QUANTIFICATION OF THE EFFECT OF SYMMETRY IN FACE PERCEPTION

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ABSTRACT

QUANTIFICATION OF THE EFFECT OF SYMMETRY IN FACE PERCEPTION

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Facial symmetry has been a central component in many studies on face perception. The relationship between bilateral symmetry and subjective judgments on faces is still arguable in the literature. In this study, a database of natural looking face images with different levels of symmetry is constructed using several digital preprocessing and morphing methods. Our aim is to investigate the correlations between quantified asymmetry, perceived symmetry and a subjective judgment: 'attractiveness'. Images in the METU-Face Database are built to represent three levels of symmetry (original, intermediate, and symmetrical) within five classes which also represent the orientation of bilateral symmetry: left versus right. In addition, the asymmetry of original images is quantified using a landmark-based method. Based on the theory of holistic face perception, we introduce a novel method to quantify facial asymmetry wholesomely: Entropy-based quantification. In Experiment 1 and 2, images were rated on attractiveness judgments and on perceived symmetry, respectively. Results indicate that landmark-based quantifications were not sufficient to account for perceived symmetry ratings (SRs), but they revealed that as the vertical deviation of the symmetry decreases, attractiveness rating (AR) collected from that face increases. Moreover, morphing classes and their relationship to both ARs and SRs were highly correlated. Consistent with the previously done research, symmetrical images were found more attractive. We found that although ARs were the same for left versus right composites, for SRs, there is a significant difference between left and right. Finally, a more elucidative quantification approach for subjective face perception is achieved through significant correlations of entropy scores with both ARs and SRs.

Keywords: Attractiveness, entropy, facial symmetry, landmarking, perceived symmetry.

ÖZ

YÜZ ALGISINDA SİMETRİNİN ETKİSİNİN ÖLÇÜLMESİ

DÖVENCİOĞLU, N. Dicle

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Yüz algısı üzerine yapılan birçok çalışmada simetri önemli bir nokta olmuştur. Literatürde yüzün simetrisi ve yüzlerle ilgili öznel yargıların ilişkisi halen tartışmaya açıktır. Bu çalışmada çeşitli dijital işlemler ve bir animasyon yöntemi kullanılarak doğal görünen fakat değişik simetri düzeylerinde olan resimlerden bir veritabanı oluşturulmuştur. Amaç, ölçülen simetri, algılanan simetri ve bir öznel yargı (çekicilik) arasındaki ilintiyi araştırmaktır. ODTÜ-Yüz Veritabanındaki resimler beş simetri sınıfına ayrılırlar; bu sınıflar üç seviye (orijinal, ara değer ve simetrik) simetriye ve de sağ ve sol ayrımı olacak şekilde simetrilerin yönüne göre ayrılmıştır. Orijinal resimlerde ayrıca sınır işaretleri kullanılarak asimetri ölçümü yapılmıştır. Bütünsel yüz algılama kuramlarına dayanarak yüz asimetrisini ölçmek için yeni bir de method tanıtmaktayız: Entropi ölçümü. Birinci ve ikinci deneylerde resimler sırasıyla çekicilik ve algılanan simetriye göre notlandırılmışlardır. Sonuçlara göre sınır işaretlerine dayalı ölçümler algılanan simetriyi açıklamaya yeterli değildir; fakat yüzlerin simetrisindeki dikey dalgalanma azaldıkça o yüzün aldığı çekicilik puanlarının arttığı saptanmıştır. Bundan başka, simetri sınıflarının farklılıklarının hem çekicilik hem de algılanan simetri notlarına yansıdığı görülmüştür. Önceki araştırmalara benzer olarak simetrik yüzlerin daha çekici bulunduğu gösterilmiştir. Çekicilik yüzün sağ veya sol tarafına göre değişik algılanmazken, simetri algısı için bu farkın önemli olduğu bulunmuştur. Son olarak, entropi değerlerinin algılanan simetri ve çekicilik ile bağıntılı olduğu bulunmuş, ve entropiye dayanan ölçümlerin öznel yüz algısı çalışmaları için daha açıklayıcı bir teknik olduğu gösterilmiştir.

Anahtar Kelimeler: Çekicilik, entropi, yüz simetrisi, sınır işaretleri, algılanan simetri.

“Anneme ve Babama”

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CHAPTER 1

INTRODUCTION

"Imago animi vultus est, indices oculi."

M. T. Cicero[†]

To describe a person we refer to facial descriptions very often, and identify peoples' look mostly on how we see their faces, such as a happy looking girl, or a frightened little boy. In our daily lives, we rely on the percept of faces so much that police sketches are considered as official records. Faces are not only

[†] The countenance is the portrait of the soul, and the eyes mark its intentions. (M. Tullius Cicero, *De Oratore* (ed. A. S. Wilkins), III, 221.)

important in terms of introspection; they are also studied systematically in cognitive science. Human infants are able to recognize faces starting at a very early age, faces are found to be perceived differently than other objects; and a face image activates a widely distributed area in the human cortex. We are better at detecting a face in a crowded scene than any other sophisticated computer algorithm. Face perception is a high level cognitive function: despite the geometrical complexity, our visual system can identify a face at an instant; detect the face holder's gender, age, or even his/her intentions towards us.

Faces have been intriguing to evolutionary psychological researchers because of the bilateral symmetrical configuration they posses. In the literature, symmetry is correlated with subjective judgments a face reflects, such as attractiveness, healthiness, and trustworthiness. Symmetry is believed to signal health and beauty, and hence its role in mate choice is also deeply investigated through both humans and animals. It is commonly accepted that how much a face is found attractive is dependent on the symmetry of the face. Facial symmetry literature accommodates several techniques to identify different symmetry classes. To start with, original face images may be converted to symmetrical images by image processing tools, and attractiveness ratings for two classes, symmetrical versus original may be compared. In a study by Swaddle and Cuthill (1999), similarly morphed images revealed that more symmetrical images are rated more attractive. A more intense way to quantify facial symmetry is to mark feature points (landmarks) on a face and evaluate distances of these. For instance, Simmons *et al.* (2004) used landmark-based quantifications, and compared original faces' quantification results with their attractiveness ratings and found that if a face is originally less symmetrical then it is perceived as more attractive. This finding is controversial with the finding of Swaddle and Cuthill. Unfortunately, from these two studies, a joint result such as ‘the eye is less sensitive to the asymmetry in landmarks in comparison to the asymmetry of the whole face’ cannot be deduced because these two studies used completely different set of images, asymmetry measurement procedures as well as ratings of the subjective asymmetry judgments. A thorough search of the literature indeed reveals a multitude of incompatible methodology, which introduces a prohibiting factor to explain the inconsistent findings.

One of the main motivations for this study is the lack of natural looking symmetrical face images to be used as stimuli. Faces are crucial for us and we eventually become face experts (Gauthier, 1997) during lifetime. Hence, unnaturalness of a face image is an important deficit, in the sense that it may be detected easily by any observer, introducing confound in ratings. Moreover, previous studies, when they imply an effect of symmetry on the level of attractiveness of a face, used morphed faces, but did not quantify symmetry more than several discontinuous points: symmetrical, asymmetrical (Mealey *et al.*, 1999) and -sometimes, intermediate symmetrical (Swaddle & Cuthill, 1995). Therefore another motivation is eliminating this type of discontinuity and finding a continuum to represent quantifications of facial symmetry. On the other hand, landmark-based methods set better ground for facial symmetry quantification than morphing; but they are only applied to original faces in the literature; hence could only be compared with subjective ratings collected from original images. In summary, related research either use morphing techniques to build symmetrical face images, or quantify only original images to investigate subjective ratings on faces, but none of them bring out a sound methodology for correlating subjective judgments on images with different levels of facial symmetry.

The present thesis, first, aims to morph five classes of symmetrical images from original face photographs, while preserving their natural looks. Quantification of the symmetry possessed by a face will then be held using two methods. First, related with the literature, facial symmetry will be quantified using a landmark-based method on original images. Second, we will quantify original and symmetrical images with an entropy-based method, which is novel to the field of subjective face perception, and return quantification results in a continuum. Another objective of this thesis is to challenge all of these measures of facial symmetry with respect to attractiveness ratings collected from human subjects.

Similarly, facial symmetry quantifications will also be compared with perceived symmetry ratings of the human subjects.

All quantification results are expected to correlate with both perceived attractiveness and perceived symmetry ratings. Initially, landmark-based results will be challenged with attractiveness ratings of original images. Consistent with the literature, an original face is anticipated to be more attractive as its level of symmetry increases. Next, morphing results will be examined to see whether different classes of symmetrical images (e.g. original, symmetrical, mirror images) acquire different ratings. Both attractiveness and perceived symmetry ratings are expected to be higher for images with higher levels of symmetry (highest for full symmetrical images). Finally, our novel method to quantify holistic symmetry of faces is predicted to correlate with both subjective judgments on faces and perceived symmetry: ratings are presumed to be higher for lower entropy quantification results, hence symmetrical images.

Remainder of this thesis consists of three chapters. In chapter 2, essential examples from related literature will be given to set ground for face perception, symmetry perception and perceived subjective judgments on faces. The following chapter covers details for the methods we used to prepare stimuli, experimental procedures and statistical analyses of current study as well as limitations. Finally, in the fourth chapter, our results are interpreted and opinion for future work is also suggested in the last chapter.

CHAPTER 2

LITERATURE REVIEW

This chapter starts with a section elaborating on face perception; regarding the developmental importance, basic theories, neural correlates and computer algorithms of the way we perceive faces. Then in the next section symmetry is reviewed starting with its types and common definitions in the literature, and research involving perception of symmetrical patterns. This section is followed by related examples from previously done research investigating the relationship between facial symmetry and the percept of face for humans. Methods for quantification of facial symmetry in both two- and three-dimensional images and constructing symmetrical images are further reviewed in the fourth section. Finally current study's intent to compensate for the discrepancies in the facial symmetry quantification field is asserted.

2.1. FACE PERCEPTION

2.1.1 Developmental psychology

Decoding faces and facial expressions is the first frontier in social communication, and it has a vital priority among all sorts of cognitive functions. From the perspective of developmental psychology, faces are crucial because acquisition of faces occur so early that babies identify face-like patterns in the first hour they are born, and are able to recognize their mother from the first several hours on (Pinker, 1997). Apart from visual attention to mother's live face, preference for a facial configuration (2d sketches of facial features) is also shown among minutes old neonatal infants (Sai, 2005). Response to the half profile and profile of mother's face is available after 4-5 weeks and 10-12 weeks, respectively (Sai, 1990). However, the results on such research still fail to answer the question whether infants learn their mother's faces depending solely on their visual abilities or intermodal experiences play the major role during face learning; hence further research controlling mother's odor, voice, tactile sense of warmth or even heartbeat is needed for a solid conclusion.

2.1.2. Cognitive Psychology: Holistic Face Perception

In addition to infants rapidity on learning faces compared to other complex objects, studies done with adults also reveal a special level of processing for face stimuli. A line of evidence that faces may be perceived differently in comparison to other objects results from psychology experiments. Just like other visual context effects in psychology such as *word superiority effect* (Johnston and McClelland, 1973), face parts are found to be better perceived when presented as a normal face stimulus compared to a set of scrambled constituent parts as stimuli.

This effect in face recognition paradigms is called *face superiority effect* (Purcell and Stewart, 1988).

Face perception is also specially influenced by the orientation of the stimulus than any other object recognition. Earlier studies with normal individuals suggest that inverted faces take longer time to identify than their upright originals. This effect, known as the *face inversion effect,* is independent from the face stimulus since its complexity and image properties like brightness and contrast remain same when you invert a face stimulus. Hence longer reaction times for perceiving an inverted face may only be explained based on related brain activity (See, for a review, Valentine, 1988). Unlike results attained from adults, children (of maximum 10 years old) show no latency for stimulus orientation when remembering faces (Carey and Diamond, 1977); they almost equally remember upright and inverted face photographs, where facial appendages suffice to convince them that the photograph belongs to a different individual. These differences in children's face perception are explained with the immaturity of right cerebral hemisphere by authors.

Both face superiority effect and inversion effect support holistic representation of faces. "*We take as a starting point the idea that visual object representations are hierarchically organized, such that the whole object is parsed into portions that are explicitly represented as parts.* [...] *In this context, the claim that faces are recognized holistically would mean that the representation of a face used in face recognition is not composed of representations of face's parts, but more as a whole face* (Tanaka and Farah, 1993, p.226)". Tanaka and Farah argue their point in the light of three experiments. In each experiment they compare whole face identification to three sets of stimuli: scrambled faces, inverted faces and houses. As a result of their first and second experiments, identification of individual face features is more accurate when presented in whole face images compared to scrambled face stimuli (Experiment 1) or inverted face stimuli (Experiment 2).

They further investigate holistic object perception in their third experiment: house parts did not show any advantage when displayed in a whole house image over individual house part displays, either. In other words, spatial organization of facial features is as important as the features themselves.

2.1.3. Neurobiology of Face Perception

Faces contain more personal information than any other body part and are important for us in several ways: 1) they are complex stimuli, in geometrical means, compared to other visual objects we encounter in everyday life. 2) Information reflected by a face is more than geometrical visual signals, they are crucial for communicating emotions and intentions between people. 3) Verbal communication is highly dependent on visual information acquired from the face; complementary roles of lip movements, eye gaze and facial gestures are indispensable for social communication. With all these data our faces convey, undoubtedly, brain functions underlying face recognition are complex.

Face perception has been central to visual cognition research for decades. Recent theories in functional neuroanatomy concerning perception of faces do not coincide: While some researchers argue that there is a brain region specifically attributed to faces, namely the *fusiform face area*, others reject this modularity hypothesis and depict that the process is an expertise for faces in object recognition. Still ongoing debate follows mainly two branches of research groups: Kanwisher *et al*. (1997), in their functional magnetic resonance imaging (fMRI) experiments, challenge the face responsive area in the brain with diverse experimental manipulations and conclude that the area is *specific* to face processing. On the other hand, Gauthier and Tarr (1997) object to previous studies` experimental designs and they find a similar activation in this putative face area even when they use non-face stimuli. They further expand this result to an expertise framework, replicate their findings with car and bird experts (2000), and finally suggest that this so called face area is in fact involved in subordinate level object recognition. Since we are exposed to faces so often, we have been face experts, they suggest; faces are perceived and processed in a subordinate level despite the complexity they possess.

Face perception is a very complex cognitive function to be localized at a restricted domain in the cortex. Hence models suggested for face perception recruit more than a single cortical domain. Moreover, thorough models for face perception include cortical mechanisms, as well as subcortical structures such as amygdala, superior colliculus and pulvinar. A widely distributed neural model for face perception was proposed by Haxby, Hoffmann and Gobbini (2000) which involve a continuous large area in the brain along with previously mentioned face responsive areas. Low spatial frequency information acquired from a face image is often reported to be used for detection of a face, which at the same time provides emotional information (such as fear), or direction for the eye gaze; and this kind of information is rapidly processed by a subcortical face processing system (See Johnson, 2005 for a review). Recognizing the identity of a face, on the other hand, entertains high spatial frequency information, and is related to cortical processing of faces. These two routes for face processing are not dissociated; but it is suggested that subcortical pathway modulates cortical domains when perceiving faces.

In addition, there exist distinctive neurological cases such as deficits specific to face recognition coexisting with intact object recognition (prosopagnosia, Damasio, 1982), or lack of learning novel faces when object learning is preserved (prosopamnesia, Tipplett, Miller, Farah, 2000). Examples of these neurological cases set further evidence for the distinctiveness of faces in object perception for human.

2.1.4. Face recognition algorithms

Data projecting to computer science help computer models of face recognition to rely on human perceptual system. For instance, perception of facial symmetry in humans' face processing is supported by studies from Carnegie Mellon Robotics Laboratory. The lack of quantitative studies for facial asymmetry motivated Liu et al. (2003) to conduct a study where they considered facial asymmetry as *"a continuous multidimensional statistical feature"* (Lui et al., 2001, p.3). They found that specific facial asymmetry measures which are stable to expression variations affect identification of faces by humans. With this new biometric they define, it is shown that distinct facial asymmetries provide complementary information for automatic face identification tools.

2.2. SYMMETRY IN BIOLOGY AND EVOLUTIONARY PSYCHOLOGY

Physical appearance of many biological creatures is symmetrical. Paired body parts such as limbs, wings, sensory organs are equally distributed at each side of the body. In evolutionary science, this trend in *phenotypes* is considered as a reflection of organism's genotypic characteristics. Here, genotype is considered as all genetic characteristics of animate organisms; however phenotype frames directly observable physical appearance unlike its broad sense including blood type, fingerprints, behavior, etc. When we consider a scale of human perception the symmetric trend in phenotypes is never perfect; deviations from symmetry, i.e. *asymmetries*, are always present. Occurrences of asymmetry are thought to be due to the environment's developmental effects on creatures' gene characteristics, or results of different functionality. Symmetry is intriguing for many research fields such as mathematics (see Section 2.2.1), but human morphology directs to two types of asymmetry found in nature: It may occur consistently towards one direction throughout the population, such as human body normally having heart on the left side. There may also be inconsistent asymmetries specific to individuals, implicating small and random differences within a single organism, moreover, normally distributed in the population. The former notion is referred to as *directional asymmetry* whereas the latter is called *fluctuating asymmetry*. Fluctuating asymmetry (FA), is central to this thesis and it is considered as an indicator of developmental, genetic, environmental instability. In other words, FA is thought to arise in the presence of environmental stress and/or genetic factors which keep the organism from stable development. Hence the perfection in genetic quality is thought to be reflected in more symmetrical phenotype. Together with this, many animal species are consistently thought to perceive symmetry in their potential sexual mates. Functionally, human visual system is believed to involve mechanisms finely tuned to detect deviations from symmetry which imply bad genes thus poor health (Swaddle, 1999).

2.2.1. The Definition of Symmetry

Symmetry notion has been appealing to scientists, philosophers and artists for millennia. Interestingly, before its modern definition was made during 19^{th} century, symmetry had a different understanding in Greek antiquity (Gr. summetria), basically it meant *proportionate*. Hon and Goldstein (2008) elaborate this difference in meaning in their recent review:

"*Its* [symmetry's] *usage can be distinguished by the contexts in which it was invoked: (1) in a mathematical context it means that two quantities share a common measure (i.e. they are commensurable), and (2) in an evaluative context (e.g., appraising the beautiful), it means well proportioned.* [...] *The coherence of* *these two trajectories corresponds to two distinct senses of the concept of symmetry: (1) a relation between two entities, and (2) a property of a unified whole, respectively.* (p.2)”

In the 19th century, the circumstantial notion of symmetry took its significant place to shed light in physics, chemistry, biology and other sciences. It was after French mathematician Legendre's (1752-1833) symmetry definition, the modern world acquired recent usage of symmetry, which, then brought E.P. Wigner (1902-1995) the Nobel Prize in physics for his contributions to particle physics with an application of fundamental symmetry principles.

Together with all sciences, symmetry notion takes its essential place in the branches of mathematics, not to mention that these branches accommodate the most concrete definitions of symmetry. Along with geometry, functional analysis, algebra, differential equations, etc. every field in mathematics has an essential use of symmetry notion, such as to understand equations or matrices, to define algebraic group structures, or to position around coordinate systems. Accordingly, many kinds of symmetry definitions exist in mathematics; however, in the scope of this study, it is conventional to dismiss many other types but to concentrate on the geometrical interpretation.

In spatial concern, symmetry of a function *f* with respect to y-axis may be defined as follows:

$$f(x,y) = f(-x,y) \qquad \text{Eqn. 1}$$

With this equation, points in f come in pairs and their distances to y-axis, the symmetry axis, are always equal.

Definitions in visual symmetry detection literature also refer to mathematical notions:

"Informally, symmetry means self-similarity under a class of transformations, usually the group of Euclidean transformations in the plane, that is, translations, rotations, and reflections (also collectively denoted by 'isometries'). (Wagemans, 1996, p.26)"

In other words, geometrical objects are considered symmetrical if the object remains same through certain transformations. For instance an equilateral triangle has six symmetry groups:

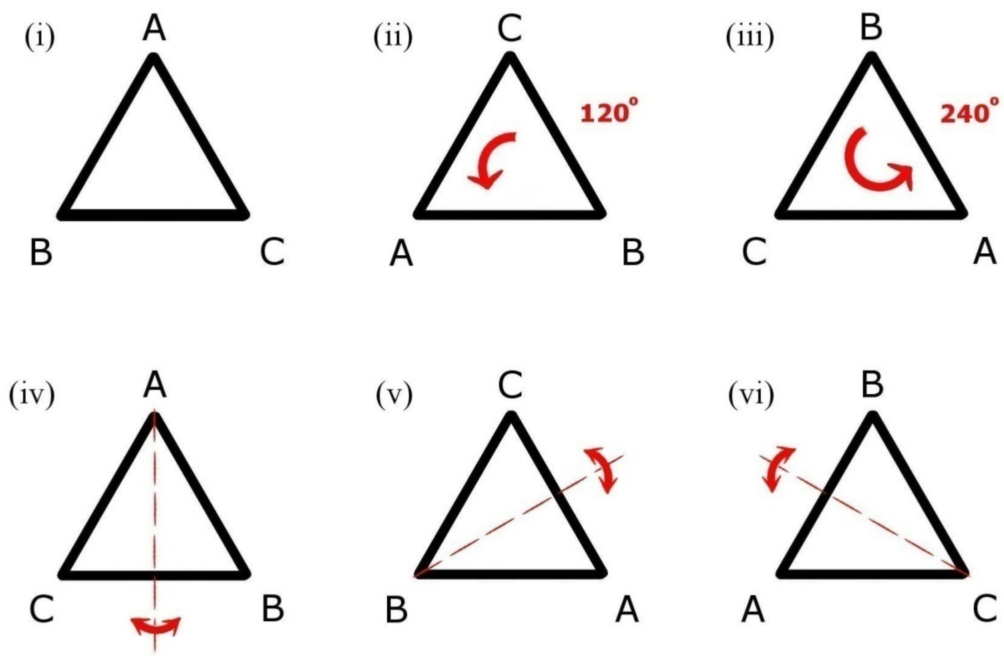

Figure 1: Symmetry groups of ABC triangle (i) are shown: Rotation by 120 degrees (ii), rotation by 240 degrees (iii), mirror reflections with respect to symmetry axes passing through A, B, C vertices (iv, v, vi, respectively).

