LOCALIZATION OF FACIAL SYMMETRY PERCEPTION THROUGH FMRI

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LOCALIZATION OF FACIAL SYMMETRY PERCEPTION THROUGH FMRI

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ABSTRACT

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Humans are extremely sensitive and accurate about detecting the amount of symmetry that a face possesses. However perception of facial symmetry has not been investigated in terms of its neural correlates yet. In this thesis, we investigated localization of facial symmetry perception in the brain through the use of the fMR adaptation method. In this method, marginally active neuronal populations can be detected by presenting faces with varying symmetry. By standardizing all aspects of the faces such as illumination, pose and contrast, we manipulated only the amount of fluctuating asymmetry in the face images. Previous studies have shown that a specific area, lateral occipital complex (LOC) exhibits sensitivity to orientation and position changes to faces and other objects. We observed that facial symmetry activation is specifically localized within the LOC boundaries. Within the LOC, we found that previously defined areas namely LO1 and LO2 are both responsive to manipulations of facial symmetry. We also tested our fMR-adaptation paradigm on non-face images, generated by scrambling the face stimuli used in our experiments. We replicated

earlier results which demonstrated that LO1 and LO2 are activated in detecting differences between symmetric versus asymmetric patches. This suggests that although facial symmetry perception is not processed by a function specific area of the LOC, it uses main resources allocated for the object recognition system in an efficient manner. To the best of our knowledge, our study is the first to investigate face symmetry perception through fMR-adaptation.

Keywords: symmetry, fMRI, adaptation, face perception, lateral occipital complex

ÖZ

YÜZ SİMETRİSİ ALGISININ FMRG İLE LOKALİZASYONU

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İnsanların yüzlerin sahip olduğu simetriye yüksek ölçüde duyarlı oldukları ve bu simetriyi belirlemede keskin başarı gösterdikleri gözlemlenmiştir. Buna rağmen, yüz simetrisi algısı henüz nöral bağlantıları yönünden incelenmemiştir. Bu tezde, fonksiyonel magnetik rezonans görüntüleme (fMRG) adaptasyon yöntemi kullanılarak beyinde yüz simetrisi algısının lokalizasyonunu inceledik. Bu yöntemle, katılımcılara simetri özelliği farklılık gösteren yüzler gösterilerek, belirgin oranda daha fazla aktif olan nöron grupları tespit edilebilmektedir. Kullandığımız görsel uyaranları sahip oldukları aydınlık, pozisyon ve kontrast gibi değerleri normalize edilerek sadece simetri özelliği değişecek şekilde bu çalışma için özel olarak hazırladık. Önceki çalışmalar beyinde Lateral Oksipital Korteks (LOK) denilen özel bir bölgenin objeler ve yüzlerdeki oryantasyon ve pozisyon değişimine duyarlılık gösterdiğini ortaya çıkarmıştır. Tasarladığımız deneyin sonucunda, yüz simetrisine duyarlı hareketlenmenin LOK sınırları dahilinde olduğunu gözlemledik. LOK'un içerininde daha önceden tanımlanmış ve yüzle ilgili değişikliklere duyarlı olan LO1 ve LO2 isimli alanların ikisinin de yüz simetrisindeki değişikliklerde rol oynadığını gözlemledik. Aynı

zamanda, fMR-adaptasyon yöntemini yüz dışındaki objeler için de kullandık. Bunun için, içindeki görsel bilgiler yüz görselleriyle aynı olan ancak anlam ifade etmeyen resimler kullandık. Böylece, yüz dışındaki objelerin simetri algısında da LO1 ve LO2'nin rol oynadığını öneren önceki çalışmaları yineledik. Bu bulgularımız ortaya koydu ki, yüz simetrisi algısı, LOK'un yalnızca farklı işlevler için özelleşmiş bir bölgesinde gerçekleşmemekte ancak obje algısı için ayrılmış daha geniş kaynakları kullanmaktadır. Şu anda bildiğimiz kadarıyla, yüzlerdeki simetri algısını fMR-adaptasyonu yöntemiyle inceleyen ilk çalışmayı böylece gerçekleştirmiş bulunduk.

Anahtar kelimeler: simetri, fMRG, adaptasyon, yüz algısı, lateral oksipital korteks

To my family...

