially rapid, non-conscious, mandatory and capacity-free [17, 23]. In other words, usually we are not aware when pareidolia deceives our perception.

The limited static contrast of our eyes may render problematic the perception of low-contrast images, as in the case of the various stains on the Shroud. Several works have proposed interpretations of patterns on the Shroud that become visible only after the use of image processing tools, like presumed inscriptions [13], coins [12, 25] and flowers [26] “seen” on the frontal side of the Shroud, as well as a face-like image perceived on the reverse side of the Shroud [20]. The results summarized in Sections 4 and 5 suggest that these “discoveries” and interpretations should be considered interesting tracks to stimulate further studies, but they cannot be considered self-consistent proofs. In fact, we have shown that image processing of recent, high-resolution photographs of the Shroud may lead some to perceive inscriptions and patterns that do not actually exist, see Fig. 3. This is because our ability to retrieve incomplete information acts in synergy with the pareidolia effect to interpret false image pixels emerging after image processing, to finally perceive patterns that “make sense” but do not exist in the original image. In addition, we have shown for the first time that the “discovery” of a hidden image of a face on the reverse side of the Shroud reported in [20] has a very poor spatial correlation with the corresponding face image on the frontal side of the Shroud, see Figs. 4 and 6. As a consequence, it is likely the face-like pattern we perceive on the reverse side of the Shroud after a deep image processing is due to a combined effect of the brain’s ability to supply the missing contours [4], Gestalt [5], pareidolia [16, 17] and to our innate propensity to interpret stimuli as faces based on minimal cues [19, 23, 24], see Figs. 8 and 9.

The validity of the above findings is not limited to the images of the Shroud, as very similar arguments can be used in a number of low-contrast images, like those analyzed e.g., in radiology [27] and forensic science [28]. As an example, studies of expert perception of forensic pattern recognition [29] have revealed that the perception process can be influenced by emotional context, external events, expectation and personal beliefs linked to the observed pattern, in addition to the previously discussed pareidolia, Gestalt and "filling information" ability of our brain.

A method to reduce bias which is used in forensic science is the blind test process. According to the American Bar Association Standard for criminal justice [30] "*testing should follow procedures designed to minimize bias when interpreting test results*" and this can be achieved if the examiner is "blind" to the case's circumstances and other evidences.

A blind investigation could be useful in the case of letters on the Shroud (see figure 2), but it cannot circumvent our innate propensity to interpret stimuli as faces based on minimal cues (figures 4, 8 and 9). The use of clustering [31] in the case of letters and of facial recognition algorithms [32] in the case of face-like patterns may help to obtain objective data for decisions. Table 1 summarizes causes and possible methods to prevent the incorrect perception of the low-contrast patterns discussed in this paper.

Incorrect perception	**Causes**	**Possible solutions**
Letters	Brain supplying missing information [4], Gestalt [5], Pareidolia [16, 17], Lateral neural inhibition [18]	Blind testing [29, 30], Clustering algorithms [31]
Face	Brain supplying missing information [4], Pareidolia [16, 17], innate propensity to interpret stimuli as faces based on minimal cues [19, 23, 24]	Facial recognition algorithms [32]

Table 1. Summary of causes and possible methods to prevent the incorrect perception of the low-contrast patterns discussed in this paper.

In conclusion, we should consider the subjectivity risk and cognitive bias when using image processing tools, because people tend to see what they expect to see but what may not be really embedded in the original, low contrast image. In general, the results illustrated in this paper confirm there is a narrow line between enhancement and manipulation of low-contrast images.

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References

1. See, e.g., V. Bruce, P.R. Green, M.A. Georgeson: *Visual perception: Physiology, Psychology, & Ecology* (Psychology Press 2003).

2. See, e.g., D. Atchison, G. Smith: *Optics of the Human Eye* (Elsevier Health Sciences 2000).

3. A. Mazour, S. King: Design and development of human equivalent inspection system, Proc. SPIE **3016** (1997) 223-229).

4. G. Kanizsa: Subjective contours, Scientific American **234** (1976) 48-52.

5. M. Wertheimer: *Gestalt theory,* (Hayes Barton Press, 1944).

6. E.H. Adelson: Lightness Perception and Lightness Illusions *The New Cognitive Neurosciences*, 2nd Ed., M. Gazzaniga ed. Cambridge, MA: MIT Press, pp. 339-351 (2000).