On the other hand, objects need not necessarily be wholly symmetrical, but they might contain symmetrical parts, which is better emphasized in the following definition:

"Symmetry is a general concept that refers to any manner in which part of a pattern may be mapped on to another part (or the whole pattern onto itself)."(Tyler 2002, p.3)

Symmetries occur from compositions of some basic transformations: Translation, rotation, reflection and scaling (See Figure 2).

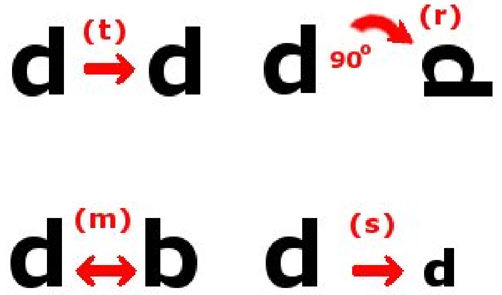

Figure 2: Basic transformations for symmetrical forms: Translation (t), rotation, 900 here (r), mirror reflection (m), and scaling (s).

There are other kinds of symmetrical patterns such as helical symmetry (e.g. models of DNA), rotational symmetry, repetition symmetry, and symmetry involved in fractals which are certain combinations of previously listed basic transformation steps (see Figure 3).

Figure 3: Examples of rotational (i), repetition symmetries (ii) and fractals (iii).

2.2.2. Perception of Symmetry

We are exposed to all kinds of symmetry in almost every instant of life. Animals possess a mirror symmetry with respect to the axis of their movement through the environment, or if their locomotion is not linear (e.g. starfish or jellyfish) they have cylindrical or multifold symmetry. Plants, on the other hand, reveal various kinds of symmetry which are explained due to gravitational effects, principle of economy of design, or their motion direction. For instance, trees exhibit cylindrical or helical symmetry in their organization of leaves and branches, plus repetition symmetry with numerous similar leaves, and there is bilateral symmetry within each leaf. Crystals, although being considered as perfectly symmetrical, are not found isolated in nature, neither their symmetry is visible at human scale. Artificial objects also represent the symmetry present in nature either for functional purposes (e.g. two-armlet chairs conforming the bilateral symmetry of human body), because of inspiration from nature (e.g. airplanes), or for aesthetically pleasing purposes (See below).

Table 2: Types of symmetries present in nature (adopted from Tyler, 2002, p.11)

Vertebrate animal	Mirror symmetry
Invertebrate animal	Mirror and repetition symmetry
Vegetable	Multiple symmetries (emphasizing repetition, scale, cylindrical, helical and multifold)
Mineral	None (at the macroscopic scale)
Constructed	Multiple symmetries (emphasizing two-fold)

Within an environment designed by the rules of symmetry, it is inevitable for organisms to develop visual mechanisms adapted to perceive symmetry. Symmetry perception is studied among many creatures such as rhesus macaques (Sasaki *et al.*, 2005), pigeons (Delius and Novak, 1982), bees and flower-visiting insects (Menzel, Giurfa, and Eichmann, 1996). Human infants (4 months old) are also shown to discriminate symmetrical patterns from asymmetrical ones (Bornstein, Ferdinandsen, and Gross, 1981), which suggests the role of symmetry perception in human ontogeny.

Symmetrical properties of objects are considered to be special on account of visual representation:

"*Most studies in pattern recognition are based on a past memory of a recognized object and therefore deal with the nature of representation in memory. Symmetry perception is distinct, however, in that it is based on a comparison of representations in immediate perception rather than memory. (Tyler, 2002, p.12)*"

Among various types of symmetrical structures, mirror symmetry is paid special attention in visual perception literature. It is experimentally demonstrated that mirror symmetry is a salient visual property (Cohen & Zaidi 2007). Salience of mirror symmetry is challenged in psychophysical experiments by manipulating stimulus size and complexity and analyzing reaction times; where latencies indicate serial or parallel visual search mechanisms.

In a study by Baylis and Driver (1994), stimuli consisting of (mirror) symmetric and repetition symmetric boundaries were used in two experiments. In their first experiment, rectangular like block shaped stimuli differed both with respect to their symmetry axes (vertical and horizontal) and their boundary asymmetries (mirror symmetric and asymmetric). In the second experiment, they used similarly organized types of stimuli, but shapes with repetition symmetrical boundaries were used instead of mirror symmetrical boundaries. The task was to judge whether a shape has symmetrical contour in the first experiment, and to judge whether it has a repeated contour in the second. Stimuli were manipulated with respect to the complex of boundary properties (steps changing from 4-8 to 16 discontinuities in the boundary), symmetry conditions, and orientation of the symmetry axis. As a result of data collected from both experiments, it is found that repetition symmetry judgments were affected from the complexity of the stimulus significantly, whereas (mirror) symmetry judgments did not show significant delays for stimulus complexity. Authors concluded that symmetry perception was preattentive providing evidence for the salience of mirror symmetry: "*We found that* [mirror] *symmetry perception appears to operate in parallel for single shapes, but repetition is apparently detected by serial checking.* (p.398)"

Along with behavioral results, brain imaging data also show specialized cortical domains for symmetry perception; moreover there is ongoing fMRI research to demonstrate distinctive activation for facial symmetry rather than object symmetry.

In an imaging study investigating symmetry perception with random dot and line stimuli, authors located several areas in both human and macaque visual cortex specific to symmetry perception (Sasaki *et al.*, 2005). Random patterns were sparse white dots on a black background, and symmetry was controlled with the percentage of randomly placed dots. Highly significant activation in the human extrastriate cortex, especially in the areas V3A, V4v/d, V7 and lateral occipital was reported. Contrary to these higher level visual areas, there was no specific activation in the primary visual cortex, namely in V1 and V2. Functional MRI data obtained from macaque visual cortex was also present but with relatively weaker sensitivity to symmetry than humans. In relation to previously mentioned psychophysical study (Baylis and Driver, 1994), Sasaki and others, in one of their experiments, compared symmetrical patterns with tilings and repetitions; the cortical regions which showed symmetry sensitivity were neither activated by repetition patterns nor tilings. In addition to cortical activation, authors also collected judgments from the subjects by asking whether the same stimuli are symmetric outside the scanner; and they have reported high correlation between fMRI activity and percept. This correlation result and weakness of monkey response to symmetry were together suggested to demonstrate that symmetry perception needs cortical calculation, i.e. it is not at a neuronal level.

Yet another thorough study that requires special attention was conducted by Chen and others (2006). Authors investigated how humans process facial configurations throughout several fMRI experiments and they used various types of visual stimuli: 2D frontal face images from FERET database (**see Chapter 3),** inverted faces, ¾-view faces together with symmetrical and asymmetrical scrambled images derived from a frontal face image set (see Section 2.3.2 for methods used). Symmetry was considered in two fashions: Image symmetry (2D) and object symmetry (3D, challenged by using ¾ -view images compared to frontal faces). Authors first found face sensitive areas convenient with previous literature (fusiform, inferior and middle occipital gyri, superior temporal and intraoccipital sulci); and symmetry sensitive areas (mainly middle occipital gyrus and intraoccipital sulcus but not fusiform or occipital face areas). Activity related to facial configuration was observed with upright versus inverted face images in the fusiform, inferior and middle occipital gyri, around the intraoccipital sulcus and precuneus. It was deduced that occipital face area might be involved in symmetry processing specific to faces. Finally, contrasting face sets for 2D and 3D symmetry perception to understand viewpoint dependence revealed activation in middle occipital gyrus and intraoccipital sulcus. Together with the evidence they provide for facial symmetry perception literature; these results also contribute the theory of holistic face perception and they suggest that humans process faces independent of the viewpoint.

2.3. SUBJECTIVE JUDGEMENTS ON FACES

Faces serve as the controlling information for interaction between people, while communities reflect our species' adeptness in social interaction. In evolutionary perspective, bodily, particularly facial symmetry has been appealing to explore mate choices in humans, and subjective judgments for unfamiliar faces have been central to evolutionary psychology research regarding how we process faces. In a study done with normal and symmetrical face images (see Section 4), different characteristics of faces are thought to exist in either halves of the face (Zaidel, Chen, German, 1995). Symmetrical images of women consisting of two right half-faces were found to be more attractive than left-left composites. In the same study, a second experiment revealed that smile is more salient on the left-left composite images of both men and women. The latter finding is consistent with the literature suggesting that facial expressions are more salient on the left side; which may be explained facial muscles being dominated by both ipsilateral and contralateral hemispheres.

The relation between perceived health and attractiveness on faces led to another field of research investigating healthiness extracted from faces. In a different study by the same group of researchers women's faces were rated healthier in right-right composite images where no face side difference arose for men (Reis, Zaidel, 2001). Comparing these results with their previous findings (Zaidel, Chen, German, 1995) authors also reported correlated ratings for perceived attractiveness and healthiness in faces. In women's faces a correlation between trustworthiness and attractiveness is also reported (Zaidel, Bava, Reis, 2003), suggesting that symmetry is connected to *trustworthiness* as well in a remote fashion.

Several experiments reported correlations between symmetry levels and perceived attractiveness of a face. Within these studies the symmetry possessed by the face has been referred to as an attribute of facial attractiveness (see Thornhill, Gangestad, 1999 for a review). Direct effect of symmetry on facial attractiveness is hard to isolate because Thornhill and Gangestad (1999), in their review, combine two important confounds of facial attractiveness to symmetry: *averageness* and *sexual traits*. Average faces can be constructed by compositing individual faces over each other, and they are shown to be more attractive than individual faces. Averageness of a face can also be metrically measured by its features, and the preference for average facial features may be shown in individual faces (Grammer, Thornhill, 1994). Sexual traits are considered to be dimorphisms[1], i.e. hormone markers in facial characteristics of male and female faces. In puberty, testosterone levels affect the growth of the cheekbones,

[1] Differences for men and women

mandibles and chin, together with the lengthening of the lower facial bones of male faces. Similarly, in pubertal females, estrogen levels cause fat deposition, i.e. enlargement of the lips and upper cheek area, and prevent growth of the bony structures typical to male faces. These characteristics determined by sex-hormones are also reported to be perceived as more attractive. These studies have shown that facial configurations other than symmetry also play an important role in our subjective judgments about a person.

In the literature, the role of symmetry as a positive or a negative effect on facial attractiveness (Grammer, Thornhill, 1994; Swaddle, Cuthill, 1995) remains equivocal. While some results suggest that symmetry implies facial attractiveness; others report evidence for symmetric faces being perceived less attractive.

There are various examples which attempt to evaluate the effect of symmetry on the subjective perception of faces, implicated by 'attractiveness'. In a study by Swaddle and Cuthill (1995), symmetric faces were created from composites of the original face and the whole mirror image of it. Intermediate level faces, namely nearly symmetric and nearly asymmetric, were also used as stimuli. Stimuli are also prepared such that the hair, ears and neck are excluded by placing a black ellipse around faces creating an unnatural background. Thirty-seven male and 45 female subjects were instructed to rate images from 1 (least attractive) to 10 (most attractive). No effect of sex on facial attractiveness ratings was found, i.e. female and male raters were almost equally generous to images when rating, but images that belong to female individuals were rated as more attractive. Authors reported that attractiveness rating of a face decreased as its symmetry level increase, most importantly, this was due to an overall effect of manipulation on images. Although the composite faces used in this study come up with *averageness* effect, which is previously considered as a part of facial attractiveness, average faces (symmetric face images, here) are not rated as the most attractive ones. Another objection would be that the exclusion of facial features, such as ears, withdraws a face from its natural view. Hence, results might be dependent on the unnatural face images, and reflect defectiveness of techniques used in constructing face stimuli instead of showing the genuine connection between original FA and perceived attractiveness of a face.

Contradicting findings are reported in a later study: Mealey et al. (1999), used photographs of monozygotic twin pairs as stimuli. This study is crucial, in the sense that even though twins are identical in their genetic conditions, their appearance differ as a result of environmental development factors. Two half faces were morphed into a symmetric face (see below for details) resulting two types of symmetric faces for each individual: left-left and right-right symmetric images. First set of raters (25 male and 38 female) were shown the symmetric faces and asked to choose which pair looked more similar to each other, i.e. observers saw 4 images in each trial, left-left and right-right for each twin brother. So if left-left and right-right composite of a twin is rated as more similar, then he would be regarded as more symmetric. To another group of raters (32 male 43 female), the original photographs were shown, and asked first to decide on which twin was more attractive and then rate him on a scale of 7 ranging from *extremely attractive* to *not attractive at all*. Between subjects results indicated that, the more symmetric a twin is perceived, the more attractive s/he is rated. Moreover, there was no sex effect but groups of ratings from both female and male raters were almost equally affected from the FA of face images. This was pointed to be a counterexample for evolutionary psychology theories of symmetry relating to mate choice, as the authors explained, not only possible mates but also rating of an "unsuitable individual" might as well be affected from facial symmetry. Gender difference was remarkable in attractiveness ratings results; male raters were reported to give significantly lower ratings to other males, and this was explained by an intrinsic psychological mechanism suggesting that *"males derogating other males, both in the eyes of potential mates and in their own thoughts"*.

Unlike previous studies using morphing techniques, Simmons et al. (2004) used only original images of faces. First they measured distances between 15 points they marked on original face photographs. Their statistical descriptive revealed that directional asymmetry is present in both sexes, i.e. right side of the face is reported to be larger. After statistical evaluations of these measures, from a pool of 111 raters (54 males and 57 females), experimenters randomly separated this into two groups; they asked first group of raters to rate how symmetric and the second group how attractive each face was. As a result, more symmetric looking faces were also the ones which are rated as more attractive. More importantly, they found that people's perception of symmetry is dependent on small deviations from symmetry (FA) but not on directional asymmetry. In their study, authors have not identified levels of symmetry for the stimuli they used, nor did they make a comment on asymmetry scores.

2.4. QUANTIFICATION OF SYMMETRY AND CONSTRUCTION OF SYMMETRIC FACES

Visually perceiving an object gains us two kinds of information about its form: *shape* and *size*. While the former is invariant throughout species, size may differ for each individual sample. In systematic study of biological morphology, the definition of shape is given as follows: "*The geometric properties of a configuration of points that are invariant to changes in translation, rotation, and scale. (Slice et al., 1996)*"

To study an organism's morphology, data acquisition is an essential first step in quantification. Unlike three dimensional (3D) studies, one cannot obtain data directly from the sample in a two dimensional (2D) study, but devices such as digital cameras, scanners, photocopying, etc. are used to acquire representations of samples. From digitized 2D images, special landmark points are extracted, and individual samples are compared on the basis of this landmark set. A set of points gives coordinates, and from these points distances and angles can be derived. Quantification of form is important because resulting data is reliable, universal and comparable to previously done research.

In facial attractiveness literature, qualitative results without remarks on quantifications are adapted more commonly; these studies use dichotomous stimuli sets, i.e. symmetric and asymmetric face images. There are also several studies using a third level of face images consisting of intermediate value symmetrical faces (see below). These distinct sets were acquired by morphing techniques; methods that involve changing the shape (and sometimes size) of face images, i.e. *morphing* faces. Results from these poorly controlled stimuli, however, fall short for reasoning for scattered and dense sets of numerical subjective ratings on faces.

Using landmark techniques provides more intense quantification for face images. Rather than classifying face images into symmetric or asymmetric sets, one can represent the amount of asymmetry of an image with distances and angles derived from featural (e.g. eyes, nose, mouth) landmarks. This method obviously offers better comparison between stimuli presented and data collected in an experiment, but it is still limited with landmark points selected: Texture of the face (such as skeletal asymmetries apparent from fluctuations of skin surface), outside the landmarks are left non-quantified.

With current techniques in image processing software such as Matlab Image Processing Toolbox (version 5.1), we can quantify the image wholesomely, beyond a limited set of points. Specifically, a built-in *image entropy* function evaluates the amount of information an image contains, by taking into account every single pixel in the image and giving the result after a logarithmic calculation of pixel intensities. Quantification of facial symmetry with such an algorithm allows us to represent image quantification results in a continuum, instead of dichotomous or discreet sets; providing a better environment for interpreting subjective ratings. In addition, by reporting facial symmetry based on the points embodied by the whole face, holistic interpretation of face perception is supported as well.

Similar experimental settings described in the previous section diverge to equivocal findings, and this diversity in their results might be explained by further investigating the stimulus preparation stages.

In Mealey et al. (1999), faces are cut vertically along a facial midline using Adobe Photoshop, Ver 3.05(1994). Then, symmetric version of each face was derived by aligning a half face with its mirror image, which resulted in two full symmetric faces: a left-left and a right-right face (Figure 4).

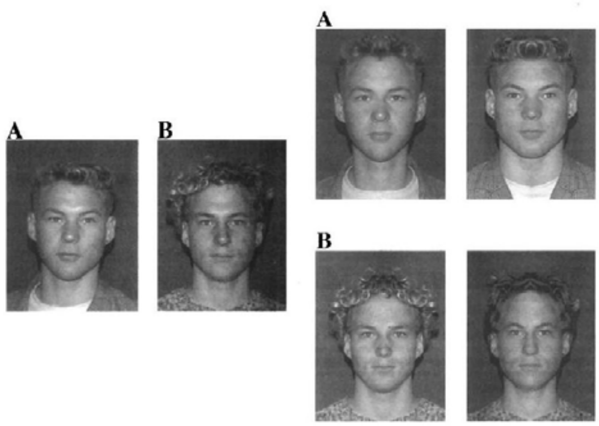

Figure 4: Two symmetrical face images derived from each twin: Left-left and right-right compositions.

Here, the detection of facial midline is ambiguous. The base of the nose is used as a reference point as reported, but there is no further comment whether this midline passes through the center of the mouth, or the midpoint between the eyes. Even if this midline is adopted, then aligned half faces would result in different mean sizes than the original face. Directional asymmetry of faces would cause larger right-right composites than left-left. In addition to this size issue, it is hard to establish a smooth facial plane with two aligned half faces, and resulting face, even though being symmetrical, would contain sharp discontinuities along the midline.

In a study by Swaddle & Cuthill (1995), Gryphon Software Corporation's Morph program was used to create a spatially warped cross fade between the original face and its mirror counterpart. Roughly, resulting face is a composite of a left and a right half face on each side. Images were also masked by severe black ellipses framing each face which cause an abruptness along the face border. The software morphs a blend of two images by replacing the elements of each image to an intermediate position between them. Intermediate morphs (25% and 75%) were captured during morphing an original face and the mirror image (Figure 5).

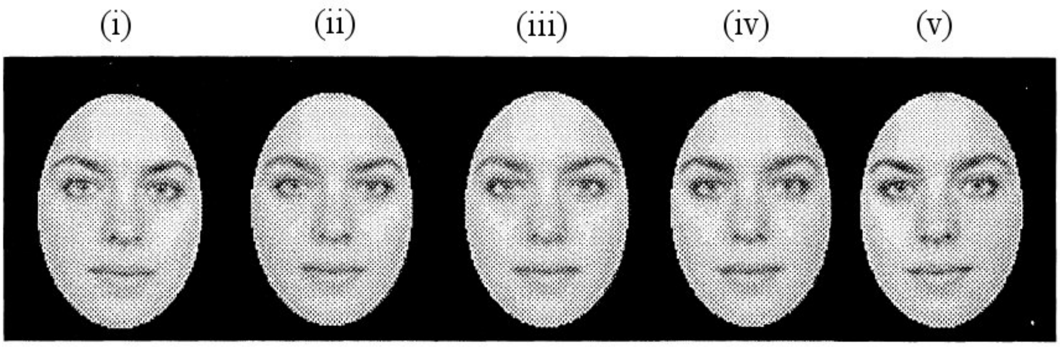

Figure 5: Five classes of symmetrical images generated with Gryphon Software: Original (i), 25% symmetrical (ii), Full symmetrical (iii), 75% symmetrical (iv), and mirror (v).

This technique, although preserving characteristics of facial plane, should be approached critically; for morphing software generates composite images with lower resolutions than their originals. Images with different resolutions violate the homogeneity of a stimulus set, hence are hard to be analyzed as a comparable set of stimuli.

Tjan and Liu (2005), on the other hand, used three dimensional face models, and represented each model, **O**, as an $512x512$ array of 3D surface position (x, y, z) and pigmentation. Then by swapping these shape and color values, they created the mirror twin, **O'**, of each face. They manipulated different levels of asymmetry by taking a weighted vector average of **O** and **O'**, but keeping surface pigmentation same as the perfectly symmetric face.

$$F(m) = {}^{1}/_{2}\,[(1+m)\boldsymbol{O} + (1-m)\boldsymbol{O'}] \qquad \text{Eqn. 2}$$

As seen from the above equation, each individual has a specific asymmetry scale. For $m = 1$ the synthetic face model represents the original face, and for $m = 0$, $F(m)$ is the perfectly symmetric version **(**Figure 6**)**. Clearly, this translation handles the continuity of the facial plane along with averaging intensity values between corresponding pixels of the half faces.

(i) (ii) (iii)

Figure 6: Resulting face morphs from Equation 2: Starts with an original image (i), symmetrical image in the middle of the figure (ii), and the mirror version at the end (iii).

In addition to these morphing methods, Chen *et al.* (2006) computed the symmetry index for each face with an intricate algorithm as follows:

"The symmetry index is computed based on the power spectrum of the Fourier transform of the face images. Here we were only interested in the horizontal symmetry. Hence, we computed the difference of the power at the points (kx, ky) *and*$(-kx, ky)$*, where kx and ky are horizontal and vertical spatial frequencies of the images (in the upper halfplane, excluding the horizontal axis). The symmetry index is computed as a function of the root mean square difference of the power between corresponding frequencies summed over the spectrum."* (p. 2, Chen, Kao, Tyler, 2006)

Although being an elaborative approach to quantify symmetry, Chen *et al.*'s method is not the most convenient quantification algorithm to adopt in current thesis, due to lack of documentation of its relationship with subjective judgments.

2.5. MOTIVATION FOR THE PRESENT THESIS

Faces have been focus of attention in perception studies, for evolutionary, developmental, and social psychological research for decades. The amount of information they possess will keep researchers continue investigating what a face means to us. Our perceiving of faces may be judged *qualitatively* with respect to subjective ratings reported by the viewer. However, quantifying the amount of information an image represents needs a thorough practice.

Subjective judgments on faces have been analyzed in detail by numerous studies, and the role of facial symmetry is emphasized in almost all of them. Healthiness, attractiveness, trustworthiness have been related to symmetry. These results also reveal qualitative facts, without suggesting any quantitative interpretation between the image presented and subjective data collected.