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CHAPTER 1

INTRODUCTION

Faces contain valuable knowledge about a person. We can make inferences about someone's age, gender or emotions depending on their body, attire or dress, while faces usually aid in reaching a final decision about their identity. Facial features are used to assess many subjective attributes such as attractiveness, trustworthiness, familiarity and healthiness (Gauthier and Tarr, 1997) as well as objective features like symmetry and race. There are well-established face recognition algorithms sensitive to the changes in texture, illumination and size. Still, humans are better at detecting faces in a crowd compared to sophisticated computer algorithms (Tsao & Livingstone, 2008).

Face perception is a high-level cognitive function investigated broadly under the study areas of developmental psychology and evolutionary psychology. Collecting wide information from these disciplines, face perception has also been investigated in terms of their neural correlates in the literature lately. Several imaging studies showed that face perception activates a widely distributed area. In a broad sense high level visual areas such as bilaterally located V4+ regions are involved in face perception. In addition, the inferior occipital gyri, the lateral fusiform gyrus, and the superior temporal sulcus (Chen et al., 2006) constitute core human face perceptive cortices (Kanwisher et al., 1997; Gauthier, 1999; Haxby et al, 2000).

Unfortunately the literature on face perception contains several inconsistent results, some of which may be attributed to variability in the stimuli such as illumination, texture and pose presented subjects. For instance, there are various studies about the effect of symmetry on attractiveness. However, these studies indicate inconsistent results for symmetry either having positive (e.g. Dövencioğlu, 2008; Grammer & Thornhill, 1994) or having negative (e.g. Swaddle & Cuthill, 1995) effect on the perceived attractiveness on faces.

In the light of this knowledge, we concur that the environmental factors on the face stimuli used in experiments might be causing the confounding factors on the results. Hence using standardized faces in terms of the values mentioned by Kemp et al. (1996) is crucial to obtain reliable measurements in face perception studies. For this reason, Dövencioğlu (2008) developed a new face database (METU-Face Database 1.0) by standardizing the images with respect to various attributes. More recently, a new face database, METU-FaceTwo is developed by Yildirim (2010), eliminating some shortcomings of METU-Face 1.0. Using this database, several studies have been carried out in the METUNEURO Laboratory based at Middle East Technical University. Yildirim (2010) showed that subjects were more accurate in distinguishing symmetrical faces from originals, suggesting that there might be a pre-attentive system for facial symmetry perception. In independent studies, it is shown that symmetric images are more attractive (Dövencioğlu, 2008) and attractive faces are better remembered (Dewhurst et al., 2005). Consistent with these results, Yildirim (2010) showed that the symmetric faces are better remembered.

Finding out such correlations between face symmetry and cognitive aspects related to face perception brings out questions about the basis of face processing in the brain. There are several approaches trying to identify the procedures that our brain goes through while processing a face. The most commonly accepted approach is called holistic approach which states that faces are represented as indecomposable wholes. This approach might be considered as a counter argument for other theories suggesting that faces are represented as combinations of independently represented features such as eyes, nose, mouth, as well as their configural positioning (Farah et al., 1998). According to its definition, holistic approach may be correlated with Gestalt systems (Mondloch & Maurer, 2008) because, although facial features are meaningful alone, they form a different whole other than themselves when aggregated. In order to make supporting arguments about either of these approaches, the neural correlates of face perception needs to be investigated in detail.

Recent studies have tested perception of inverted and 3⁄4-view of faces. Chen et. al. (2006) found out that correlated activations for original and viewpoint changed versions of face images are different than those evoked by the object images. The regions that are found to be important for viewpoint changes and inversion of the faces in this study are higher visual fields, intraoccipital sulci (IOS) and middle occipital gyri (MOG) regions in the brain which are parts of the lateral occipital cortex (LOC).

Despite improving research on face perception, the perception of facial symmetry in humans, which is believed to be an evolutionary capability, has not been investigated in detail. The studies of Tyler et al. (2005) pointed out that there are cortical areas activated by especially symmetrical stimuli. How brain interprets symmetry and how does the perception of symmetry differ between objects and faces are still unknown. Whether face symmetry perception is localized to a specialized area in the brain is an important question.