7. See, e.g., S. Tolansky: *Optical illusions* (Pergamon Press, Oxford 1964). Updated illusions may be found in http://illusioncontest.neuralcorrelate.com/ Retrieved 2012-9-19

8. B.J. Culliton: The mystery of the Shroud challenges 20th-century science, Science **201** (1978) 235-239.

9. L.A. Schwalbe, R.N. Rogers: Physics and chemistry of the Shroud of Turin, a summary of the 1978 investigations, Analytica Chimica Acta **135** (1982) 3-49.

10. E.J. Jumper, A.D. Adler, J.P. Jackson, S.F. Pellicori, J.H. Heller, J.R. Druzik: A comprehensive examination of the various stains and images on the Shroud of Turin, Archaeological Chemistry III, ACS Advances in Chemistry **205** (J.B. Lambert ed. American Chemical Society, Washington 1984) pp. 447-476.

11. L.R. Doyle, J.J. Lorre and E.B. Doyle: The application of computer image processing techniques to artifact analysis as applied to the Shroud of Turin study, Studies in Conservation **31**, (1986) 1-6.

12. C.A. Pickover: Rendering of the Shroud of Turin using sinusoidal pseudocolor and other image processing techniques, Computers & Graphics **12** (1988) 81-90.

13. A. Marion: Discovery of inscriptions on the shroud of Turin by digital image processing, Opt. Eng. **37** (1998) 2308-2313.

14. M. Guscin: The 'Inscriptions' on the Shroud, British Society for the Turin Shroud Newsletter (1999). Available at www.shroud.com/pdfs/guscin2.pdf Retrieved 2012-9-19

15. B. Schwortz: Science by press release. Editorial response by Barrie Schwortz, (2009). Available at www.shroud.com/pdfs/schwortzedit02.pdf Retrieved 2012-9-19

16. G. Reed: *The Psychology of Anomalous Experience: A Cognitive Approach* (Buffalo NY Prometheus Books, 1988).

17. See, e.g., J. Voss, K. Federmeier, K. Paller: Neural hallmarks of conceptual processing associated with finding novel shapes subjectively meaningful, Cerebral Cortex 22 (2012) 2354 – 2364.

18. G. Von Békésy: *Sensory Inhibition* (Princeton University Press, 1967).

19. N. Hadjikhani, K. Kveraga, P. Naik, S. Ahlfors: Early (N170) activation of face-specific cortex by face-like objects, Neuroreport **20** (2009) 403-407.

20. G. Fanti, R. Maggiolo: The double superficiality of the frontal image of the Turin Shroud, J. Opt. A: Pure Appl. Opt. **6** (2004) 491-503.

21. G. Ghiberti: *Sindone le Immagini* (ODPF Torino, 2002).

22. N. Balossino: Sul retro della Sindone non vi è impronta: osservazione diretta ed elaborazioni informatiche, Sindon **19** (2003) 57-69.

23. R. Palermo, G. Rhodes: Are you always on my mind? A review of how face perception and attention interact, Neuropsychologia **45** (2007) 75-92.

24. A J. Calder, G. Rhodes, M. Johnson: *The Oxford Handbook of Face Perception* (Oxford University Press, 2011).

25. A.D. Whanger, M. Whanger: Polarized image overlay technique: a new image comparison method and its applications, Appl. Opt. **24** (1985) 766-772.

26. A. Danin, A.D. Whanger, U. Baruch, M. Whanger: *Flora of the Shroud of Turin* (Missouri Botanical Garden Press, St. Louis MO, 1999).

27. L. Berlin, R.W. Hendrix: Malpractice issue in radiology: perceptual errors and negligence, American Journal of Roentgenology **170** (1998) 863-867.

28. S.A. Cole: More than zero: Accounting for errors in latent fingerprints identification, Journal of Criminal law & Criminology **95** (2005) 985-1078.

29. See, e.g., I.E. Dror, S.A. Cole: The vision in 'blind' justice: expert perception, judgment, and visual cognition in forensic pattern recognition, Psychonomic Bulletin & Review **17** (2010) 161-167.

30. http://www.americanbar.org/groups/criminal_justice/policy/standards.html Retrieved 2012-9-19.

31. C. D. Manning, P. Raghavan, H. Schutze: *Introduction to Information Retrieval* (Cambridge University Press, 2008).

32. X. Tan, S. Chen, Z. Zhou, F. Zhang: Face recognition from a single image per person: A survey, Pattern Recognition **39** (2006) 1725-1745. See also I. Naseem, R. Togneri, M. Bennamoun: Robust regression for face recognition, Pattern Recognition **45** (2012) 104-118.