Realizing the role of symmetry in face perception, to determine a quantitative measure for facial asymmetry becomes an issue of ultimate importance. However, quantifying symmetry in face images has not been well defined as it is in mathematical sense. Previously mentioned methods are either insufficient for controlling face stimuli, or when they sophisticatedly quantify images with complicated algorithms they lack comparisons with subjective data.

Hence, there is an obvious need in the face perception research for comparison of sophisticated quantifications and controlled face stimuli with subjective judgments on faces.

CHAPTER 3

EXPERIMENTS

Evidence provided in the previous chapter demonstrates that there is a relationship between perceived symmetry and subjective judgments on faces. However, qualitative results from such research leave a gap in literature about quantifying the effect of symmetry perception. Previously reported studies also imply conflicting results on whether symmetric faces are attractive or not; which in part, may be explained by variant techniques used for symmetrizing face images.

There are two behavioral experiments covered in this chapter. For both experiments, we used computer-manipulated and natural looking face images which are quantified in terms of symmetry they possess with two different methods: landmark-based quantification and entropy-based quantification as a novel approach. The techniques used to quantify face images are explained in detail in the next section. In the first experiment, the goal is to correlate quantified symmetry levels of face images with attractiveness ratings to find the main effect of symmetry on facial attractiveness. In the second experiment, subjective reports of participants on perceived symmetry is tested against previously quantified symmetry levels.

3.1. CONSTRUCTION OF STIMULUS SET

The stimuli used in both experiments are chosen from the METU Face Database, which are a set of face images, especially prepared for this study. Except for the specific purpose of preparation, this database may serve as stimuli for future behavioral research as well as imaging studies. In this section, preparation of database is explained in detail.

3.1.1. METU-Face Database

METU Face Database consists of two parts. The first part is a collection of 50 colored face photographs (DBC). Faces in the DBC database are in upright frontal pose and they are neutral, *i.e.* they do not express emotion. The pictures in this collection are raw material, the images are not manipulated. Second part of the database includes normalized black/white photographs, acquired by processing the pictures in the first part. It consists of 250 frontal face photographs, which are grouped into five subsets: 1) Original Database (DBO), 2) Mirror Database (DBM), 3) Symmetric Database (DBS), 4) Intermediate Original Database (DBIO), and 5) Intermediate Mirror Database (DBIM). Subsets are defined according to gradual differences in asymmetry of faces. Original face photographs, located in the DBO, are obtained from the DBC database after several normalization steps involving gray scale standardization, face-size rescaling and head-tilt adjustments. The remaining databases, DBM, DBS, DBIO and DBIM are obtained from DBO by using image morphing techniques to produce several different levels of symmetry. As an important contribution, on each face picture, asymmetry is quantified using both landmark-based and entropy-based methods.

3.1.1.1. Physical Adjustments and Acquisition of Pictures

Appropriate physical conditions are provided in the computer laboratory of Informatics Institute, METU, using two halogen lamps with 250W, a shelf mounted on the background wall where the participants sat, and an HP R706 digital camera attached to a tripod. Lamps are located 90 centimeters away from subjects with 30^0 of eccentricity. Tripod, hence the camera was 130 centimeters away from the wall, and was positioned on the center line perpendicular to the wall. Participants were seated upright in front of the wall with their heads located under the shelf. The shelf was used to minimize head tilts. In addition to this shelf, a grid with 2x2 centimeter squares was stuck on the wall so that the photographer sees and corrects the models' body postures while shooting. Models were instructed to look directly into the camera and pose in neutral expression.

In this configuration, mug shots of 75 people were taken. 22 photographs were excluded from the database due to the extremeness of some features such as eyebrows, facial wrinkles and unacceptable widening effects in the eyes while filming. Overall, 53 pictures are collected as JPEG files in dimensions 2208x1664 or 2256x1696 pixels. After the pilot studies on subjective ratings of these images, three more images were excluded because they were outliers according to the ratings. We used these excluded images for practice sessions in part one and two.

3.1.1.1.1. Digital Pre-Processing Procedures

In the raw set of 50 photographs, faces of the models show subtle variations in head orientation, head size, texture quality and skin color. As illustrated in Figure 7, several processes are run in order to minimize these variations and normalize photographs to produce the DBO.

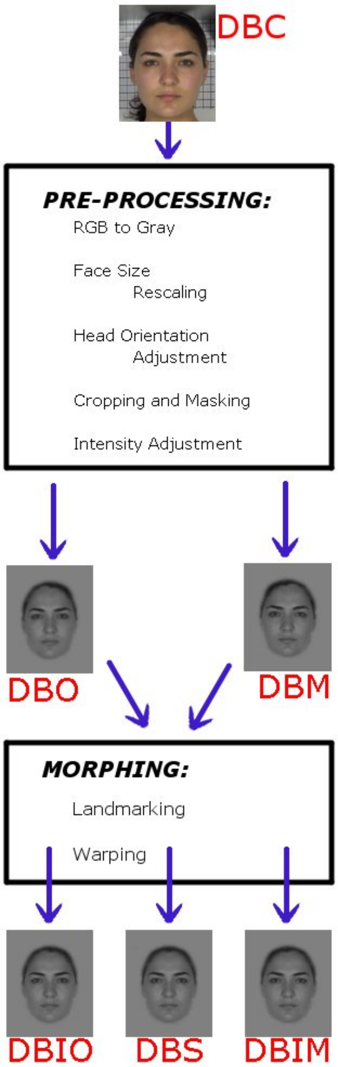

Figure 7: Steps of pre-processing and morphing procedures, with input and output databases.

RGB to Gray:

Using GNU Image Manipulation Program (GIMP), colored images in DBC are first converted to gray scale images. As a result, each pixel's value was reduced from three layer (red-green-blue) values to single intensity values.

Face size rescaling:

To reduce head size differences, re-scaling faces was carried out through the following steps: Four reference points are taken on boundary of each face; uppermost (*u*), lowermost (*w*), leftmost (*l*) and rightmost (*r*). After images are read in Matlab, we labeled four extreme points for each image using mouse. These four extreme landmarks are also used to find vertical and horizontal axes for faces (see Figure 8 below).

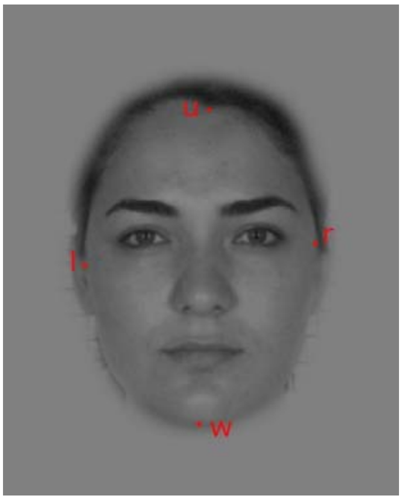

Figure 8: Extreme points of a face: uppermost (u), lowermost (w), leftmost (l) and rightmost (r).

The difference between x-coordinates of left and right extremes gives us **width** of a face. Similarly, we subtract y-coordinate of lower extreme from upper extreme point's y-coordinate to find **length** of a face. The average width of faces is 383 pixels, where length averages to 519 pixels. Using GIMP we resized each image to match average width and kept a constant aspect ratio[2] 1.36 (Std Dev = 0.06) for images. At the end of this process, we had 50 gray scale images with same head size, and aspect ratio.

Head Orientation Adjustment:

Varying head orientations were minimized by physical adjustments during shooting photographs. For further precision, the line connecting left and right endocanthions, namely endocanthion line, is corrected to horizontal by rotating each image in GIMP. Then by translation, the midpoint of endocanthion line is located exactly in same coordinates for each face (x=250, y=300 in GIMP coordinates).

Cropping and Masking:

Images are cropped to fit dimensions 500x620 pixels to disengage unnecessary background material. Still existing grid displays are concealed by putting a gray mask around each face in GIMP (the intensity value for gray mask= 128).

Intensity Adjustment:

Intensity of background grid's black and white is fixed to certain values (black lines intensity value= 79 and white squares intensity value= 121) for each image to avoid instant lighting variations. Extreme landmark points apparent on images are blurred to disappear.

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[2] Aspect ratio is computed by dividing the height of an image to its length.

Blurring:

Final process was to smooth images with a Gaussian blur filter[3] (3 pixels radius), and it was only applied to databases pre-DBO and pre-DBM. This was done to equalize the texture of original and mirror images with other images' texture, which are already blurred as a result of morphing.

After all, normalized images regarding to orientation, size and texture constitute the original database (DBO). In other words, DBO includes 50 black and white images of identical dimensions (500x620 pixels), with the same gray level intensity; where each face has equivalent width and height; and eyes are located in the middle of each image.

3.1.1.2. Creation of Faces with Variable Asymmetry

Once original images are prepared, it is rather straightforward to derive mirror images from them. By using the GIMP software, we flip images in DBO with respect to the middle vertical axis of the frame (please note that this is not the same as the vertical axis defined above) to build DBM. As a result, DBM consists of mirror-reversed displays of the images in DBO; in other words, left in DBO goes to right in DBM and vice versa.

[3]A Gaussian blur filter is a built-in function of GIMP; it blurs regions with low contrast, and results in a dimmer image.

3.1.1.2.1. Morphing

For the remaining three databases, Fantamorph[4] software is utilized using the DBO and DBM datasets. With Fantamorph, we created a morphing video between two corresponding source images taken from DBO and DBM. While morphing a certain image to its mirror version, we extracted the middle frame (50%) during the course of movie. This frame is the half way through original to mirror, thus it displays a symmetrical face. By extracting the middle frames from all movies, 50 symmetric faces are acquired and they make up the symmetric database (DBS).

In a similar fashion, the frame at a 25 per cent instant of the morphing movie course gives us an intermediate original face; i.e. resulting face is a composite of the original and symmetric versions of the same face. Likewise, to obtain the face between symmetric and mirror-image face, we extracted the frame in 75% of movie. These extracted frames in 25% and 75% of the each movie form pictures in the intermediate original (DBIO) and intermediate mirror (DBIM) databases respectively. The main difference between 25% morphed and 75% morphed images is that 25% is the composite of an original and a symmetrical image, where 75% is composed of a symmetrical image and a mirror image; hence these two kinds of images are flipped versions of each other. Substantially, 25% and 75% images have the same level of asymmetry; however they are not identical since they are derived from original and mirror images, respectively. The purpose of using two sets of stimuli with the same level of asymmetry is to examine whether symmetry processing is different with respect to left and right half faces.

[4] Available from website URL: http://www.fantamorph.com/

Upon completing the morphing process, we end up with five different versions for each image in DBC (Figure 9).

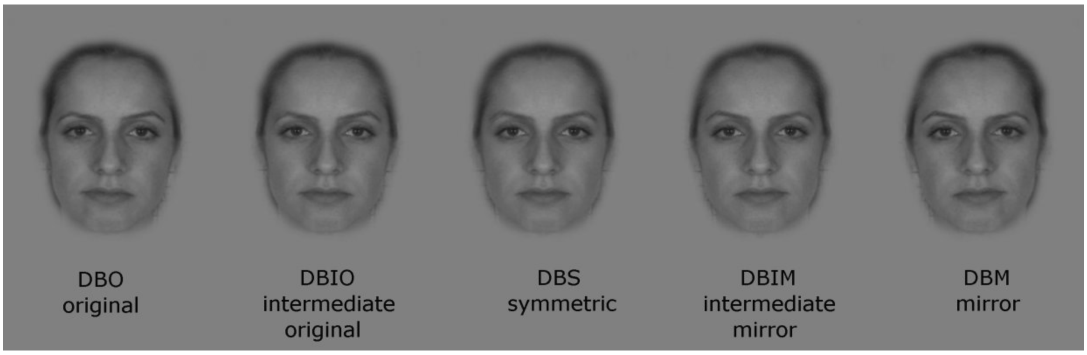

Figure 9: Examples from each database

3.1.1.2.2. Asymmetry Quantification

Two methods were used to quantify asymmetry in this thesis: landmark-based and an entropy based quantifications. Results of landmark-based quantification are available for 50 images in DBO, where entropy results are obtained using 300 images and are classified in three levels of asymmetry: original (DBO and DBM), intermediate level (DBIO and DBIM), and symmetric (DBS and flipped DBS).

3.1.1.2.2.a. Landmark-Based Asymmetry Quantification

All images in DBO are digitized and landmarks are recorded using TPSDIG[5] software (Rholf, 2001). Consistent with Ras et al. (1995), a subset of facial

[5] Rholf, F. J. (2004), tpsDig, downloadable from: http://life.bio.sunysb.edu/morph/

anatomical landmarks, such as, *exocanthion (ex), endocanthion (en), nasalion (na),* and *cheilion (ch)* is used (Figure 10). There are two points for left and right half faces, which brings about four bilateral landmarks (1: *ex*, *ex'*; 2: *en*, *en'*; 3: *na*, *na'*; 4: *ch*, *ch'*) for a face. After digitizing, every face has 24 coordinate values: 8 anatomical landmarks, 4 extreme landmarks; each having x and y-coordinates (see Appendices G, H, and I).

For each face, the midpoint of the line connecting left and right extremes define the x-coordinate of **vertical axis (v_x)**. Correspondingly, upper and lower extremes' midpoint is the y-coordinate of **horizontal axis (h_y)** (see Appendix I).

$$l_x + {}^{1}/_{2}\,(r_x - l_x) = v_x \qquad \text{Eqn. 3}$$

$$u_y + {}^{1}/_{2}\,(w_y - u_y) = h_y \qquad \text{Eqn. 4}$$

The four extreme points mentioned above are not directly included in future distance measurements once the vertical and horizontal axes are defined.

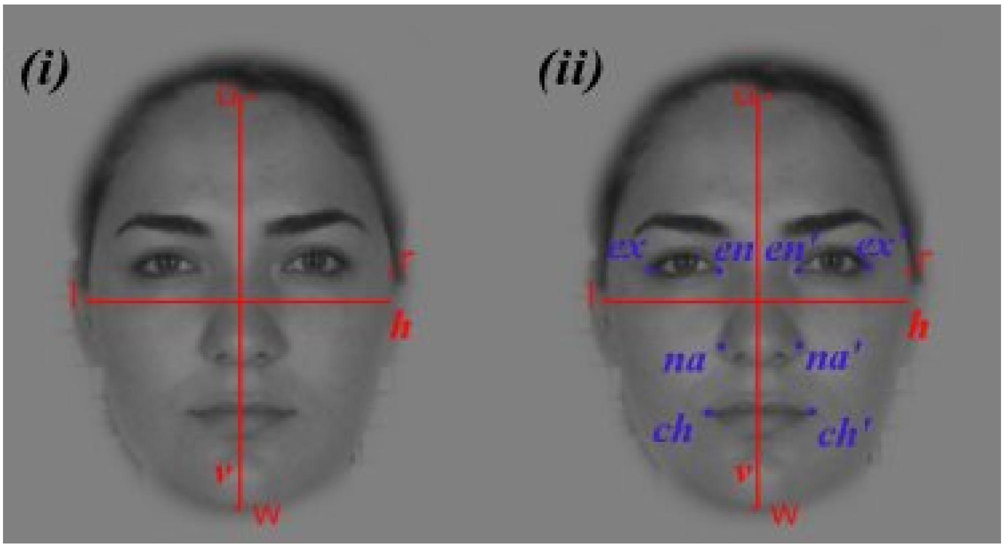

Figure 10: Extreme points and axes (i), facial landmarks (ii).

Concerning our asymmetry quantification method, asymmetry scores are calculated separately for each landmark, by using distances of landmarks from the horizontal and vertical axes. For example, *horizontal deviation* of exocanthion (∂_{hexl}) for left half-face may be calculated by subtracting x-coordinate of left exocanthion (ex) from x-coordinate of the vertical axis:

$$v_x - ex_x = \partial_{hexl} \qquad \text{Eqn. 5}$$

And *vertical deviation* (∂_{vexl}), by subtracting y-coordinate of left exocanthion (ex) from y-coordinate of the horizontal axis:

$$h_y - ex_y = \partial_{vexl} \qquad \text{Eqn. 6}$$

Similarly, ∂_{hexr} ∂_{vexr} are calculated for the right exocanthion, and indicate the horizontal and vertical deviations of the right exocanthion respectively:

$$ex'_x - v_x = \partial_{hexr} \qquad \text{Eqn. 7}$$

$$h_y - ex'_y = \partial_{vexr} \qquad \text{Eqn. 8}$$

In order to calculate asymmetry score of a specific landmark, for instance, exocanthion, its distance to the vertical and horizontal axes on the L and R sides must be compared. To illustrate, if we subtract right exocanthion's distance to ***v*** (denoted as ∂_{hexr}) from left exocanthion's distance to ***v*** (∂_{hexl}) we get the first asymmetry score EX_v:

$$EX_v = \partial_{hexr} - \partial_{hexl} \qquad \text{Eqn. 9}$$

Please note that this shows the **h**orizontal asymmetry of the exocanthion, but since it is computed depending on the **v**ertical axis, notation is EX_v instead of EX_h.

Similarly, the difference between left and right exocanthions' distance to the horizontal axis defines EX_h :

$$EX_h = \partial_{vexr} - \partial_{vexl} \qquad \text{Eqn. 10}$$

As a result, for each face, there are four *local scores* dependent on the vertical axis (EX_v, NA_v, CH_v, EN_v); and three *local scores* are dependent on the horizontal axis (EX_h, NA_h, CH_h)[6]. While vertical axis dependent scores reveal mostly the

[6] As mentioned before, in order to normalize head orientations we changed coordinates of endocanthions. Their y-coordinates are relocated to be on the same line for each image; hence do not represent individual information any more, as being the cost of head justification. For this reason, we omitted two landmarks (en, en') while measuring vertical distances.

directional asymmetry to the sides; vertically based scores show fluctuating asymmetry along upright direction (See Appendix K).

Other than individual vertical and horizontal asymmetry scores for the landmarks, we also calculated two *global asymmetry scores* for each face:

$$AI_v = EX_v + NA_v + CH_v + EN_v \qquad \text{Eqn. 11}$$

$$AI_h = EX_h + NA_h + CH_h \qquad \text{Eqn. 12}$$

3.1.1.2.2.b. Entropy-Based Asymmetry Quantification

Apart from facial landmarks, we also checked asymmetry of the whole face. Considering images, bilateral symmetry notion is re-defined with respect to the middle vertical axis of the image frame. Asymmetry is quantified by evaluating the image entropy (the amount of information the image carries) as follows.

We registered the original and flipped images in Matlab, which in this case means original (from DBO) and mirror (from DBM) images of the same face. First we subtract the mirror image from the original with '`imsubtract`' function which is a built-in function of Matlab library. This algorithm handles images pixel by pixel; hence each pixel of the left half is subtracted from corresponding pixel on the right. As a result, we have a matrix for every pair, displaying the difference between right half of the image and left half of the image. After subtraction, '`entropy`' function is run for each matrix, and we end up with an entropy value (a scalar value) for each original and mirror image pair, these line of processes gave us entropy values for *original level* symmetrical images. Same steps are followed for pairs of one image from DBIO and corresponding image from DBIM to establish entropy values of *intermediate level symmetrical* images. For fully symmetric images, we created a new image set by flipping the symmetric image vertically (DBSf). Image differences of pairs from DBS and DBSf were quantified, and entropy values for *symmetrical* images were found. As a result of entropy based quantification, five classes (DBO, DBIO, DBS, DBIM, and DBM) of symmetry were reduced to three levels: 1) asymmetrical, 2) intermediate level symmetrical, and 3) symmetrical.

3.1.1.3. Participants for the METU Face Database

Participants are chosen from the Middle East Technical University graduate student body (29 women, 24 men, Age = 25.3 ±2.7). All participants signed a consent form expressing their agreement for the pictures to be used in relevant studies and their publication for academic purposes. Male participants with beard and/or mustache are excluded from the study, female participants are asked to remove make-up when necessary. Both male and female participants are asked to take off their glasses, ear-rings, and other facial accessories before photographing.

3.1.1.4. Results

Results from the entropy based quantifications revealed the amount of information between image pairs; in other words, if the images of a pair were highly different, then their entropy value was also larger (demonstrated in Figure 11). As expected, mean entropy value for original images was the largest ($Mean = 1.7259 \pm 0.12$). Entropy values for intermediate level symmetrical images were relatively lower ($Mean = 1.4791 \pm 0.10$), because their asymmetries were reduced during morphing into intermediate levels. Finally, lowest entropy values were acquired from symmetrical images ($Mean = 0.9575 \pm 0.03$, see Appendix F). One would speculate that the mean entropy value for a symmetrical image would be zero, because symmetrical images are expected to be identical to flipped symmetrical images. However, it is not the case for images in DBS and DBSf; mainly due to flickering noise added naturally during the picture acquisition and normalization procedures.

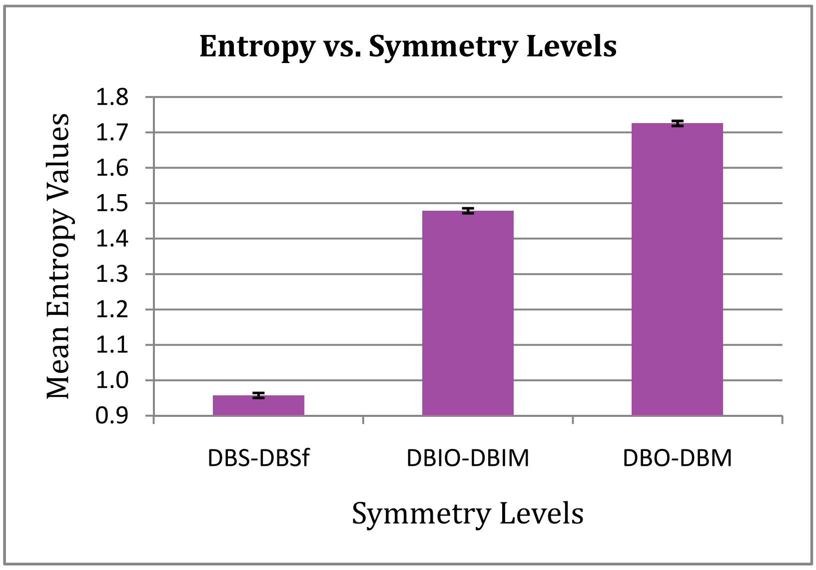

Figure 11: Average entropy values for three levels of symmetry.