There are various kinds of symmetry types that are discussed in section 2.2. Baylis and Driver (1995) highlighted that mirror symmetry (or bilateral symmetry) is a pre-attentive process which indicates that perceiving this kind of symmetry might involve a different neural pathway. However, none of the studies in the literature have investigated the neural correlates of this kind of symmetry in faces. The stimuli used in facial symmetry perception need to be standardized images for which confounding factors such as lighting, unnatural texture are eliminated, while the bi-lateral symmetry attribute is manipulated exclusively. We will use METU-FaceTwo Database developed by Yildirim (2010) for this purpose.

Resolving the neural correlates of facial symmetry will help us elaborate theories on face perception. Also, several neuropsychological deficits related to face perception as well as obsessions and compulsions associated with symmetry or exactness (Rasmussen, 1986) might benefit from understanding the underlying process of symmetry perception in the future.

In this thesis we will investigate the manifestation of facial symmetry perception in the higher-level visual areas of the human cerebral cortex. We will question whether voxels in higher-level brain regions contain a mixture of neuronal populations tuned to symmetry aspect of the faces. Failure of our hypothesis would otherwise indicate that the neurons are symmetry invariant, in other words, representation of the faces are holistic. More specifically, our main hypothesis is to find a symmetry responsive area specialized for faces in lateral occipital cortex (LOC). The role of the LOC will be explained in more detail in Chapter 2. Within the LOC, we expect to find a region distinguished from previously found symmetry specific areas for patches. In Chapter 3 we will go through the details of our experimental design, the fMRI adaptation paradigm and the analysis we used to test our main hypothesis. In Chapter 4, results of our fMRI experiment are presented. Finally, a detailed discussion will be provided in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

Adults are extremely sensitive to small changes in the distance between features (Haid, 1984). One study shows that people remembered 90% of their classmates 35 years after the graduation (Bahrick and Wittlinger, 1975). There are various unique features that enable us to recognize faces. These aspects vary from the skin and eye color to spatial positioning. The symmetry amount that a face possesses is also important information we use for encoding faces.

Human face is naturally symmetric along the vertical meridian, but there exists a small amount of mild structural asymmetry, called fluctuating asymmetry. In their study, Farkas & Cheung (1981) measured a three percent average distance differing between left and right hemiface measurements. A more recent study reveals that the distance between central points on the face and landmarks on the facial features vary from 4% to 12% from left to right (Ferrario et al. 2001). Even in the experiments that are carried out with people who are expected to show high amount of facial symmetry such as beauty contest winners and professional models, researchers failed to find a perfectly symmetric face (Peck et al., 1991). There are studies showing the facial asymmetry varies as a function of occupation (Smith, 1998), sex (Ferrario et al. 1993; Smith, 2000) and handedness (Hardie et al. 2005).

In the human body, asymmetry occurs from molecular to multicellular levels. In addition to the asymmetries occurring in the healthy population such as the anatomical asymmetries in the arm length and brain hemispheres, there are also some disorders such as situs inversus, where the patients have a body in the opposite form (McManus, 2005). As a part of their daily lives humans are exposed to symmetry judgments for being estimated about healthiness, physical attractiveness and personality.

2.1.Face Perception

Face symmetry is a good biometric measure to be used in face recognition systems. This biometry can also help understanding the emotions from the facial expressions by telling which facial feature changed how much. But why is it hard to recognize faces for computers?

While processing face images, the relation between the facial features differ from one image to another. In addition, absolute values of luminance vary due to the combination of textural aspects of lighting, make-up and aging. Extrinsic parameters (e.g. angle of the head relative to the camera) and intrinsic parameters (e.g. the camera and camera lens itself) contribute to variance in the two-dimensional positional relationships between component parts of the face. The automatic recognition system performances suffer significantly due to problems caused by these variations in the pattern of light produced by a given facial pose (Phillips et al. 2000, 2003).

There are two mainstream face representation accounts: Holistic and feature-based. Holistic approach states that faces are represented as indecomposable wholes. This approach might be considered as a counter argument for other theories suggesting that faces are represented as combinations of independently represented features like eyes, nose, mouth and the spatial relations between them such as their positions and the distance (Farah et al., 1998). The holistic approach is based on two paradigms namely part-whole and composite effects (Tsao & Livingstone, 2008).