3.2. EXPERIMENT 1: RATING ON ATTRACTIVENESS

In this part, a subjective rating task was used. Images from the METU-Face Database were shown on the computer screen as stimuli and subjects were asked to assign a score on attractiveness for each image. Facial symmetry of images was estimated with the two algorithms discussed in the previous section: One landmark-based method relating to the literature and a novel entropy-based method. The aim of this experiment is to investigate the role of facial symmetry on perceived attractiveness.

3.2.1. Method

3.2.1.1. Participants

Thirty-seven Middle East Technical University students (17 male and 20 female) voluntarily participated in the experiment, in response to the posters on library bulletin board. All participants gave written consent to their participation (See Appendix N). Subjects completed the Edinburgh Handedness Inventory (Oldfield, 1971, see Appendix M), and 34 were evaluated as right-handed (3 left-handed). Undergraduate and graduate students ($Mean\ Age = 21.5, SD = 1.5$) mainly from the Faculty of Engineering were involved.

3.2.1.2. Apparatus

The software program E-Prime (v 1.2) installed on a notebook personal computer (HP PAVILION DV2000) was used to present stimuli and collect responses. Participants viewed images on a 1280x800 resolution, 32 bit True Color display and they used number keys aligned horizontally on the keyboard. After the handedness inventory and instructions, participants were seated in a comfortable chair which is located in a dimmed and sound attenuated carrel in the METU library.

3.2.1.3. Procedure

Participants were instructed both verbally and with a detailed handout (see Appendix N) to rate each *image* -not each face- on attractiveness as quickly as possible. They were also informed that this is a two-part study, and they will be rating images for second experiment as well, but this time on a different criterion. Until the second experiment, no mentioning of symmetry was made; neither in the call for participation nor in the instructions. Hence participants were impartial to facial symmetry in the first part.

A practice session was run before the experiment, where participants rated 10 images different from the ones in test session. In the test session, each participant rated 250 images from the METU-Face database in a randomized sequence. Randomization was achieved through E-Prime software options. Images were presented in five sets of 50 images; every 50-image-sets consisted of 50 different individuals and five different symmetry groups (10 from each database: DBO, DBIO, DBS, DBIM, and DBM).

A fixation cross slide preceded every image slide, and the participant had the liberty to rest before stimulus onset, where s/he could terminate the fixation period anytime by pressing space bar. Face stimuli were displayed one by one in the center of the screen with a scale from 1 to 9 (1=not attractive at all, 9=very attractive, Figure 12) at the bottom.

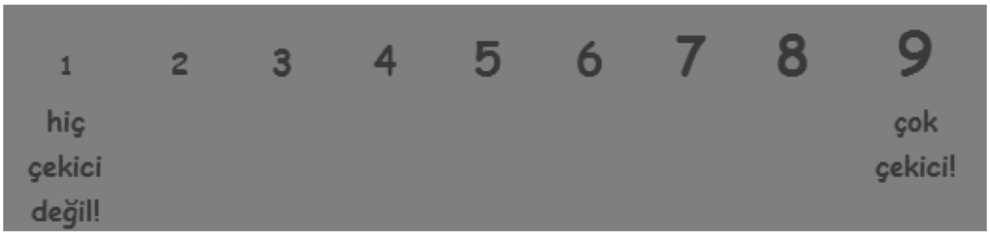

Figure 12: Each face image appeared with a rating scale at the bottom.

Inter-stimulus interval was determined according to the response of the subject: it was set to terminate when the participant presses one of the number keys on keyboard. Inter-stimulus interval was allowed to extend for a maximum of 5 seconds, and trial was considered invalid if no answer is collected during this time. Attractiveness rating took 15 minutes on average. At the end of this experiment, participants were asked to call the person in charge to start the second experiment.

3.2.2. Results and Discussion

At the end of the first part, each image in the database had 37 attractiveness ratings, one from each subject (except for the 56 invalid trials among $250 \times 37 = 9250$ trials in total). Each image is represented with one attractiveness rating: the arithmetic mean of all 37 ratings collected (see Appendix A). Hence data analyzed throughout this study is represented with image identities.

To begin with, landmark-based global asymmetry scores were analyzed against average attractiveness ratings for original images (DBO). Attractiveness ratings were significantly related to AI_h's, i.e. fluctuating asymmetry was significantly correlated with attractiveness ratings collected $r = -0.35$, p (one-tailed) < 0.01. However, AI_v and rating correlations were not significant ($r = -0.16$, $p = 0.13$). Analysis with local symmetry scores did not reveal any significant correlations (all $p's > 0.18$).

Next, analysis was made for five symmetry groups resulted from morphing, to observe if there is an effect of symmetry on attractiveness (Figure 13). A one-way repeated ANOVA with the five levels factor of symmetry (original, intermediate original, symmetric, intermediate mirror, mirror) revealed a significant effect of symmetry groups on attractiveness ratings ($F\ (4, 196) = 27.80, p < 0.001$, $\eta 2 = 0.362$). Mean differences were investigated through pairwise comparisons;

both intermediate symmetry groups (DBIO and DBIM) had significantly higher scores than the original symmetry groups (DBO and DBM), but there was no significant difference between the means of images from DBO and DBM. The mean differences between symmetric group (DBS) and intermediate symmetry groups were not significant; mainly due to high correlation (thus low variability) between symmetric and intermediate symmetry groups.

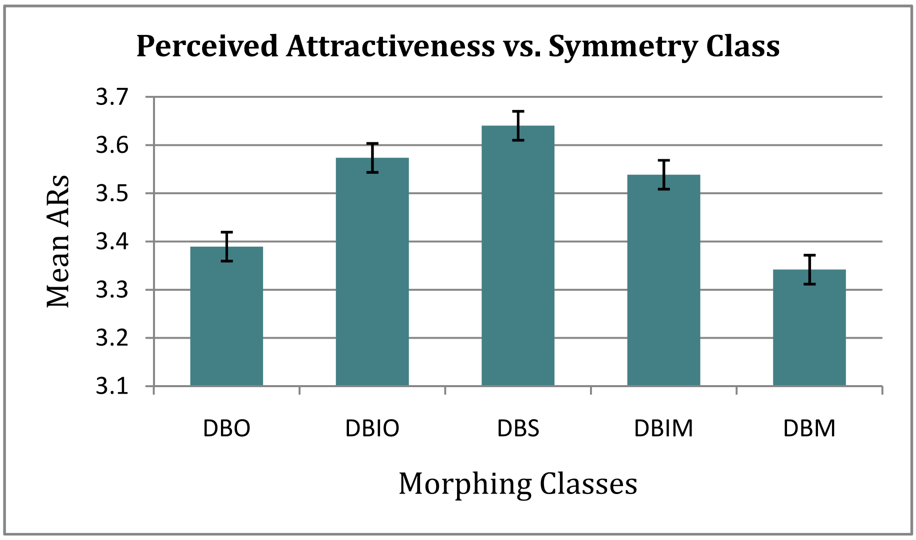

Figure 13: Attractiveness scores averaged over morphing classes representing symmetry.

Further analysis on attractiveness ratings was made for paired symmetry groups with same level of asymmetry (DBO vs. DBM and DBIO vs. DBIM); purpose was to diminish five *groups* of symmetry to three *levels* of symmetry. This decision is made because the results for paired samples t-test were insignificant on attractiveness ratings of DBO and DBM images ($t\ (49)\ = 1.60, p >\ 0.1$), i.e. they did not differ significantly. Similarly, paired sample t-test for DBIO and DBIM showed no significant difference to group means ($t\ (49)\ = 1.13, p > 0.2$). According to these results, five symmetry groups' attractiveness ratings were combined with respect to their symmetry levels; which in turn gave three levels of image sets: original (combination of DBO and DBM), intermediate (combination of DBIO and DBIM), and symmetric (DBS remained same) images.

Finally, entropy quantifications were examined against attractiveness ratings. Before looking at the relation between entropy and attractiveness, we checked whether distinction between symmetry levels is evident within entropy quantifications. A one-way repeated ANOVA with three levels of entropy revealed significant differences among symmetry levels' entropies ($F\ (1.1, 51.4)\ = 2158.6, p < 0.001\ , \eta 2\ = 0.978$). In other words, images in the original level had higher entropy values than intermediate level ($Mean\ difference\ = 0.522$), and symmetric level ($Mean\ difference\ = 0.768$); where mean difference between intermediate and symmetric was 0.247 (all p's< 0.05).

In consequence, attractiveness ratings (AR) were averaged within corresponding groups (Figure 14). A one-way repeated ANOVA with factors of symmetry levels (3 levels) showed a significant effect of quantifications on attractiveness ratings ($F\ (2, 98)\ = 42.847, p < 0.001, \eta 2\ = 0.467$). The level with the lowest entropy values, symmetric images, had highest mean ARs, followed by intermediate level's mean and finally original level's mean (all p's <.05).

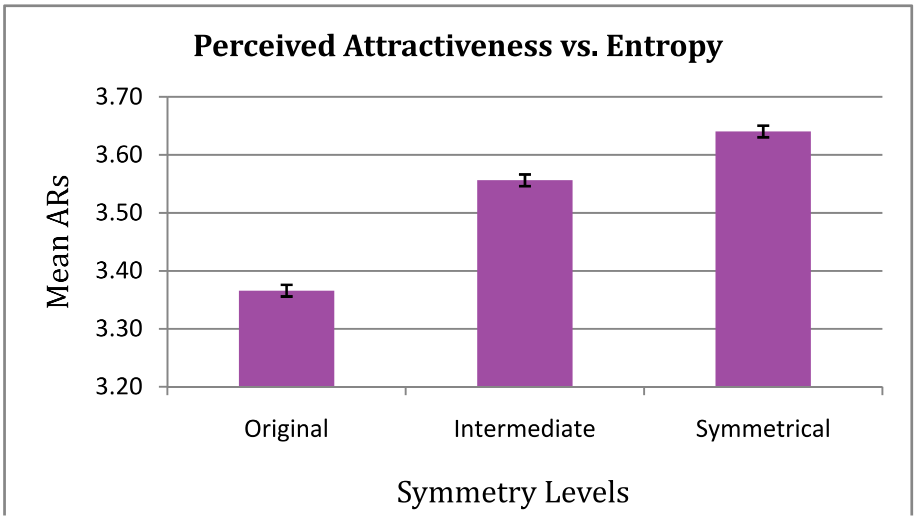

Figure 14: Attractiveness scores averaged over entropy classes representing symmetry levels.

Reaction times were also logged, to see if there is a considerable difference between judgment durations for symmetric and asymmetric images; but statistics for this analysis did not reach any significance level.

Interestingly, we have also found a main effect of gender after a repeated measures one-way ANOVA (Figure 15). As regards to perceived attractiveness, the interaction between image gender and gender of the observer was highly significant $(F\ (1, 35) = 6.488, p < 0.02, \eta^2 = 0.156, SE = 0.282)$. Female images were rated as more attractive by both female and male raters. There was an overall same sex influence: For male images alone, male raters gave higher attractiveness scores compared to female raters; similarly for female images, female raters were more generous than male raters.

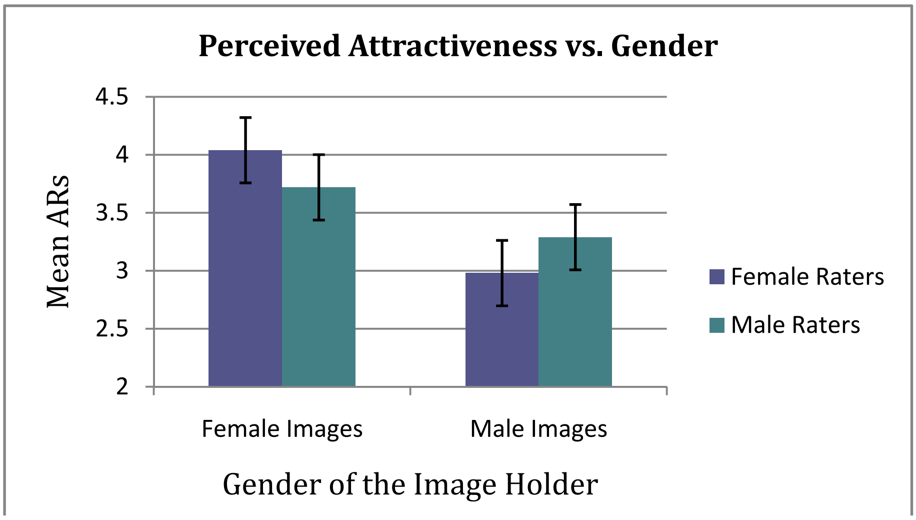

Figure 15: Mean ARs representing two genders: male and female.

3.3. EXPERIMENT 2: RATING ON SYMMETRY

In this part, a similar task and same stimuli set was used with a different criterion for rating; this time participants were asked to rate perceived symmetry. In this part of the experiment, the objective is to relate perceived symmetry with actual symmetry of images; and further investigate the relation between perceived symmetry levels and attractiveness ratings from the first experiment.

3.3.1. Method

3.3.1.1. Participants

Same participants in experiment 1 are involved; they did not leave the carrel upon completion of experiment 1; instead they waited seated for the experimenter to start the second experiment.

3.3.1.2. Apparatus

Apparatus and setup are the same as in experiment 1.

3.3.1.3. Procedure

Before starting participants were instructed to rate *images* on the symmetry they posses. They were asked: “How much symmetric do you consider this image?” and they rated images in a similar fashion with Experiment 1, although this time with a different scale: from 1=”not symmetric at all!” to 9=”highly symmetric!” Some participants asked for a definition of symmetry; for them bilateral symmetry was explained as left and right halves of the image being the same, assuming there is a vertical line in the middle of the screen.

In the practice session, 10 images which are different from both the first experiment’s practice session and current test session were used. Stimuli, randomization, duration and all other aspects had the same configuration as in Experiment 1. Upon completion, there was no debriefing but a small questionnaire was run and participants' questions were answered upon request. Questionnaire results showed that individuals in the database were unfamiliar to participants. The task was not described as hard, but few reported that they were bored in the second part. Two participants were familiar with the type of research, i.e. the relationship between attractiveness and symmetry of a face, but they reported that they did not rely on the symmetry of the images in the first part while judging on attractiveness.

3.3.2. Results and Discussion

Similar to the first part, overall symmetry ratings (SRs) were averaged between subjects to represent each image with a single rating on symmetry (see Appendix C). The SRs for original images were expected to relate with global asymmetry scores AI_h and AI_v. Unlike the negative correlation between AI_h and ARs in the first experiment, results for this part did not show any significant relations; neither for the correlation for AI_v and SRs ($r = -0.13, p = 0.19$) nor for AI_h and SRs ($r = -0.22, p = 0.06$). Local symmetry scores again failed to correlate with symmetry ratings of original images (all p's > 0.25).

A one-way repeated ANOVA with the five levels factor of symmetry (original, intermediate original, symmetric, intermediate mirror, mirror) was conducted (Figure 16). Quantified symmetry groups were expected to differ from each other with respect to the SRs they have been assigned. Accordingly, ANOVA results exhibited significant differences between SRs of symmetry groups ($F\ (4, 196) = 375.79, p < 0.001, \eta 2\ = 0.885$).

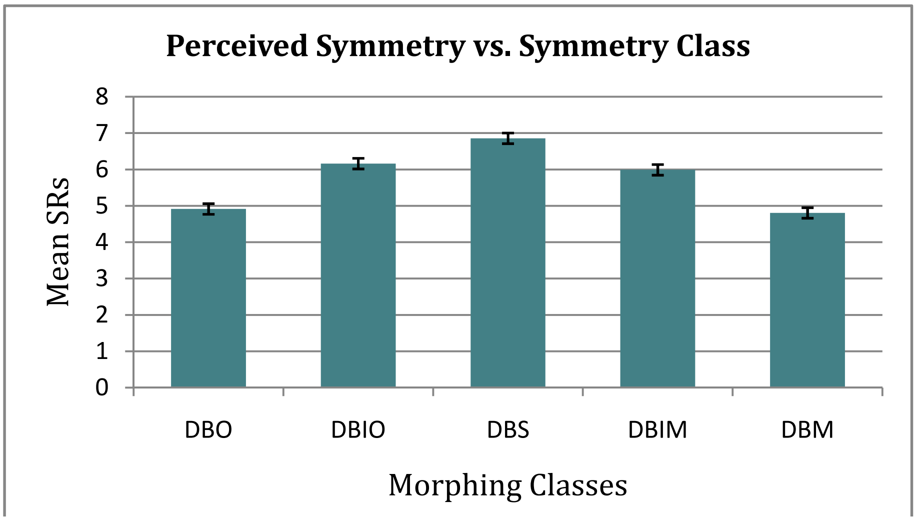

Figure 16: Perceived symmetry scores averaged over morphing classes representing symmetry.

Similar to ARs, five groups of SRs were aimed to combine into three levels of symmetry; but paired samples t-tests resulted in highly significant differences between DBO and DBM, and also between DBIO and DBIM. Hence, five groups of symmetry could not be decreased to three levels.

Analysis with respect to gender was also run for perceived symmetry through one-way repeated measures ANOVA (Figure 17). The interaction between image gender and observer's gender was again evident from perceived symmetry ratings ($F(1, 35) = 6.23$, $\eta^2 = 0.151$, $p < 0.02$, $SE = 0.108$). Female raters gave significantly lower scores than male raters.

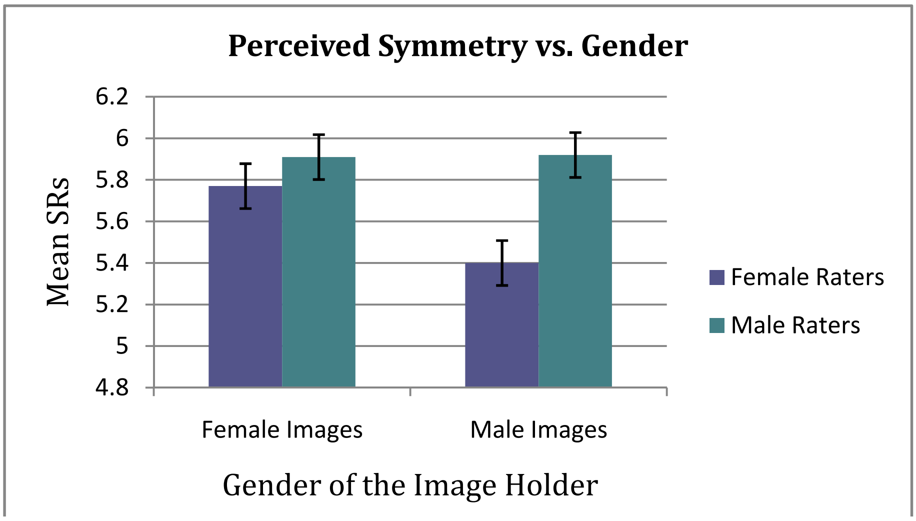

Figure 17: Mean SRs representing two genders: male and female.

Finally, the ARs from the first experiment and SRs from the second were further investigated to find out the relationship between perceived symmetry and judged attractiveness of a face. A simple regression was conducted to predict attractiveness values of DBO images using a linear model on symmetry values of the same images (Figure 18). Attractiveness ($Mean = 3.4, SD = 0.95$) of an image was significantly correlated to the perceived symmetry rating ($Mean = 4.9, SD = 0.62$), r= 0.54, $AR = -0.58 + 0.82 \times SR, p < 0.001$.

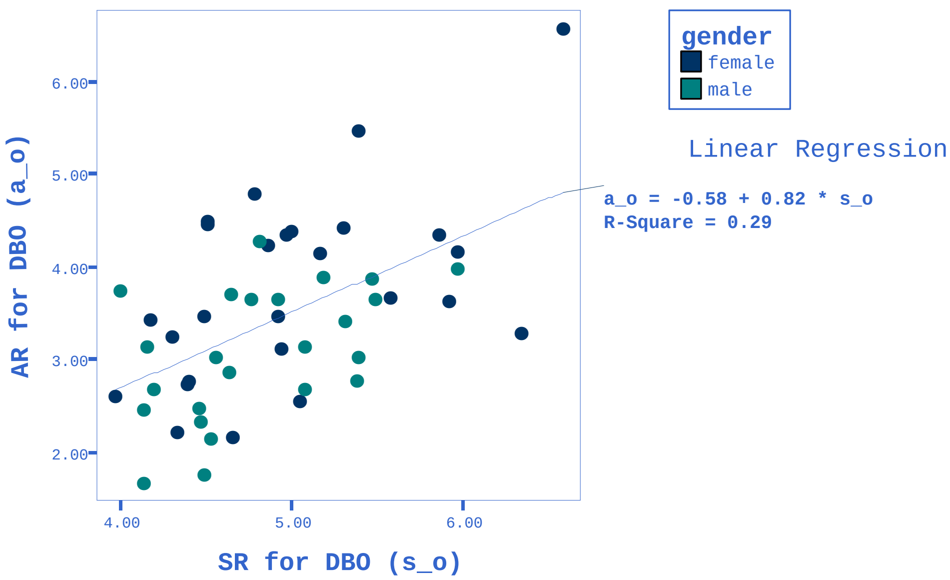

Figure 18: Regression graph demonstrating the relationship between SRs and ARs of original images.

3.4. LIMITATIONS OF THE STUDY

Two experiments were conducted with inspiration from the literature, and stimuli were highly controlled with respect to previously done research. Despite these meaningful findings from these two experiments, there were limitations to this study. First of all, METU Face Database consisted of images from 50 individuals, and this is a limited set. With a larger set of stimuli, landmarking quantifications may be better correlated with both perceived attractiveness and perceived symmetry results. Moreover, participants for experiments were chosen from METU students, which were mainly from the Department of Engineering. Course of engineering is widely accepted to be technical, which may cause engineering students to judge images in this study mathematically, instead of esthetically. What we anticipate is that if the same experiments would be done with participants from different fields, such as Fine Arts students, ratings on both attractiveness and symmetry would vary. This would provide a better subject pool, and homogeneity in results.

CHAPTER 4

DISCUSSION AND CONCLUSION

The effect of symmetry on face perception was studied thoroughly in the evolutionary psychology literature, and the relationship between facial symmetry and attractiveness is a well established concept in the field (Thornhill, Gangestad, 1999). Symmetry is repeatedly shown to signal facial attractiveness, but conflicting evidence is also present. One way to resolve this issue is to use similar experimental designs with better controlled stimuli, and this inspires the first motivation of current thesis. In the literature, quantification of symmetry in face images has been handled *via* a multitude of methods such as morphing images or landmarking facial features. Despite the fact that these methods could explain some aspects of the relationship between subjective ratings and facial symmetry, they were insufficient to quantify faces wholesomely, and correlate subjective ratings with quantified symmetry measures numerically. Relying on the theories of holistic face perception, the present study aimed to find a novel approach for holistic face symmetry quantification and remain consistent with the subjective face perception literature at the same time. In addition, the general goal was to correlate quantified subjective judgments on faces with the proposed face symmetry measures.

As a first step, natural looking images with varying symmetry levels were constructed. As explained in Chapter 3, through several image processing and morphing procedures, we established different symmetry classes for images with continuous facial planes and natural looking skin textures. METU-Face Database consists of 250 images clustered in five classes of symmetry: Original (DBO), Intermediate-Original (DBIO), Symmetrical (DBS), Intermediate-Mirror (DBIM), and Mirror (DBM). These distinct classes were challenged to receive different attractiveness and symmetry ratings in Experiment 1 and Experiment 2, respectively. As a result, the images in DBS were found to have the highest mean ratings for both attractiveness and perceived symmetry. Once again, this result demonstrated that symmetry and attractiveness vary along the same lines, even when stimuli (images in DBO) were strictly controlled. In addition to this, symmetry reports collected in the second experiment revealed that the five morphing classes were actually apparent to observers, because in observer's ratings, these classes were differentiated from each other significantly through the analysis of the SRs. Regression analysis results showed a strong relationship between ARs and SRs considered on these five morphing classes. As this result indicates, it is possible to account for the attractiveness of a face with the symmetry level it conveys.

Specifically, we have found exactly the opposite result of Swaddle and Cuthill study (1995) with using a similar experimental setting. Morphing process was almost same with theirs, except that we used Fantamorph software instead of Gryphon software they have used. They have reported a main effect of image manipulation, and concluded that symmetric images were the least attractive found set. Contrary to their result, images in DBS were found to be the most attractive. In our face images, the degree of manipulation has been minimized.

Due to this, we believe that we have eliminated the effect of manipulation which repotedly effects perceived attractiveness. Thereby showing the relation between symmetry and attractiveness with natural looking but also quantified images. And hence eliminating the manipulation aftereffects might be the cause for the mismatch in our results and Swaddle and Cuthill's results.

We also observed that the interaction between image gender and observer's gender was significant. Female images were found more attractive regardless of the observer's gender. Females gave higher ARs for female images than male raters; but it was not the case for male images. For male images, male raters gave higher ARs than female raters. This result can be summarized as each gender was in favor of his/her own sex; females supported female images, where males' preferences were towards males. This finding is conflicting with the results of Mealey *et al.* They have accounted for males rating male images lower by suggesting an evolutionary approach; our results do not indicate any devaluation approach for males. For symmetry ratings, males rated both types of images similarly symmetrical, where female raters showed a difference for the gender of the image. They rated female images more symmetrical than male images. This result can be explained by female observers' more elaborative perceptual skills compared to males. While female raters closely examined each image before they rated; male observers might have expected a more salient asymmetry in images, hence could not differentiate subtle deviations. This is just an intuitive reasoning, mostly depending on post-experimental communications with raters, where males reported that image repetition was more frequent than it actually was.

Generation of five classes of symmetry was only one method through which we tried to quantify facial symmetry and its correlation with subjective ratings. The other two methods were: 1. Quantification of facial symmetry with landmarks based on facial features, and 2. Quantification of facial symmetry through a holistic measure, entropy.

For landmark-based symmetry quantification, we used the first set of images (DBO). Landmark-based quantification was efficient to account for perceived attractiveness; as expected, images with lower scores of facial asymmetry on the vertical direction (AI_h) received higher ARs in Experiment 1. However, horizontal deviations (AI_v) did not show any correlation with the perceived attractiveness of a face. As a conclusion from this finding, it can be said that observers' perception of facial symmetry appears to be more sensitive to vertical deviations than horizontal deviations of the face. Landmark-based scores were also used to investigate perceived symmetry in Experiment 2, but they were not correlated with each other. Therefore, it can be said that observers' reports on the symmetry they perceived are not sensitive to facial landmarks. Even though different classes of images was adequate to explain subjects' reports on symmetry levels of morphed images, their perception of symmetry in the original faces could not be explained with the landmarking scores. Together with the previous result, one could deduce that, although observers' ratings relied on their sensation of vertical deviations of faces, they were not strong enough to be reported; hence were not evident in SRs.

Through the other method, entropy-based symmetry quantification, the five classes of symmetry were successfully differentiated. Since this type of holistic quantification was insensitive to the display of the face as original or mirror; we joined DBO with DBM and DBIO with DBIM. Hence, entropy-based quantification let us investigate the five symmetry groups as three.

These three symmetry levels, however, is consistent with our finding that within morphing classes, there was no difference for DBM and DBO, and for DBIO and DBIM regarding to ARs as revealed by the t-tests in Experiment 1. These pairs of classes possess same levels of symmetry, as acquired with entropy-based quantification, they are more like mirror reflections of each other. Hence, overlapping ARs suggest that there is no left-right difference when we consider observers' perception of attractiveness: left half of the face is perceived as equally attractive as the right half. Consequently, in analysis done with three levels of symmetry, it is demonstrated that our entropy scores were highly sufficient to elaborate on the ARs they were given. Images with lower entropy scores (less asymmetry) received higher ARs.

On the other hand, in Experiment 2, significant t-test results showed that SRs for DBO and DBM images are not the same, neither is it true for DBIO and DBIM image pairs. In this case, we were not able to join two classes of symmetry; hence it was impossible to examine the perception of symmetry against entropy scores. Significant results in this part clearly points out a difference for symmetry perception for the right and left of a face. This outcome may bear important contingencies for research involving left-left and right-right symmetrical face construction. Besides disturbing the facial plane, building face images with two half faces is not plausible since symmetry perception is not the same for left and right. To sum up, we found that L-R differences do not change attractiveness judgments, but carry importance in perceived symmetry of a face.

To conclude, our efforts to quantify perceived symmetry with morphing classes as well as entropy quantifications produced results consistent with the literature. Landmark scores were correlated with attractiveness ratings, as hypothesized. However, the landmark scores failed to rationalize symmetry ratings. This failure may be due to discontinuous approach of landmarking, where only facial feature points are quantified; instead of quantifying the whole face. Morphing classes were speculated to represent differences in both symmetry and attractiveness ratings, and this conjecture was also verified. All of our findings were consistent with previous literature, as the symmetry of a face increased, the chance of it being perceived more attractive increased as well.

In addition to these, we have introduced a novel measure to quantify facial symmetry: entropy. Attractiveness rating of a face increased as its entropy score (hence asymmetry) decreased. Entropy-based quantifications of symmetry were more accurate than splitting faces into symmetry groups; hence correlation of subjective judgments with this type of facial symmetry measure increased the precision of findings in the literature.

In our study, we present a set of stimuli with well-defined quantifications of symmetry; and these data might be used in various fields concerning symmetry research. For further study, current database should be upgraded to include at least twice as many images so that the results are more definite. After this process is done, database would provide a better stimulus set for experimental settings that require longer stimulus presentation. With current 250 images, we have shown expressive behavioral results; these results may be challenged with brain imaging research in the future, and examined to see whether entropy measures can also be used to account for brain activity. Furthermore, entropy quantifications may also be used in computer face recognition algorithms to extend the already available biometric data to increase the precision of automatic face recognition.

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APPENDIX

APPENDIX A: Attractiveness Ratings ordered by Image_id

Image_id	DBO	DBIO	DBS	DBIM	DBM
f2247	2.54	2.7	2.7	2.51	2.3
f2274	4.35	4.65	4.46	4.62	3.81
f2283	2.16	2.65	2.51	2.36	2.27
f2290	4.16	4.33	4.16	4.33	3.84
f2293	4.38	4.51	4.41	4	4.35
f2300	5.46	5.54	6	5.78	5.19
f2334	2.59	3.16	3.22	2.92	2.83
f2340	4.35	4.51	4.33	4.49	4.24
f2349	2.73	2.89	2.84	2.86	2.57
f2354	4.49	5.06	5.08	4.84	4.78
f2363	2.76	2.84	2.78	2.97	2.95
f2374	3.66	3.89	3.95	3.78	3.57
f2374-1	3.46	3.54	3.94	3.89	3.24
f2388	4.42	4.65	4.67	4.86	4.41
f2397	4.14	4.84	4.43	4.65	4.19
f2425	4.24	5.08	5.03	4.61	4.32
f2431	3.46	3.27	3.86	3.73	3.46
f2442	3.62	4.03	3.76	4.08	3.76
f2460	2.22	2.54	2.65	2.51	2.58
f2478	3.11	3.57	3.46	3.58	3.41
f2484	6.57	6.65	6.84	6.81	6.38
f2504	3.27	3.7	3.78	3.62	3.5
f2506	4.78	4.76	5	5	4.58
f2513	3.42	3.57	3.62	3.81	3.32
f2522	3.24	3.62	3.89	3.3	2.95
f2541	4.46	4.41	4.7	4.23	4.19
m2244	2.14	2.38	2.35	2.22	2.24

m2252	2.33	2.43	2.64	2.35	2.49
m2264	2.76	2.76	2.97	3.03	2.62
m2272	3.14	3.22	3.11	3.32	3.19
m2305	3.03	3.16	2.92	2.81	2.78
m2312	2.46	2.32	2.32	2.41	2.22
m2314	3.41	3.19	3.27	3.03	3.14
m2320	3.86	3.72	3.81	4	3.47
m2324	3.7	3.94	3.92	3.65	3.84
m2331	2.68	3.44	3.61	3.3	2.57
m2345	4.27	4.46	4.25	4.42	4.3
m2359	1.75	1.76	2.03	1.86	1.81
m2367	2.86	3.36	3.46	3.36	2.92
m2370	1.67	1.76	1.86	1.57	1.84
m2379	3.65	3.86	3.95	3.76	3.19
m2404	3.03	3.43	3.11	3.14	2.89
m2427	2.47	2.49	3.14	2.43	2.46
m2445	2.68	2.84	2.68	2.57	2.41
m2448	3.64	3.81	4.27	3.58	3.84
m2464	3.89	3.65	3.92	3.81	3.86
m2480	3.97	3.95	3.86	4.03	3.95
m2496	3.73	3.51	4.08	4	3.7
m2510	3.14	3.35	3.41	3.43	3.22
m2533	3.65	3.86	3.65	3.59	3.69
AVERAGE	3.44	3.63	3.69	3.60	3.39
STD DEV	0.95	0.96	0.97	0.99	0.90

APPENDIX B: Attractiveness Ratings ordered by Subject_id

Subject_id	DBO	DBIO	DBS	DBIM	DBM
11	3.34	3.52	3.7	3.64	3.28
12	3.9	4	3.88	3.74	3.76
13	2.56	2.84	2.82	2.57	2.4
14	4.44	4.44	4.73	4.57	4.18
15	4.22	4.64	4.96	4.4	4.48
16	4.54	4.82	4.56	4.36	4.16
17	4.49	4.96	5.08	4.88	4.58
18	3.27	3.43	3.6	3.57	2.92
19	6.4	6.17	6.47	6.33	6.28
20	4	4.48	4.43	4.3	3.94
21	2.94	2.92	2.9	2.76	2.9
22	4.26	4.72	4.5	4.48	4.38
23	2.22	2.56	2.46	2.52	2.18
24	3.38	3.94	3.88	3.96	3.38
25	2.59	3.02	2.98	2.82	2.38
26	3.08	3.44	3.35	3.12	3.12
27	2.9	2.58	2.96	2.9	2.76
29	2.2	2.46	2.48	2.44	2.56
30	2.82	2.64	2.66	2.98	2.41
31	1.14	1.24	1.22	1.12	1.22
32	3.52	3.5	3.72	4	3.64
33	2.96	3.4	3.16	2.96	3.12
34	1.3	1.33	1.38	1.42	1.24
35	4.56	4.64	5	4.68	4.44
36	2.29	2.4	2.69	2.76	1.98
37	4.5	4.44	4.6	4.46	4.3
38	4.1	4.64	4.24	4.2	4.1
39	4.04	4.18	4.24	3.88	3.96
40	2.12	2.34	2.16	2.34	2.2
41	4.48	4.76	4.86	4.54	4.4
42	4.6	4.8	4.76	4.53	4.42
43	2.76	3	3.14	2.86	2.72
44	2.64	2.36	2.88	2.7	2.5
45	3.18	3.37	3.44	3.76	3.32
46	2.94	3.12	3.08	3.24	3
47	4.68	5.24	5.4	5.02	4.8
48	3.96	3.88	4.26	4.28	4.1
AVERAGE	**3.44**	**3.63**	**3.69**	**3.60**	**3.39**
STD DEV	**1.07**	**1.11**	**1.13**	**1.06**	**1.07**

APPENDIX C: Symmetry Ratings ordered by Image_id

Image_id	DBO	DBIO	DBS	DBIM	DBM	AVG
f2247	5.05	5.94	6.68	5.62	4.92	**5.64**
f2274	4.97	6.57	6.95	5.92	4.89	**5.86**
f2283	4.66	6.46	7.05	6.22	4.54	**5.8**
f2290	5.97	7.27	7.22	7.28	6.19	**6.79**
f2293	5	6.84	7.14	6.11	4.62	**5.94**
f2300	5.39	6.81	7.62	6.89	5.22	**6.39**
f2334	3.97	5.49	6.29	5.16	4.03	**4.97**
f2340	5.86	6.78	7.31	6.19	5.41	**6.31**
f2349	4.39	6.7	6.81	5.94	4.14	**5.6**
f2354	4.51	6.21	7.08	6	4.76	**5.69**
f2363	4.4	5.14	5.81	4.92	4.19	**4.89**
f2374	5.58	7	6.86	6.42	5.05	**6.19**
f2374-1	4.92	5.78	7.08	5.66	4.53	**5.6**
f2388	5.3	6.57	7.14	6.43	4.86	**6.07**
f2397	5.17	6.54	6.95	6.34	5	**6**
f2425	4.86	6.42	7.49	6.27	4.62	**5.93**
f2431	4.49	5.78	7.08	5.72	4.7	**5.55**
f2442	5.92	6.46	7.27	6.28	5.78	**6.34**
f2460	4.33	5.75	6.71	5.62	4.22	**5.31**
f2478	4.94	5.41	6.46	6.16	5.16	**5.63**
f2484	6.59	7.7	8.33	7.38	6.32	**7.26**
f2504	6.35	6.56	6.7	6.73	6.06	**6.48**
f2506	4.78	6.43	7.05	6.19	4.68	**5.83**
f2513	4.17	5.44	6.17	5	4	**4.95**
f2522	4.3	5.58	6.51	5.33	4.56	**5.26**
f2541	4.51	5.94	7.3	6.2	4.22	**5.62**
m2244	4.53	5.5	6	4.92	4	**4.98**
m2252	4.47	6.27	6.22	5.11	4.28	**5.28**
m2264	5.38	6.33	7.11	5.78	4.35	**5.78**
m2272	5.08	6.11	7	6.39	5	**5.91**
m2305	5.39	6.39	6.36	6.56	5.86	**6.12**
m2312	4.14	5.32	6.32	5.3	4.14	**5.05**
m2314	5.31	5.92	6.73	6.32	5.06	**5.88**
m2320	5.47	6.81	6.84	6.67	5.36	**6.23**
m2324	4.65	6.03	6.81	6.14	4.81	**5.68**
m2331	4.19	5.46	6.78	5.42	4	**5.17**

m2345	4.81	5.41	6.43	5.75	4.49	**5.38**
m2359	4.49	6.24	6.78	5.5	4.49	**5.49**
m2367	4.64	6.43	6.86	6.06	4.81	**5.77**
m2370	4.14	5.74	6.72	6.38	4.32	**5.46**
m2379	4.92	6	6.72	6.83	4.92	**5.87**
m2404	4.56	5.38	6.57	5.5	4.28	**5.26**
m2427	4.46	5.74	6.67	4.89	4.25	**5.19**
m2445	5.08	5.69	6.51	6.03	4.49	**5.56**
m2448	4.76	6.53	7.27	6	5.35	**5.98**
m2464	5.19	6.36	6.95	5.97	5.32	**5.95**
m2480	5.97	6.49	6.92	6.27	5.57	**6.24**
m2496	4	6.08	7.03	5.43	3.92	**5.29**
m2510	4.16	5.81	7.16	5.72	4.33	**5.44**
m2533	5.49	6.49	7.06	6.65	6.22	**6.38**
AVERAGE	4.91	6.16	6.86	5.99	4.81	**5.74**
STD DEV	0.63	0.60	0.49	0.61	0.63	**0.49**

APPENDIX D: Symmetry Ratings ordered by Subject_id

Subject_id	DBO	DBIO	DBS	DBIM	DBM
11	5.26	6.84	7.65	6.9	5.46
12	4.94	6.15	7.16	6.44	4.82
13	5.84	6.55	7.44	6.41	5.66
14	3.88	5.59	6.67	5.39	3.94
15	6.28	7.54	7.94	7.58	6.42
16	5.3	6.1	7.28	5.94	5.22
17	4.16	4.53	4.73	4.37	4
18	4.54	7.04	7.88	6.82	4.16
19	5.83	7.29	7.98	7.44	5.87
20	5.38	7.28	7.83	7.08	5.32
21	4.64	5.98	7.06	5.78	4.09
22	5.2	6.62	7.54	6.38	5
23	4.02	6.26	7.56	5.82	4
24	3.57	6.27	8.38	6.3	3.62
25	4.22	5.6	6.28	5.2	3.84
26	3.59	4.76	5.78	4.61	3.28
27	6.78	7.62	7.82	7.3	6.76
29	4.96	6.66	6.8	5.67	4.48
30	5.38	6.02	6.1	5.7	5.62
31	6.1	6.6	6.8	6.68	6.1
32	5.16	6.96	7.98	6.92	5
33	4.32	6.08	6.68	5.36	3.86
34	1.96	2.5	2.35	2.48	1.94
35	7.2	8.02	8.14	7.86	6.96
36	5.04	6.43	7.11	6.37	5.67
37	5.88	6.66	7.44	6.67	5.92
38	3.34	5.16	5.9	5.02	3.48
39	6.96	7.78	8.02	7.7	6.68
40	3.56	3.9	4.42	4.18	3.54
41	4.72	5.98	6.76	5.52	4.45
42	4.54	4.6	5.06	4.69	4.26
43	5.02	5.49	5.66	5.38	5.12
44	2.82	3.49	5.36	3.8	2.29
45	4.41	6.78	8.19	6.37	4.27
46	3.92	4.98	5	4.28	3.36
47	6.54	7.94	8.58	7.42	6.3
48	6.54	8.14	8.5	7.84	6.94
AVERAGE	4.91	6.17	6.86	5.99	4.80
STD DEV	1.19	1.28	1.36	1.25	1.27

APPENDIX E: Attractiveness Reaction Times ordered by Image_id

Image_id	DBO	DBIO	DBS	DBIM	DBM
f2247	2241.22	2242.54	2560.14	2245.46	2211.11
f2274	2126.43	2346.27	2067.54	2225.35	2293.05
f2283	2300.41	2076.51	2399.89	2088.49	2233.95
f2290	2376.11	2115.35	2023.38	2078.38	2184.78
f2293	2100.41	2211.65	2201.81	2300.73	1998.35
f2300	2247.84	2597.19	2583.59	2238.11	2402.76
f2334	2176.08	2417.3	2497.65	2189.97	2131.92
f2340	2478.03	2231.78	2257.62	2364.24	2291.68
f2349	2374	2361.11	2218.24	2133.49	2096.51
f2354	2365.43	2169.68	2218.89	2302.81	2344.92
f2363	1987.11	2414.14	2327.16	2203.7	2297.62
f2374	2362.16	2382.62	2300.84	2115.24	2530.62
f2374-1	2401.49	2256.86	2352.27	2500.11	1766.54
f2388	2370.11	2343.16	2307.54	2265.76	2324.54
f2397	2505.24	2437.41	2199.95	2123.43	2155.59
f2425	2116.92	2291.62	2295.22	2387.24	2359.7
f2431	2331.11	2164.49	2138.46	2167.43	2148.73
f2442	2432.03	2209.38	2372.92	2421.62	2370.24
f2460	2014.76	2314.22	2512.62	2050.35	2099.08
f2478	2394.73	2310	2300.03	2065.27	2288.03
f2484	2488.41	2455.78	2293.05	2177.78	2501.81
f2504	2347.05	2332.84	2321.76	2150.49	2326.35
f2506	2333.14	2554.16	2284.41	2404.46	2449.68
f2513	2091.62	2162.27	2400.03	2196.95	2151.68
f2522	2106.62	2317.65	2220.54	1966.59	2093.43
f2541	2612.51	2353.54	2451.35	2225.3	2172.22
m2244	2273.97	2294.7	2454.7	2240.27	2222.59
m2252	2432.84	2454.03	2278.57	2410.03	2121.57
m2264	2410.51	2485.81	2254.92	2274.51	2332.65
m2272	2286.08	2252.22	2149.62	2280.27	2451.03
m2305	2000.78	2050.35	2254.54	1956.08	2354.95
m2312	1944.76	2389.68	2394.19	2267.24	2031.16
m2314	2002.19	1983.62	2458.03	2663.81	2084.11
m2320	2457.84	2471.08	2498.92	2014.03	2277.32
m2324	2289.86	2079.68	2210.89	2331.73	2375.81
m2331	2249.62	2368.7	2130.65	2253.38	2084.14
m2345	2344.68	2114.24	2454.62	2405.24	2428.11

m2359	2297.7	2370.16	2314.19	2431.46	2302.05
m2367	1893.08	2375.84	2269.73	2143.27	2221.84
m2370	2247.43	1862.97	2389.49	2320.51	2559.22
m2379	2189.54	2076.41	2310.59	2041.7	2073.35
m2404	2443.89	2454.84	2341.41	2586.43	2089.46
m2427	2277.92	2178.59	2203.65	2229.08	1886.43
m2445	2370.41	2164.51	2497.46	2242.68	2243.76
m2448	2208.24	2096.08	2387.22	2234.16	2124.95
m2464	2371.11	1997.59	2285.54	2125.27	2364.3
m2480	2288.24	2487.73	2164.35	2235.16	2380.51
m2496	2069.97	2098.62	2314.68	2364.81	2094.14
m2510	2198.78	2573.43	2298.14	2140.89	1947.76
m2533	2449.62	2577.32	2337.97	2211.68	2486.27
AVERAGE	2273.601	2286.554	2315.219	2239.849	2235.247
STD DEV	162	170	123	147	169