2.1.1. Part-whole effect

Faces are better recognized as a whole than its separated parts. This is called part-whole effect (Tanaka & Farah 1993). A contribution to this approach has been made from Leder and Carbon (2005). They have tested this effect by comparing the recognition performance of the subjects for the faces they learned by either seeing them as a whole or seeing them in separated parts. Recognition performance was impaired when the parts learned were embedded in full faces. Identification of a face is not only a matter of recognition of separate parts but also the relation between the parts of a face. On the other hand, the non-face objects do not perceptually depend on the perceptual whole (see also Farah et al. 1995; Tanaka & Farah, 1993). These findings suggest that assembled aspects within an object contains more information for faces than other objects.

2.1.2 Composite effect

Another important phenomenon which is called composite effect was proposed by Young et al. (1987). In this study, the subjects were asked to make derivations about emotions from the face images where only half of the faces are presented (eg. only the upper half). However, when the lacking part was completed with an inconsistent stimuli, which is obtained from another face image, the emotional derivations about the faces have changed. This disruption points out that the perception is affected by the holistic image even though it is unrelated with the task.

There are other theories about face processing besides the holistic processing (Mondloch & Maurer, 2004). According to feature-wise processing, face processing is based on the individual features. Besides, second order relational processing suggests that the spatial features are the key elements of face processing. Another alternative approach to holistic face perception suggests that faces are just different kind of objects and the same cognitive system is being used for processing both.

Questions about the existence of specialized systems allocated for face and/or object perception can be answered by finding how exactly these systems function in the brain. Are we born with a face specialized area or do we develop sensitivity to faces by learning? Basically there are two controversial approaches for explaining the underlying neural structures in face perception: The first approach states that a specific area of the brain is allocated to face processing innately. Kanwisher (1997) showed that there is significantly greater activation for the face images compared to other objects and patterns in the face responsive area of the fusiform gyrus. The second approach states that face processing requires expertise and we, as face experts, have developed such specialized functionality.

Gauthier et al. (1999) showed that the same areas for face processing are also activated when car images are presented to car experts, arguing that this area is not only involved in face processing but in expert-level image processing. However, there is strong evidence that we have a specialized neural system for face perception:

2.1.3. Neuropsychological Cases

There are patients having deficits specifically about face recognition. Prosopagnosia patients (Damasio, 1982) have difficulties recognizing faces among other visual stimuli while their abilities about object perception stay intact. Prosopamnesia patients (Tipplett, Miller, Farah, 2000) lack learning novel faces while object learning is preserved. Last but not least, mirror agnosia patients cannot imagine the mirror reversed version of one image (Ramachandran, 1997). Existence of these neurological cases shows a further evidence for the distinction of neural correlates between face and object perception.

2.1.4 Face Inversion Effect

It takes longer time to identify the inverted faces than upright faces (Leder et al. 2001; Collishaw & Hole, 2000). This is known as face inversion effect. The inversion effect does not occur in object recognition and non-face objects (Yin, 1969; Robbins & McKone, 2007). Furthermore, in the studies where the subjects are asked to perform tasks based on component features, face recognition was interrupted when the spatial arrangements of features are disrupted (Freire et al 2000; Leder & Bruce, 2000; Leder et al. 2001). Similarly, houses do not show any advantage when presented as a whole but faces do (Tanaka and Farah, 1993).

Other than these effects, infant studies and studies in vision are also in favor of a specialized system for face perception. Infants can recognize faces at an early age. They can distinguish face-like patterns from the first several hours they are born and their mother after a few months (Pinker,1997). Not just attention but a preference for a facial configuration is present within minutes after birth (Sai, 2005). Reversing the luminance of the face images causes a decrease in the face recognition performance (e.g. Kemp et al. 1990). A later study by Kemp et al. (1996) demonstrated that recognition of unfamiliar faces were affected by the changes in hue as well as luminance although recognition of familiar ones was impaired by the change in luminance, but not by hue.

2.1.5. Effect of geometrical transformations

A study by Hole et al. (2002) showed that in terms of recognition performance of the subjects the face images of famous people was not effected by stretching the image to twice the size of its original (Figure 1c),. Although 'shearing' an image (Figure 1d) and stretching the image to twice (Figure 1b) has slightly disrupted the recognition performance, the effect was not robust. These findings might form a co-argument to the feature-based perception approach for the faces.