APPENDIX F: Symmetry Reaction Times ordered by Image_id

Image_id	DBO	DBIO	DBS	DBIM	DBM
f2247	2241.22	2242.54	2245.46	2560.14	2211.11
f2274	2126.43	2346.27	2225.35	2067.54	2293.05
f2283	2300.41	2076.51	2088.49	2399.89	2233.95
f2290	2376.11	2115.35	2078.38	2023.38	2184.78
f2293	2100.41	2211.65	2300.73	2201.81	1998.35
f2300	2247.84	2597.19	2238.11	2583.59	2402.76
f2334	2176.08	2417.3	2189.97	2497.65	2131.92
f2340	2478.03	2231.78	2364.24	2257.62	2291.68
f2349	2374	2361.11	2133.49	2218.24	2096.51
f2354	2365.43	2169.68	2302.81	2218.89	2344.92
f2363	1987.11	2414.14	2203.7	2327.16	2297.62
f2374	2362.16	2382.62	2115.24	2300.84	2530.62
f2374-1	2401.49	2256.86	2500.11	2352.27	1766.54
f2388	2370.11	2343.16	2265.76	2307.54	2324.54
f2397	2505.24	2437.41	2123.43	2199.95	2155.59
f2425	2116.92	2291.62	2387.24	2295.22	2359.7
f2431	2331.11	2164.49	2167.43	2138.46	2148.73
f2442	2432.03	2209.38	2421.62	2372.92	2370.24
f2460	2014.76	2314.22	2050.35	2512.62	2099.08
f2478	2394.73	2310	2065.27	2300.03	2288.03
f2484	2488.41	2455.78	2177.78	2293.05	2501.81
f2504	2347.05	2332.84	2150.49	2321.76	2326.35
f2506	2333.14	2554.16	2404.46	2284.41	2449.68
f2513	2091.62	2162.27	2196.95	2400.03	2151.68
f2522	2106.62	2317.65	1966.59	2220.54	2093.43
f2541	2612.51	2353.54	2225.3	2451.35	2172.22
m2244	2273.97	2294.7	2240.27	2454.7	2222.59
m2252	2432.84	2454.03	2410.03	2278.57	2121.57
m2264	2410.51	2485.81	2274.51	2254.92	2332.65
m2272	2286.08	2252.22	2280.27	2149.62	2451.03
m2305	2000.78	2050.35	1956.08	2254.54	2354.95
m2312	1944.76	2389.68	2267.24	2394.19	2031.16
m2314	2002.19	1983.62	2663.81	2458.03	2084.11
m2320	2457.84	2471.08	2014.03	2498.92	2277.32
m2324	2289.86	2079.68	2331.73	2210.89	2375.81
m2331	2249.62	2368.7	2253.38	2130.65	2084.14
m2345	2344.68	2114.24	2405.24	2454.62	2428.11

m2359	2297.7	2370.16	2431.46	2314.19	2302.05
m2367	1893.08	2375.84	2143.27	2269.73	2221.84
m2370	2247.43	1862.97	2320.51	2389.49	2559.22
m2379	2189.54	2076.41	2041.7	2310.59	2073.35
m2404	2443.89	2454.84	2586.43	2341.41	2089.46
m2427	2277.92	2178.59	2229.08	2203.65	1886.43
m2445	2370.41	2164.51	2242.68	2497.46	2243.76
m2448	2208.24	2096.08	2234.16	2387.22	2124.95
m2464	2371.11	1997.59	2125.27	2285.54	2364.3
m2480	2288.24	2487.73	2235.16	2164.35	2380.51
m2496	2069.97	2098.62	2364.81	2314.68	2094.14
m2510	2198.78	2573.43	2140.89	2298.14	1947.76
m2533	2449.62	2577.32	2211.68	2337.97	2486.27
AVERAGE	2273.601	2286.554	2239.849	2315.219	2235.247
STD DEV	162	170	147	123	169

APPENDIX G: Individual Landmarks x-Coordinates

Image_id	x	x	x	x	x	x	x	x
	ex	en	en’	ex’	na	na’	ch	ch’
f2247	159	214	286	341	209	289	199	295
f2274	151	211	287	346	217	288	194	300
f2283	152	209	294	352	209	290	198	308
f2290	149	209	292	354	219	287	197	305
f2293	145	209	290	354	219	288	195	318
f2300	145	207	294	355	214	285	195	311
f2334	151	214	287	346	210	278	187	294
f2340	150	210	289	349	212	281	192	302
f2349	151	207	292	348	207	283	196	299
f2354	146	209	289	348	207	283	184	299
f2363	147	214	285	352	212	284	193	299
f2374	148	212	286	350	214	289	204	299
f2374-1	150	210	288	351	210	278	195	289
f2388	152	211	291	350	210	292	199	307
f2397	153	211	287	345	214	291	198	303
f2425	148	205	293	353	205	286	194	291
f2431	157	211	290	345	207	284	197	299
f2442	155	214	290	346	217	290	195	307
f2460	155	210	289	347	219	288	200	295
f2478	153	209	291	349	207	284	191	301
f2484	154	207	295	347	214	288	203	300
f2504	154	211	290	344	211	286	200	299
f2506	151	213	287	349	217	288	203	298
f2513	154	212	288	347	210	287	204	297
f2522	160	209	288	340	212	292	199	299
f2541	149	208	291	354	202	293	185	301
m2244	156	208	290	347	204	296	194	316
m2252	151	209	290	349	201	286	187	296
m2264	155	213	289	345	202	296	192	310
m2272	159	211	289	345	208	286	200	296
m2305	160	214	287	344	211	284	192	302
m2312	158	214	284	341	213	288	204	298
m2314	156	211	289	345	208	296	195	303
m2320	154	212	291	351	209	293	191	300
m2324	152	206	292	348	211	288	198	294
m2331	152	208	289	343	217	293	202	308
m2345	160	207	293	345	208	293	199	310

m2359	161	212	288	336	216	284	206	292
m2367	163	213	285	340	214	289	211	302
m2370	156	212	289	340	213	290	204	293
m2379	156	210	289	341	213	293	200	309
m2404	149	208	293	350	207	294	198	311
m2427	160	212	286	339	209	292	201	303
m2445	159	208	290	344	209	300	199	311
m2448	151	206	291	350	215	292	206	303
m2464	161	210	292	343	210	294	200	309
m2480	157	215	287	346	217	293	203	297
m2496	162	211	287	340	204	285	188	298
m2510	159	215	286	343	209	289	192	295
m2533	158	209	289	344	204	296	197	298
AVERAGE	154	210	289	346	211	289	197	301
STD DEV	4.7	2.5	2.5	4.4	4.6	4.7	5.7	6.5

APPENDIX H: Individual Landmarks y-Coordinates

Image_id	y	y	y	y	y	y	y	y
	ex	en	en’	ex’	na	na’	ch	ch’
f2247	328	319	321	323	247	242	176	175
f2274	326	322	323	326	243	237	179	173
f2283	323	322	321	321	246	249	184	186
f2290	321	321	321	324	234	230	166	168
f2293	323	320	321	326	232	235	179	182
f2300	324	320	320	328	236	241	179	183
f2334	324	322	321	317	241	243	170	168
f2340	320	322	321	320	247	250	174	172
f2349	324	321	320	324	235	239	177	176
f2354	324	321	321	320	243	245	187	180
f2363	327	320	320	324	237	241	178	178
f2374	323	321	321	326	241	244	181	182
f2374-1	326	322	322	317	239	240	176	172
f2388	319	319	319	322	244	246	176	179
f2397	322	321	320	321	237	240	172	171
f2425	328	319	318	322	244	244	174	170
f2431	325	321	321	322	241	241	181	182
f2442	328	322	320	327	238	239	180	179
f2460	324	320	319	320	238	240	178	178
f2478	327	321	320	324	237	242	175	175
f2484	323	321	322	325	248	250	184	184
f2504	326	320	321	325	241	244	180	176
f2506	318	322	321	321	248	249	183	181
f2513	322	322	322	320	234	239	173	175
f2522	327	323	321	324	239	245	179	177
f2541	327	322	321	327	249	246	187	180
m2244	321	321	321	325	240	248	176	183
m2252	323	323	321	319	244	245	169	170
m2264	322	321	322	320	250	249	177	174
m2272	319	322	322	323	238	243	170	169
m2305	323	321	321	322	251	254	183	185
m2312	322	322	322	320	251	251	182	180
m2314	327	323	322	325	244	244	175	176
m2320	323	322	322	319	248	247	177	181
m2324	324	321	321	322	241	244	174	172
m2331	323	322	323	325	246	249	178	184
m2345	325	321	321	326	239	239	179	181

m2359	321	322	321	321	240	245	178	182
m2367	321	320	321	325	243	245	185	191
m2370	320	321	321	321	253	255	185	185
m2379	323	321	321	325	255	259	192	194
m2404	323	324	323	327	234	241	165	167
m2427	324	321	322	326	246	249	177	182
m2445	319	322	321	322	236	241	177	175
m2448	323	323	323	325	245	248	172	174
m2464	324	323	322	324	253	261	180	186
m2480	322	323	322	319	248	250	185	185
m2496	317	322	321	317	240	247	177	179
m2510	323	322	322	322	248	247	184	180
m2533	323	322	322	320	240	243	175	176
AVERAGE	323	321	321	323	243	245	178	178
STD DEV	2.6	1.1	1.0	2.9	5.6	5.7	5.4	6.0

APPENDIX I: Extremity and Medial Axes Coordinates

Image_id	x left	x right	x upper	x lower	y left	y right	y upper	y lower	Vertical axis	Horizontal axis
f2247	102	394	254	257	288	283	475	74	**187**	**324**
f2274	100	394	252	222	315	305	489	88	**181**	**324**
f2283	105	398	247	277	286	304	498	97	**181**	**323**
f2290	105	398	246	256	300	313	473	72	**179**	**321**
f2293	99	392	243	254	303	308	493	92	**177**	**322**
f2300	103	395	246	257	289	297	486	85	**176**	**322**
f2334	96	390	259	245	304	284	475	74	**183**	**323**
f2340	105	398	245	247	282	277	463	61	**180**	**321**
f2349	103	396	254	247	290	297	498	96	**179**	**323**
f2354	101	395	249	245	316	307	494	92	**178**	**323**
f2363	104	397	256	254	291	300	486	85	**181**	**324**
f2374	100	393	248	253	288	309	482	81	**180**	**322**
f2374-1	103	397	254	249	287	295	488	86	**180**	**324**
f2388	104	398	246	254	280	278	483	84	**182**	**319**
f2397	101	395	247	251	285	281	475	74	**182**	**322**
f2425	102	395	245	249	296	292	471	71	**177**	**324**
f2431	104	397	241	247	297	296	502	99	**184**	**323**
f2442	102	395	251	257	294	282	488	86	**185**	**325**
f2460	102	395	251	253	299	296	484	81	**183**	**322**

f2478	101	394	247	250	288	298	484	83	**181**	**324**
f2484	103	396	256	253	296	289	490	89	**181**	**322**
f2504	104	398	248	252	279	275	483	82	**183**	**323**
f2506	103	397	247	254	269	266	491	90	**182**	**320**
f2513	104	397	252	240	294	280	485	85	**183**	**322**
f2522	106	400	257	251	310	299	492	92	**185**	**325**
f2541	100	394	245	260	314	305	492	91	**179**	**325**
m2244	107	401	243	241	302	295	472	71	**182**	**321**
m2252	102	395	253	242	266	302	461	59	**180**	**323**
m2264	103	396	253	245	274	250	469	68	**184**	**322**
m2272	107	400	247	252	268	280	465	65	**185**	**321**
m2305	105	398	250	247	296	287	494	92	**187**	**322**
m2312	100	394	253	249	273	260	481	81	**186**	**322**
m2314	103	396	254	232	288	292	479	76	**184**	**325**
m2320	101	393	249	250	279	292	486	83	**183**	**323**
m2324	106	399	249	249	274	287	479	78	**179**	**323**
m2331	100	394	252	242	288	296	482	82	**180**	**323**
m2345	107	399	247	249	302	295	485	83	**184**	**323**
m2359	105	398	249	252	292	301	484	83	**187**	**322**
m2367	105	398	249	254	302	303	492	91	**188**	**321**
m2370	104	397	248	251	275	274	487	85	**184**	**321**
m2379	106	398	252	256	270	272	496	96	**183**	**322**
m2404	104	397	247	252	297	305	459	56	**179**	**324**
m2427	106	399	248	234	298	292	479	77	**186**	**323**
m2445	104	397	252	257	303	313	480	78	**184**	**321**

m2448	103	396	246	255	299	305	477	76	**179**	**323**
m2464	102	395	251	255	291	287	484	82	**186**	**324**
m2480	106	399	253	253	275	292	483	80	**186**	**323**
m2496	103	398	247	245	258	283	480	79	**187**	**320**
m2510	102	395	250	246	284	284	487	85	**187**	**323**
m2533	105	399	251	249	275	269	468	67	**184**	**323**
AVERAGE	103	396	250	250	289	291	483	81	**182**	**323**
STD DEV	2.31	2.24	3.85	7.97	13.33	13.75	9.79	9.80	**3.05**	**1.36**

APPENDIX J: Distances of Landmarks from Vertical & Horizontal Axes

Image_id	X	X	X	X	X	X	X	X	Y	Y	Y	Y
	v-ex	ex'-v	v-na	na'-v	v-ch	ch'-v	v-en	en'-v	h-na	h-na'	h-ch	h-ch'
f2247	89	93	39	41	49	47	34	38	28	33	99	100
f2274	96	99	30	41	53	53	36	40	46	52	110	116
f2283	100	101	43	39	54	57	43	43	52	49	114	112
f2290	103	103	33	36	55	54	43	41	39	43	107	105
f2293	101	109	27	43	51	73	37	45	61	58	114	111
f2300	104	106	35	36	54	62	42	45	50	45	107	103
f2334	92	103	33	35	56	51	29	44	34	32	105	107
f2340	102	98	40	30	60	51	42	38	15	12	88	90
f2349	99	99	43	34	54	50	43	43	62	58	120	121
f2354	102	100	41	35	64	51	39	41	50	48	106	113
f2363	104	102	39	34	58	49	37	35	49	45	108	108
f2374	99	104	33	43	43	53	35	40	41	38	101	100
f2374-1	100	101	40	28	55	39	40	38	48	47	111	115
f2388	99	99	41	41	52	56	40	40	40	38	108	105
f2397	95	97	34	43	50	55	37	39	38	35	103	104
f2425	101	105	44	38	55	43	44	45	27	27	97	101
f2431	94	95	44	34	54	49	40	40	60	60	120	119

f2442	94	98	32	42	54	59	35	42	49	48	107	108
f2460	94	99	30	40	49	47	39	41	45	43	105	105
f2478	95	102	41	37	57	54	39	44	47	42	109	109
f2484	96	98	36	39	47	51	43	46	42	40	106	106
f2504	97	93	40	35	51	48	40	39	42	39	103	107
f2506	99	99	33	38	47	48	37	37	43	42	108	110
f2513	97	97	41	37	47	47	39	38	51	46	112	110
f2522	93	87	41	39	54	46	44	35	53	47	113	115
f2541	98	107	45	46	62	54	39	44	43	46	105	112
m2244	98	93	50	42	60	62	46	36	32	24	96	89
m2252	98	101	48	38	62	48	40	42	16	15	91	90
m2264	95	96	48	47	58	61	37	40	19	20	92	95
m2272	95	92	46	33	54	43	43	36	27	22	95	96
m2305	92	93	41	33	60	51	38	36	42	39	110	108
m2312	89	94	34	41	43	51	33	37	30	30	99	101
m2314	94	96	42	47	55	54	39	40	34	34	103	102
m2320	93	104	38	46	56	53	35	44	37	38	108	104
m2324	101	96	42	36	55	42	47	40	38	35	105	107
m2331	95	96	30	46	45	61	39	42	36	33	104	98
m2345	93	92	45	40	54	57	46	40	45	45	105	103
m2359	91	85	36	33	46	41	40	37	44	39	106	102
m2367	89	89	38	38	41	51	39	34	49	47	107	101
m2370	95	90	38	40	47	43	39	39	33	31	101	101

m2379	96	89	39	41	52	57	42	37	41	37	104	102
m2404	102	100	44	44	53	61	43	43	24	17	93	91
m2427	93	87	44	40	52	51	41	34	32	29	101	96
m2445	92	94	42	50	52	61	43	40	43	38	102	104
m2448	99	101	35	43	44	54	44	42	32	29	105	103
m2464	88	95	39	46	49	61	39	44	30	22	103	97
m2480	96	94	36	41	50	45	38	35	34	32	97	97
m2496	89	90	47	35	63	48	40	37	40	33	103	101
m2510	90	95	40	41	57	47	34	38	38	39	102	106
m2533	94	92	48	44	55	46	43	37	28	25	93	92
AVERAGE	96	97	39	39	53	52	40	40	40	37	104	104
STD DEV	4.24	5.47	5.39	4.72	5.39	6.65	3.63	3.22	10.65	10.89	6.80	7.43

APPENDIX K: Local and Global Asymmetry Scores

Image_id	EX_v	NA_v	CH_v	EN_v	EX_h	NA_h	CH_h	AI_v	AI_h
	X	X	X	X	Y	Y	Y		
f2247	-4	-2	2	-4	5	-5	-1	**-8**	**-1**
f2274	-3	-11	0	-4	0	-6	-6	**-18**	**-12**
f2283	-1	4	-3	0	2	3	2	**0**	**7**
f2290	0	-3	1	2	-3	-4	2	**0**	**-5**
f2293	-8	-16	-22	-8	-3	3	3	**-54**	**3**
f2300	-2	-1	-8	-3	-4	5	4	**-14**	**5**
f2334	-11	-2	5	-15	7	2	-2	**-23**	**7**
f2340	4	10	9	4	0	3	-2	**27**	**1**
f2349	0	9	4	0	0	4	-1	**13**	**3**
f2354	2	6	13	-2	4	2	-7	**19**	**-1**
f2363	2	5	9	2	3	4	0	**18**	**7**
f2374	-5	-10	-10	-5	-3	3	1	**-30**	**1**
f2374-1	-1	12	16	2	9	1	-4	**29**	**6**
f2388	0	0	-4	0	-3	2	3	**-4**	**2**
f2397	-2	-9	-5	-2	1	3	-1	**-18**	**3**
f2425	-4	6	12	-1	6	0	-4	**13**	**2**
f2431	-1	10	5	0	3	0	1	**14**	**4**
f2442	-4	-10	-5	-7	1	1	-1	**-26**	**1**
f2460	-5	-10	2	-2	4	2	0	**-15**	**6**
f2478	-7	4	3	-5	3	5	0	**-5**	**8**
f2484	-2	-3	-4	-3	-2	2	0	**-12**	**0**
f2504	4	5	3	1	1	3	-4	**13**	**0**
f2506	0	-5	-1	0	-3	1	-2	**-6**	**-4**
f2513	0	4	0	1	2	5	2	**5**	**9**
f2522	6	2	8	9	3	6	-2	**25**	**7**
f2541	-9	-1	8	-5	0	-3	-7	**-7**	**-10**
m2244	5	8	-2	10	-4	8	7	**21**	**11**
m2252	-3	10	14	-2	4	1	1	**19**	**6**
m2264	-1	1	-3	-3	2	-1	-3	**-6**	**-2**
m2272	3	13	11	7	-4	5	-1	**34**	**0**
m2305	-1	8	9	2	1	3	2	**18**	**6**
m2312	-5	-7	-8	-4	2	0	-2	**-24**	**0**
m2314	-2	-5	1	-1	2	0	1	**-7**	**3**
m2320	-11	-8	3	-9	4	-1	4	**-25**	**7**
m2324	5	6	13	7	2	3	-2	**31**	**3**
m2331	-1	-16	-16	-3	-2	3	6	**-36**	**7**
m2345	1	5	-3	6	-1	0	2	**9**	**1**
m2359	6	3	5	3	0	5	4	**17**	**9**

m2367	0	0	-10	5	-4	2	6	**-5**	**4**
m2370	5	-2	4	0	-1	2	0	**7**	**1**
m2379	7	-2	-5	5	-2	4	2	**5**	**4**
m2404	2	0	-8	0	-4	7	2	**-6**	**5**
m2427	6	4	1	7	-2	3	5	**18**	**6**
m2445	-2	-8	-9	3	-3	5	-2	**-16**	**0**
m2448	-2	-8	-10	2	-2	3	2	**-18**	**3**
m2464	-7	-7	-12	-5	0	8	6	**-31**	**14**
m2480	2	-5	5	3	3	2	0	**5**	**5**
m2496	-1	12	15	3	0	7	2	**29**	**9**
m2510	-5	-1	10	-4	1	-1	-4	**0**	**-4**
m2533	2	4	9	6	3	3	1	**21**	**7**
AVERAGE	-1	0	1	0	1	2	0	**0**	**3**
STD DEV	4.36	7.37	8.50	4.87	3.12	2.99	3.28	**19.97**	**4.89**

APPENDIX L: Entropy Scores

Image_id	symmetric	intermediate	original
f2247	0.9480	1.4916	1.7226
f2274	0.9966	1.4275	1.6609
f2283	0.9360	1.5106	1.7722
f2290	0.9665	1.4678	1.6995
f2293	0.9588	1.5747	1.8386
f2300	0.8999	1.4011	1.6228
f2334	1.0246	1.7639	2.0257
f2340	0.9368	1.3681	1.5992
f2349	0.9191	1.3243	1.5521
f2354	0.9451	1.5169	1.7597
f2363	0.9655	1.4778	1.7470
f2374	0.9316	1.7397	1.9853
f2374-1	0.9532	1.5716	1.7909
f2388	0.9574	1.4632	1.7024
f2397	0.9406	1.3753	1.6040
f2425	0.9540	1.6054	1.8721
f2431	0.9427	1.4559	1.7063
f2442	0.9475	1.4228	1.6737
f2460	0.9400	1.4001	1.5701
f2478	0.9287	1.4568	1.7042
f2484	0.9375	1.3523	1.5722
f2504	1.0064	1.3391	1.5711
f2506	0.9449	1.3801	1.6588
f2513	0.9113	1.3037	1.5304
f2522	0.9417	1.5568	1.8143
f2541	0.9651	1.5663	1.8143
m2244	0.9608	1.5100	1.7544
m2252	0.9597	1.6300	1.9228
m2264	0.9857	1.4141	1.6783
m2272	0.9749	1.5421	1.8235
m2305	0.9449	1.3185	1.5617
m2312	1.0100	1.5145	1.7542
m2314	0.9688	1.3780	1.6014
m2320	0.9920	1.4773	1.7213
m2324	0.9785	1.4549	1.7163
m2331	0.9618	1.5121	1.7650
m2345	0.9448	1.5198	1.7656

m2359	0.9685	1.4919	1.7286
m2367	0.9568	1.5173	1.7757
m2370	0.9649	1.3809	1.6269
m2379	0.9461	1.4662	1.7030
m2404	1.0003	1.7132	1.9725
m2427	1.0228	1.6581	1.9645
m2445	0.9513	1.4127	1.6546
m2448	0.8957	1.5062	1.7547
m2464	0.9392	1.4610	1.7294
m2480	0.9038	1.3999	1.6360
m2496	1.0065	1.4732	1.7287
m2510	0.9946	1.4520	1.6950
m2533	0.9416	1.4372	1.6888
AVERAGE	0.9575	1.4791	1.7259
STD DEV	0.0297	0.1037	0.1156

APPENDIX M: Edinburgh Handedness Inventory

Left	Right	
		Writing
		Drawing
		Throwing
		Scissors
		Toothbrush
		Knife (without a fork)
		Spoon
		Broom (upper hand)
		Striking match
		Opening box (lid)
		Which foot do you prefer to kick with?
		Which eye do you use when using only one eye?