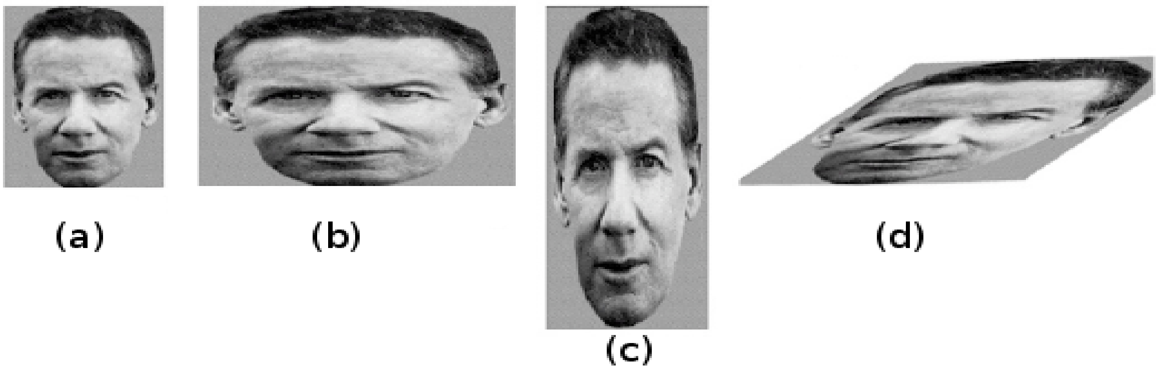

Figure 1: The distortion effects (b, c, d) carried out on veridical representation of familiar face images (a) does not have a robust effect on recognition behavior. Illustrations are taken from (Hole et al., 2002)

On the other hand, the influence of face inversion on face processing is extremely robust. Inverted faces distrupt the decision mechanisms for attractiveness (Little & Jones, 2006), gender discrimination (Bruyer et al. 1993; Stevenage & Osborne, 2006) and emotional derivations (Calder et al. 2000).

The angle of rotation of a face affects the performance of face recognition system and this is shown first by Valentine and Bruce in 1988. After this discovery, scientists tried to further demonstrate this monotonic relationship (Bruyer et al. 1993; Collishaw & Hole, 2002; Stevenage & Osborne, 2006). In 2002, Collingshaw and Hole showed that if face image is oriented away from upright, configural processing is significantly disrupted by using the demonstration of the linear relationship between rotation angle and recognition of blurred faces. This finding indicates that the general opinion regarding ‘processing shift’ being caused by inversion is wrong but it favors retaining the ‘facial Gestalt’ during the process of mental rotation. Taking this information into account, it would appear that the ‘inversion effect’ may not be the product of inversion, but rather it is the cumulative effect of angular distance from vertical orientation thus should be named as ‘rotation effect’.

2.2. Symmetry Perception

Human morphology contains two types of asymmetry found in nature: directional asymmetry and fluctuating asymmetry. **Directional asymmetry** refers to asymmetry consistently occurring at the same direction such as human heart being on the left side. **Fluctuating Asymmetry** is the asymmetry specific to individuals, having subtle and random differences in the same organism. This is thought to be due to the environmental stress and/or genetic factors that keep the organism from stable development. Phenotypes as such are considered to be the reflection of genotypes. From an evolutionary point of view, animal species prefer to choose mates according to attractiveness which is correlated with symmetry. Human visual system is also believed to involve a mechanism that detects the deviations from symmetry which is considered as an implication of bad genes and poor health (Swaddle and Cuthill,1995).

Although there are various types of symmetries in nature and in artificial objects such as mirror symmetry, helical symmetry, repetitive symmetry, the complexity of the stimulus for mirror images did not effect response time while other symmetries did (Baylis and Driver, 1994). In the same study, authors concluded that "perception was pre-attentive providing evidence for the salience of mirror symmetry". Moreover, not only adults but also bees (Giurfa et al. 1996), insects (Lehrer et al. 1995; Swaddle & Cuthill 1994; Møller 1995; Møller & Sorci, 1998) and 4 month infants (Bornstein et al. 1981) are shown to be sensitive to symmetry.