APPENDIX N: Gönüllü Katılım Formu

Öncelikle katıldığınız için teşekkürler. Dr. Didem Gökçay danışmanlığında Dicle Dövencioğlu tarafından yapılan bu çalışma yüz algısıyla ilgilidir. Çalışmada insanların çeşitli yüz resimlerine nasıl tepki verdiklerini ölçüyoruz. Ekranda siyah-beyaz ve rötuşlanmış yüz resimleri göreceksiniz. Fotoğraflar Enformatik Enstitüsü'de oluşturulmuş ODTÜ Yüz Veritabanı'ndan alınmıştır. Sizden istediğimiz, bir resme bakarken sizde ilk uyandırdığı etkiyi derecelendirmeniz. Çalışmaya katılım tamimiyle gönüllülük temelindedir. Ankette, sizden kimlik belirleyici hiçbir bilgi istenmemektedir. Cevaplarınız tamimiyle gizli tutulacak ve sadece araştırmacılar tarafından değerlendirilecektir; elde edilecek bilgiler bilimsel yayımlarda kullanılacaktır.

Çalışmamız iki kısımdan oluşmaktadır. Her ikisinde de beş saniye boyunca ekranda bir yüz resmi görünecektir. Bu süre içinde klavyeden 1'den 9'a kadar bir tuşa basarak cevap vermeniz bekleniyor. Deney yapısında bir önceki resme geri dönmek mümkün değil, bu yüzden eğer beş saniye içinde cevap vermediyseniz o resim değerlendirilmeyecek ve bir sonraki resme geçilecek. Çalışmanın ilk kısmında derecelendirmeyi şu soruya göre yapmanız isteniyor: **"Gördüğünüz resim ne kadar çekici?"** Eğer çok çekici olduğunu düşünüyorsanız 9'a; hiç çekici olmadığını düşünüyorsanız 1'e basın. Bu iki ölçütün arasında bir değer vermek için aradaki sayıları kullanabilirsiniz. Değerlendirmenizi en iyi şekilde yapabilmeniz için 1 ve 9 arasındaki değerleri kullanmanız önemlidir. Çalışmanin ikinci kısmında yine 5 saniye süreyle yüz resimlerine bakarken bu resimleri değerlendirmeniz isteniyor. Birinci kısmı bitirdiğinizde, ikinciye geçmeden önce bu kısımda size puanları neye göre vermeniz gerektiği söylenecek.

Lütfen her resmi çok fazla düşünmeden değerlendirin; resmi ilk gördüğünüzdeki tepkinize göre bir cevap vermeye çalışın.

Katılım sırasında sorulardan ya da herhangi başka bir nedenden ötürü kendinizi rahatsız hissederseniz cevaplama işini yarıda bırakıp çıkmakta serbestsiniz. Böyle bir durumda anketi uygulayan kişiye, anketi tamamlamadığınızı söylemek yeterli olacaktır.Çalışma ile ilgili daha fazla bilgi almak için Bilişsel Bilimler yüksek lisans öğrencisi Dicle Dövencioğlu'yla iletişim kurabilirsiniz (MM binası 4. Kat oda: MM-410, e-mail: dicle@ii.metu.edu.tr tlf: 532 4053400).

Bu çalışmaya tamamen gönüllü olarak katılıyorum ve istediğim zaman yarıda kesip çıkabileceğimi biliyorum. Verdiğim bilgilerin bilimsel amaçlı yayımlarda kullanılmasını kabul ediyorum. (Formu doldurup imzaladıktan sonra uygulayıcıya geri veriniz).

İsim Soyad   Tarih   İmza

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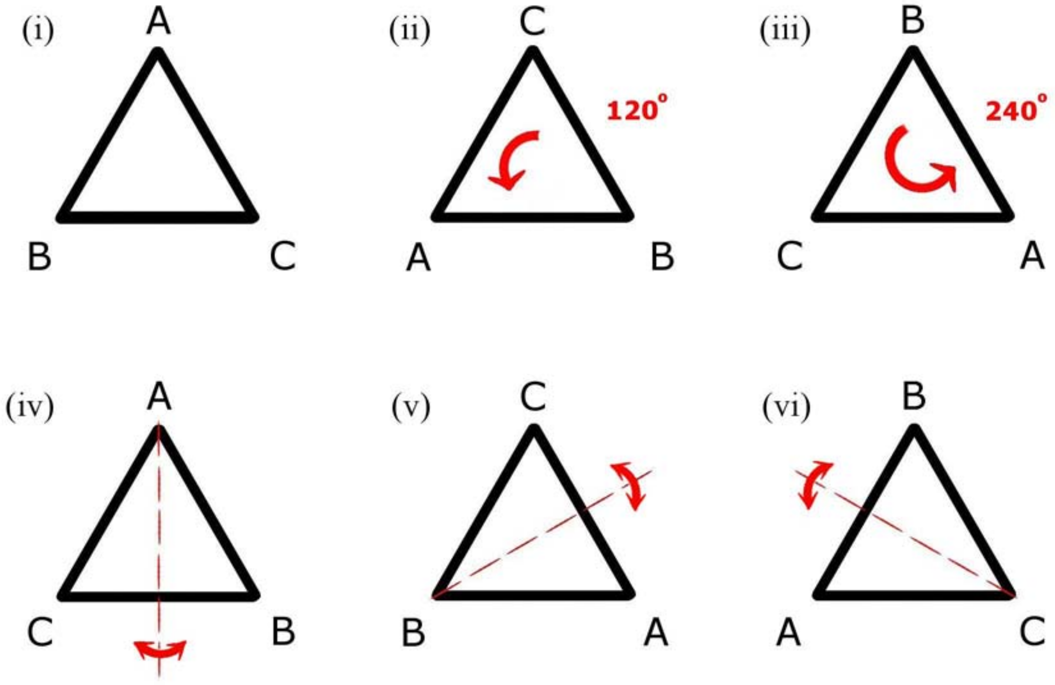
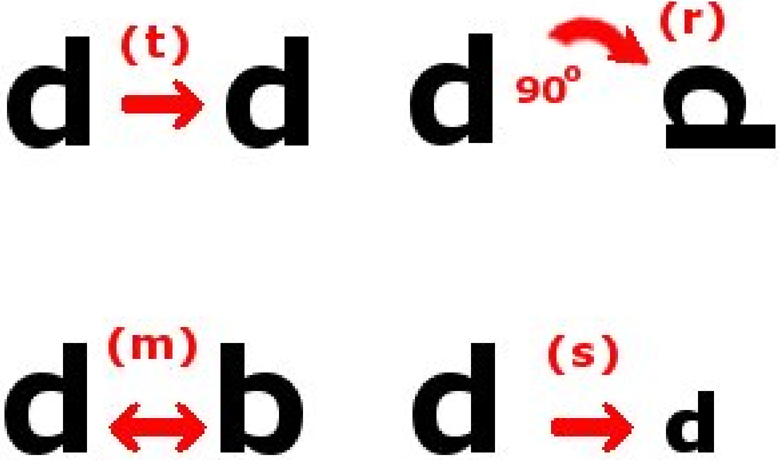
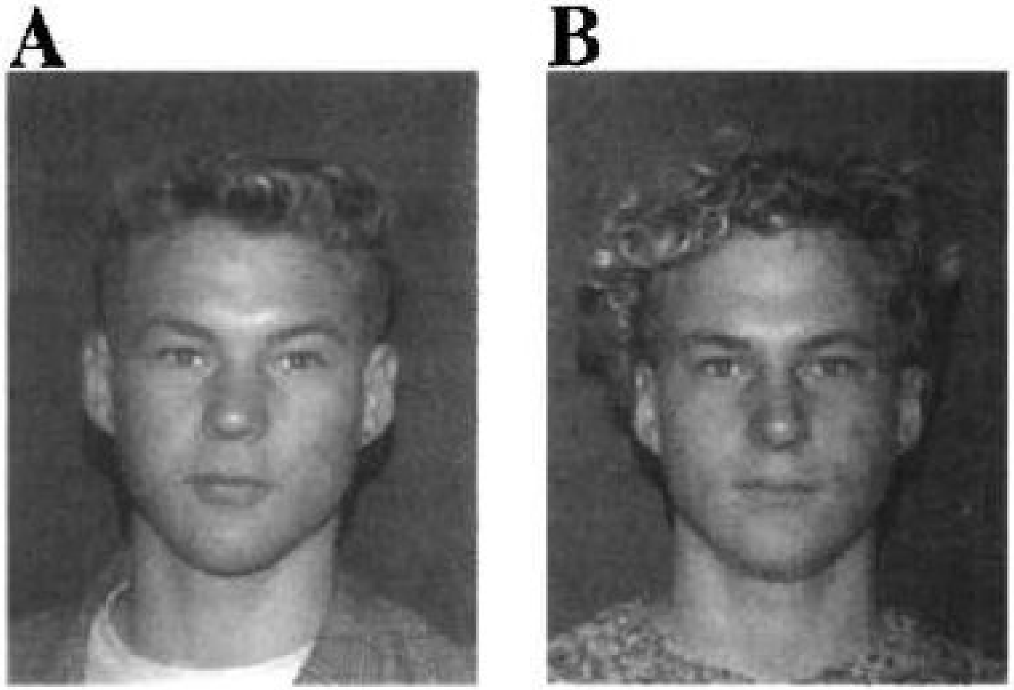
Vertebrate animal	Mirror symmetry
Invertebrate animal	Mirror and repetition symmetry
Vegetable	Multiple symmetries (emphasizing repetition, scale, cylindrical, helical and multifold)
Mineral	None (at the macroscopic scale)
Constructed	Multiple symmetries (emphasizing two-fold)

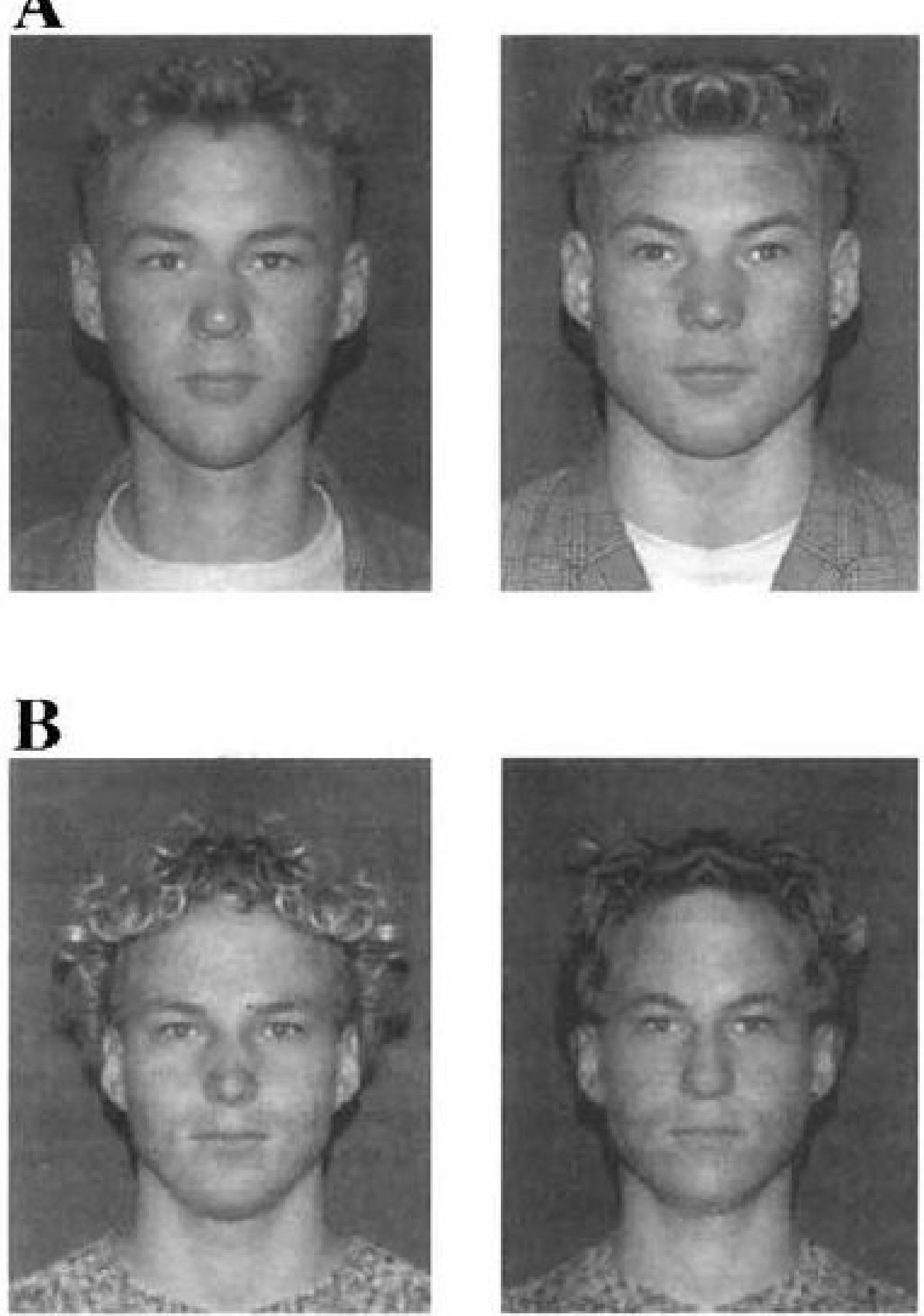


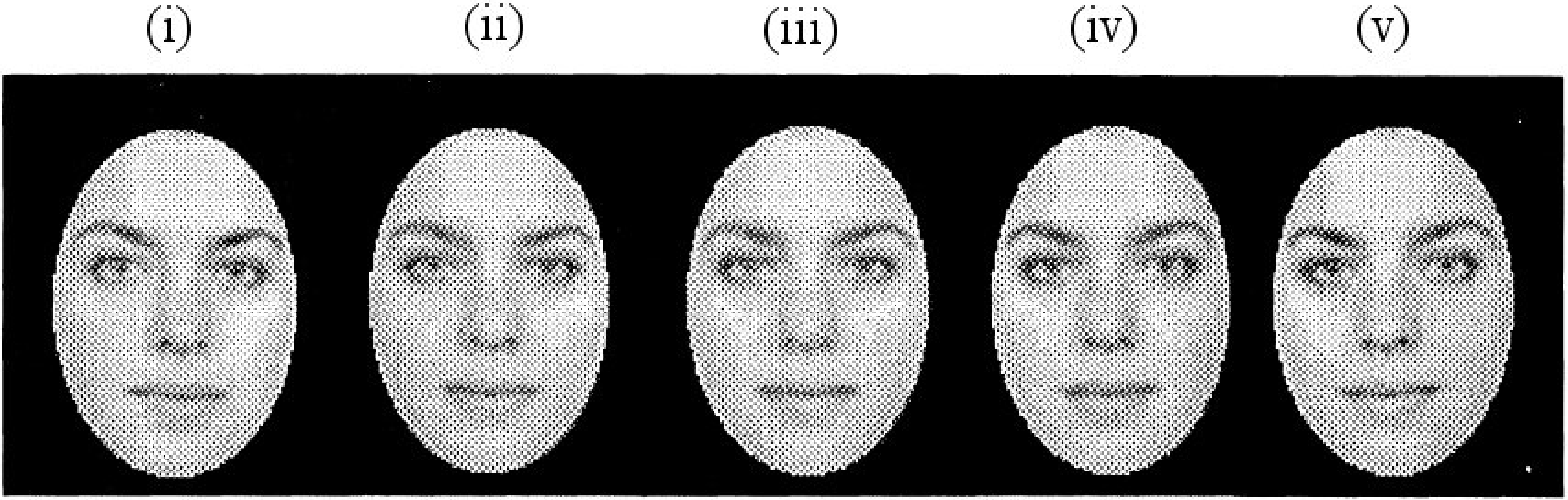
(i)
A
B
C
(ii)
C
120°
A
B
(iii)
B
240°
C
A
(iv)
A
C
B
(v)
C
B
A
(vi)
B
A
C

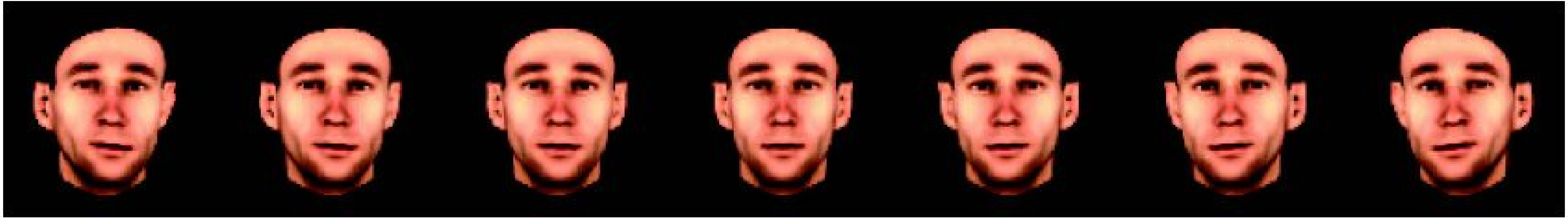

d
(t)
d
d
90°
(r)
d
(m)
b
d
(s)
d


(i)
(ii)
(iii)

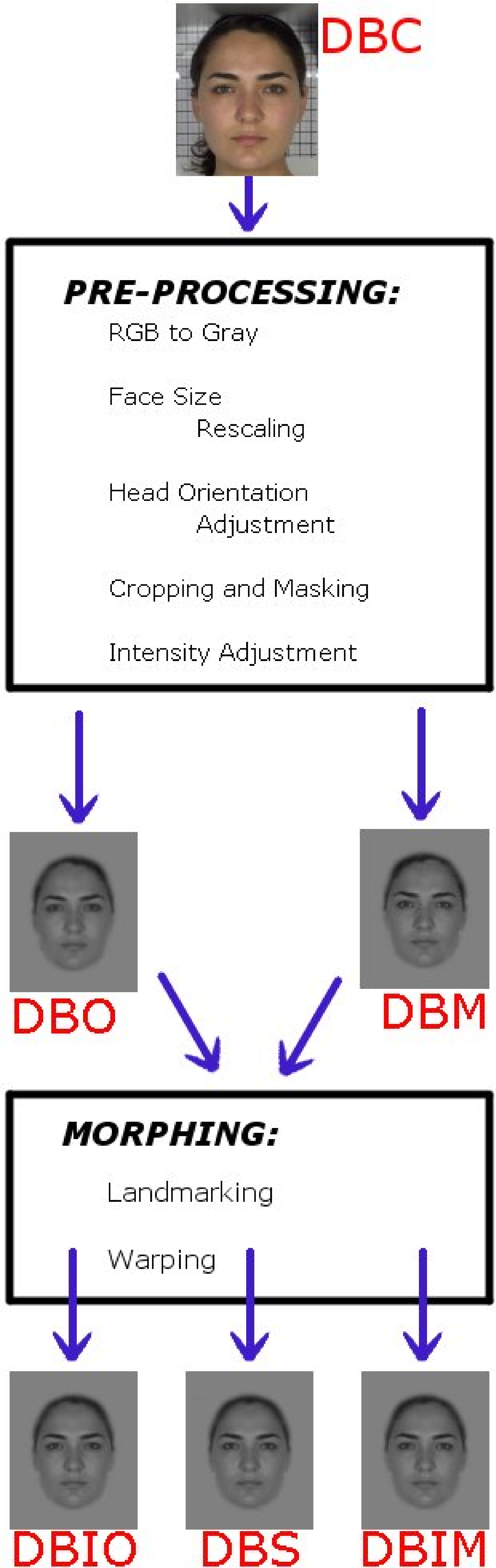

A
B


A
B

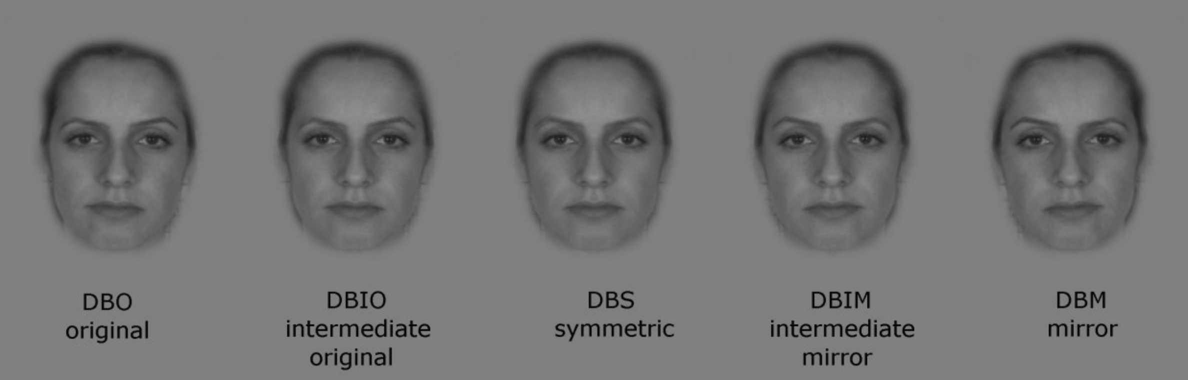

(i)
(ii)
(iii)
(iv)
(v)

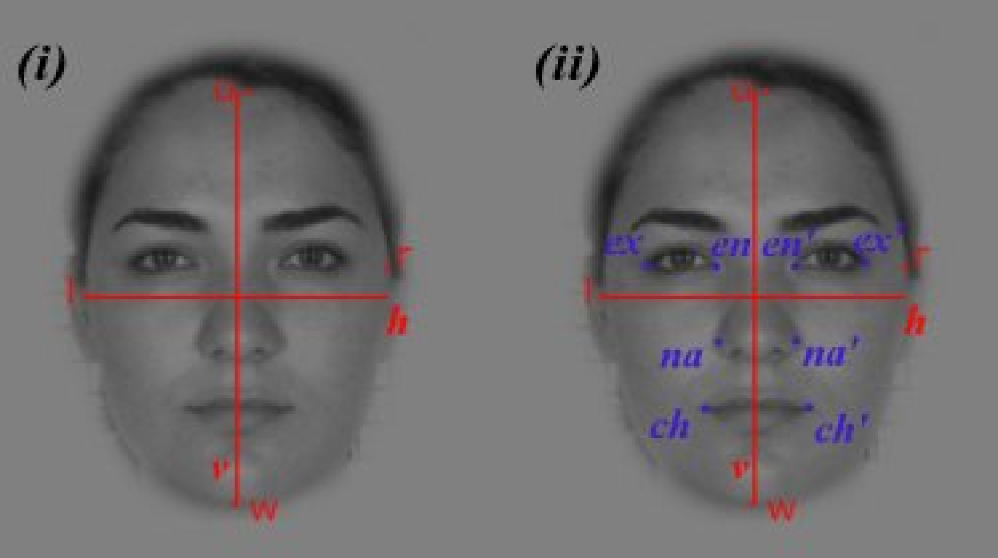


(i) (ii) (iii)

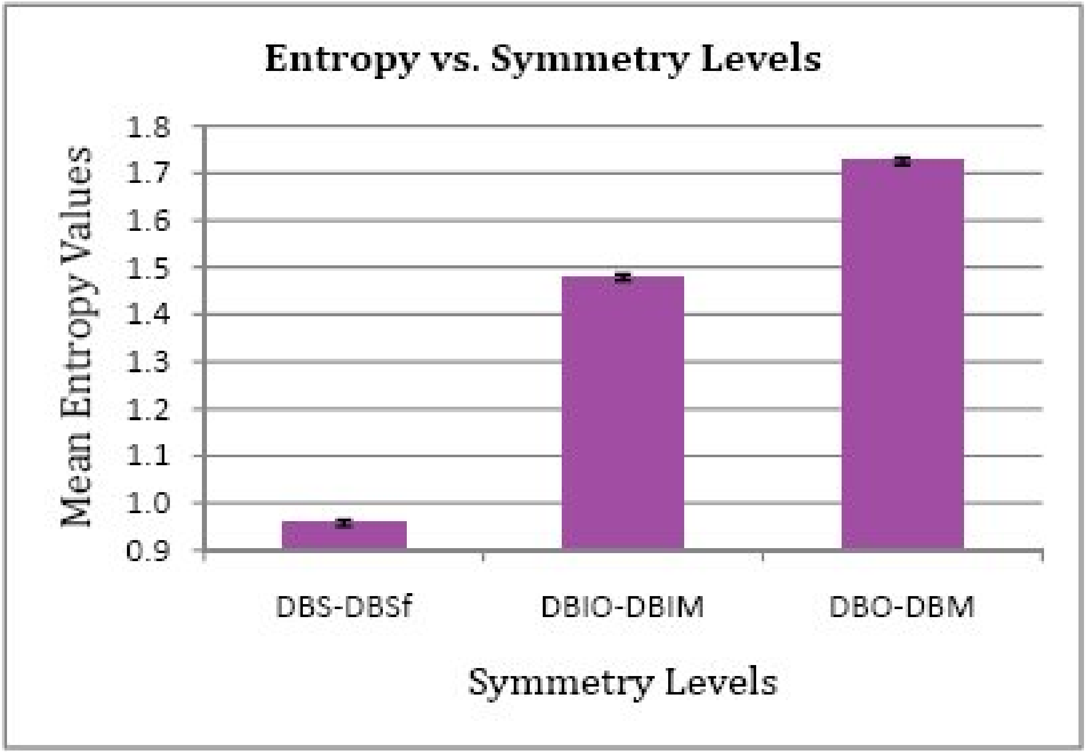

DBC
PRE-PROCESSING:
RGB to Gray
Face Size Rescaling
Head Orientation Adjustment
Cropping and Masking
Intensity Adjustment
DBO
DBM
MORPHING:
Landmarking
Warping
DBIO
DBS
DBIM

u
r
l
w


DBO
original
DBIO
intermediate
original
DBS
symmetric
DBIM
intermediate
mirror
DBM
mirror

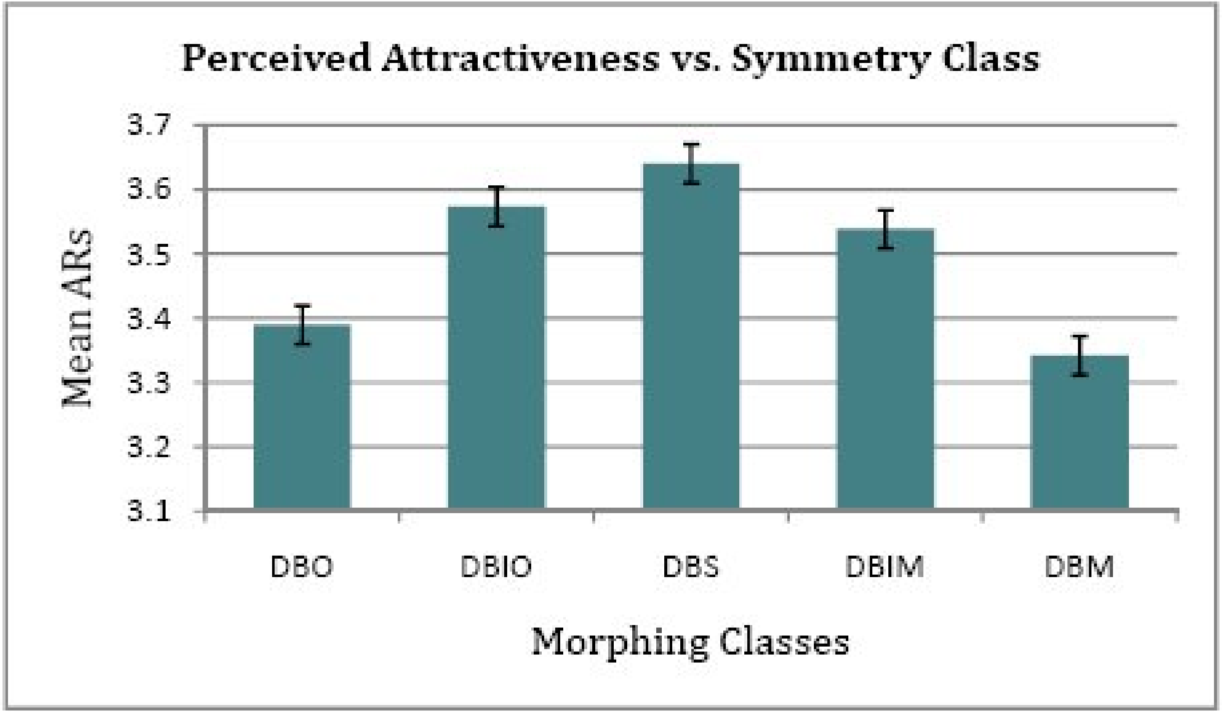


(i)
u
r
l
h
v
w
(ii)
u
ex
en
en'
ex'
r
l
h
na
na'
ch
ch'
v
w

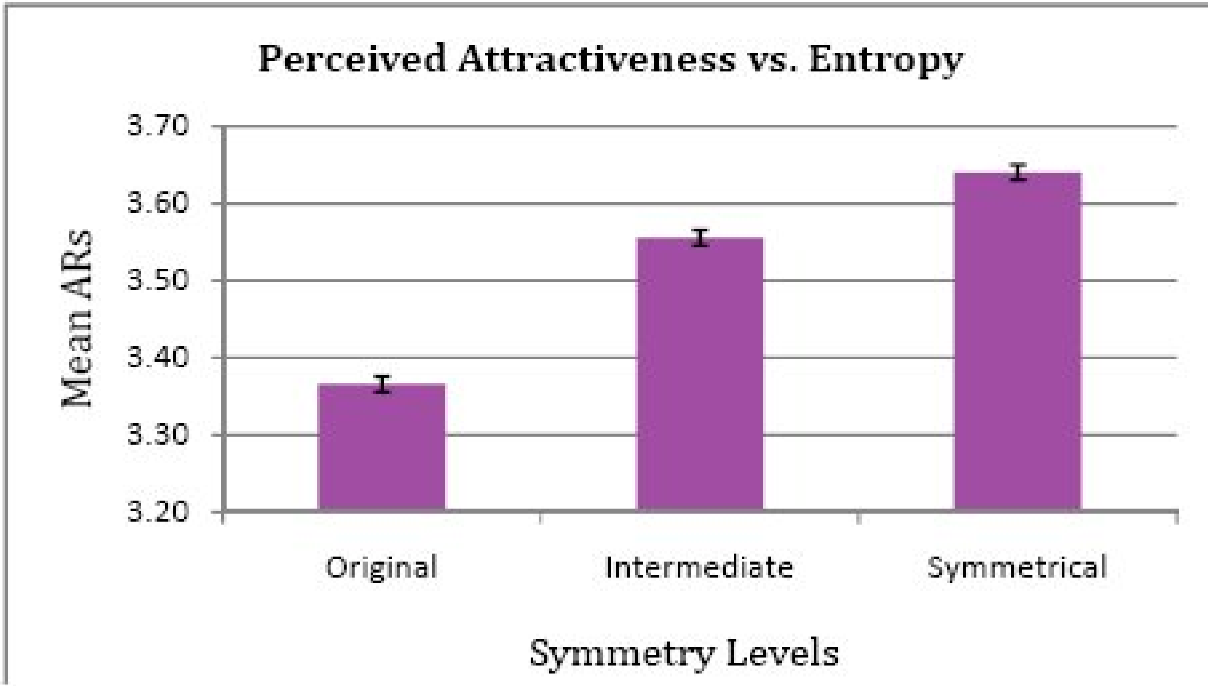


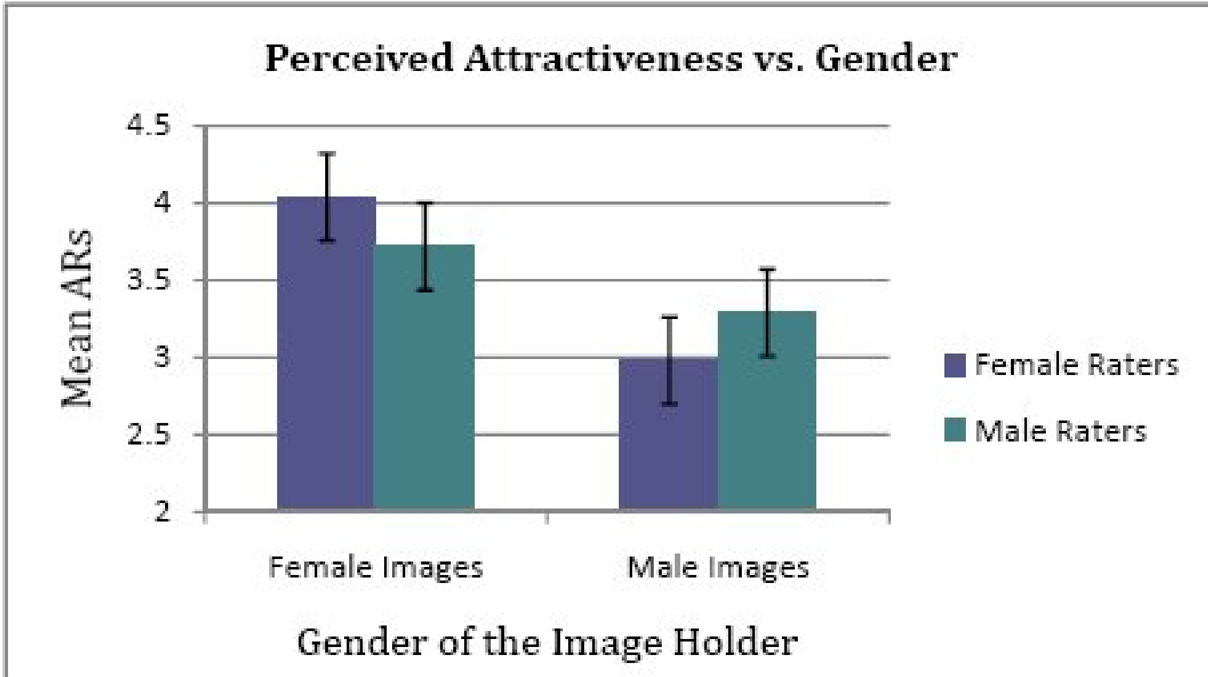
Entropy vs. Symmetry Levels
Mean Entropy Values
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
DBS-DBSf
DBIO-DBIM
DBO-DBM
Symmetry Levels

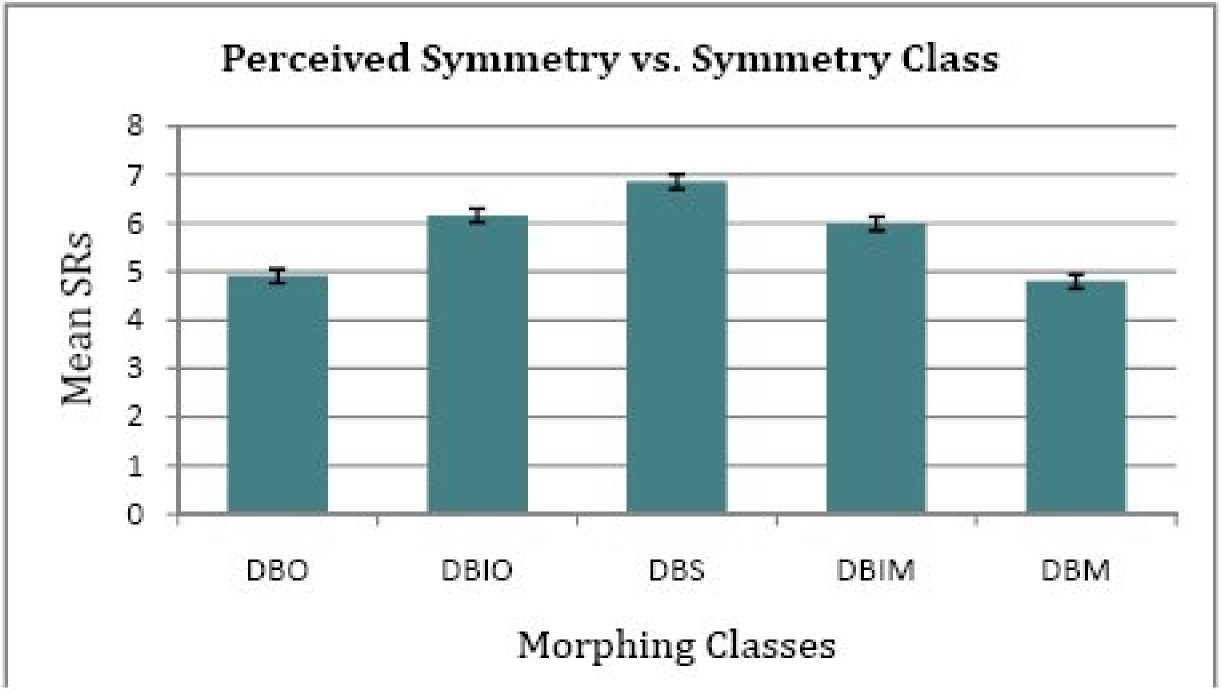
1	2	3	4	5	6	7	8	9
hiç çekici değil!								çok çekici!

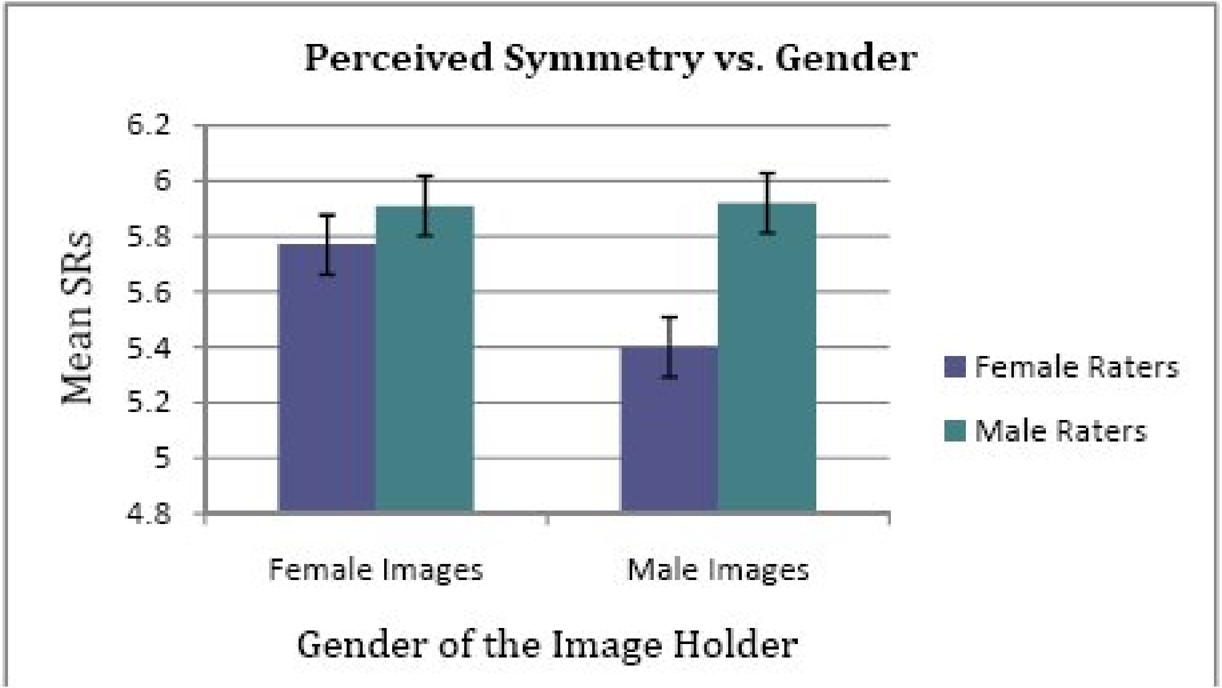


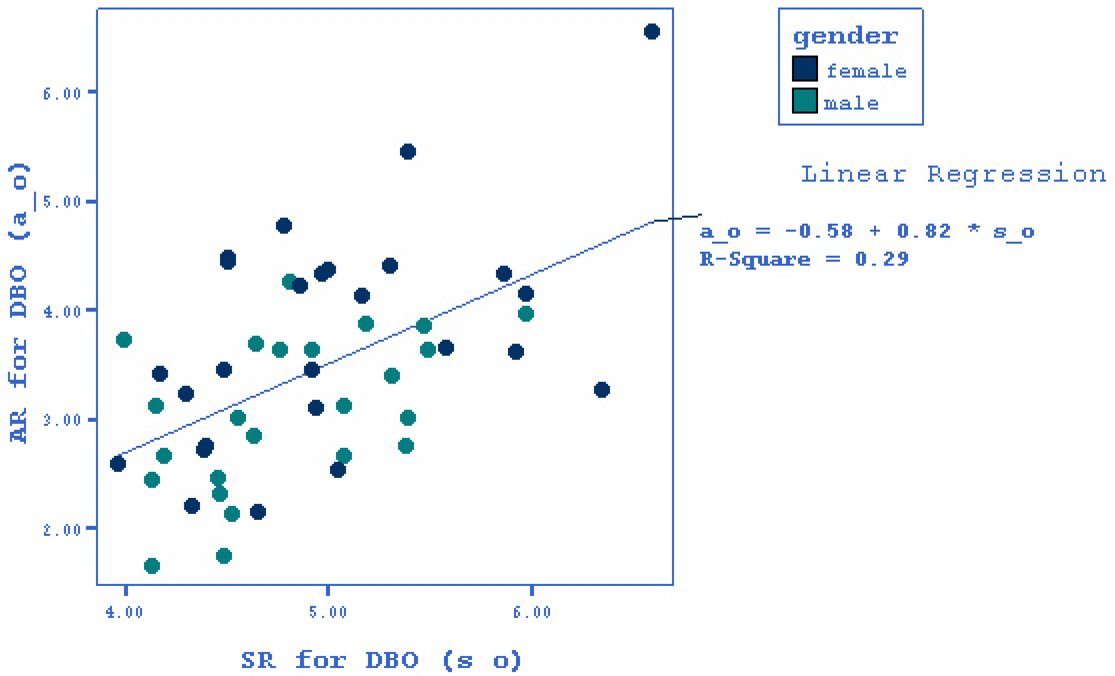
Perceived Attractiveness vs. Symmetry Class
3.7
3.6
3.5
3.4
3.3
3.2
3.1
Mean ARs
DBO
DBIO
DBS
DBIM
DBM
Morphing Classes


Perceived Attractiveness vs. Entropy
3.70
3.60
3.50
3.40
3.30
3.20
Mean ARs
Original
Intermediate
Symmetrical
Symmetry Levels


Perceived Attractiveness vs. Gender
Mean ARs
4.5
4
3.5
3
2.5
2
Female Images
Male Images
Gender of the Image Holder
Female Raters
Male Raters


Perceived Symmetry vs. Symmetry Class
Mean SRs
0
1
2
3
4
5
6
7
8
DBO
DBIO
DBS
DBIM
DBM
Morphing Classes


Perceived Symmetry vs. Gender
Mean SRs
6.2
6
5.8
5.6
5.4
5.2
5
4.8
Female Images
Male Images
Female Raters
Male Raters
Gender of the Image Holder



gender
female
male
Linear Regression
a_o = -0.58 + 0.82 * s_o
R-Square = 0.29
6.00
5.00
4.00
3.00
2.00
AR for DBO (a_o)
4.00
5.00
6.00
SR for DBO (s_o)