2.2.1. The Effect of Mirror Reversal

Mita et al. (1977) discovered the effect of mirror reversal on face recognition as early as

1970s. By using 'likeability' decision to faces, they wanted to replicate Mere Exposure Effect (Zajonc, 1968). Self images or close friends' images were presented to the subjects in original and reversed lateral orientation. Subjects were asked to indicate which image they liked. The results brought out that people commonly chose self images in the mirror orientation. For the decisions to close friends, opposite pattern was chosen. This finding was replicated by Brédart (2003) with a different test of orientation memory. Subjects were shown images of co-workers and themselves and were asked to choose familiar orientation to them from original and reversed images. Majority of the subjects indicated veridical representation of the images of co-workers while the most of them chose the mirror reversal for self images. These results also verify Rhodes' study (1986) showing that people are tend to choose veridical orientation of the images for 'likeness' test. Although these findings indicate that there is sensitivity to the fluctuating asymmetry in face recognition, unlike mirror symmetry, the left-right inversion does not have a significant effect on memory recall and recognition (White, 2008).

2.2.2. Cases on symmetry perception

There are many cases reported in which abnormalities about symmetry perception could be observed. It has been commonly reported that some people cannot tell their left from right (Snyder, 1991). Some children under 7 years old of age have difficulties in separating one image from its mirror reverse. They tend to confuse symmetrical letters like b and d (Mach, 1914; Davidson, 1935) and this confusion can be also observed while writing (Cornell 1985). Interestingly, Rollenhagen and Olson (2000) found that in macaque monkey, some foveal and peripheral neurons responded for b and d and some for p and q. Another neurological case was brought up by Davidoff and Warrington (2001) where posterior brain damage causes difficulty in evaluating repeated images in having same or different mirror orientations.

There are also cases where symmetry perception improves. For example, during menstrual cycle women are even better at detecting symmetric faces (Oinonen & Mazmanian, 2007). Such perceptual improvements may have their roots in survival instincts.

2.2.3. Holistic Interpretation in Facial Symmetry Perception

Our perceptual system is accurate not only in detecting the symmetry that faces possess (e.g. Rhodes, 1999), but also in symmetry detection of non-face objects (Wagemans, 1997). There are plenty studies supporting the existence of a mechanism specialized for processing spatial relationships, especially their asymmetry. However, whether this ability is driven by low-level or higher-level visual mechanisms still remain unknown. There are organisms which could detect symmetry regardless of their small nervous systems (e.g. Møller & Sorci, 1998). Even though these findings might suggest that the symmetry perception could function through low-level processing, when it comes to facial symmetry perception there are other important findings to take into account. In their study, Rhodes et al. (2005) observed that subjects showed decreased accuracy in a symmetry detection task while viewing upside-down faces compared to the upright faces. Such findings point out the use of high-level visual mechanisms involved in facial symmetry detection (White, 2008).

2.2.4. Eye-tracking of facial symmetry evaluation

There is a well-known phenomenon that the left side of the face receives more fixations, in other words more information is being gathered from the left side of the face than the right side. This left hemi-face bias exists even while viewing the symmetrical faces (Yildirim, 2011). According to an eye-movement study carried out by Locher and Nodine (1973), while viewing symmetric objects subjects tend to cluster on one side because because perception is optimally efficient when perceiving symmetrical objects.

A previous study that we conducted using eye-tracking methodology revealed that symmetry has an important effect on the eye-movement behavior (Yildirim, 2011). Results showed that the symmetric faces are viewed differently than the original faces. This difference also varies across the task being carried out. When the subjects are asked to evaluate the attractiveness, symmetric faces received significantly more fixation than the original faces ($p<0.001$). However, symmetric faces received significantly less fixation ($p<0.001$) than original face images when the subjects were asked to evaluate the symmetry ratio of the faces. It is important to note that the same image database (METU-FaceTwo) was used in this experiment as in this thesis. Results together showed that the symmetry information of the faces play an important role while making decisions about the faces.

2.3. Neural Correlates of Face and Symmetry Perception

Neural correlates of face perception is complicated according to the sophisticated processing required to perceive and interpret faces. There are several reasons that make face perception more complicated than the perception of other objects. First of all, the geometric configuration of faces is more complicated than daily objects. While perceiving faces, or making interpretations about the emotions reflected by faces, it is also necessary to make social interactions, communications. Furthermore, meaning of verbal communication is mostly dependent on facial expressions, lip movements and gestures.

Kanwisher (1997) found that there is a specific region responding to faces: fusiform face area (FFA). On the other hand, Gauthier(1997) argues that this region is specific to expertise and showed in her study that car and bird pictures activate the same area in car/bird experts. Obviously, face recognition requires many cognitive sub-components such as direction of eye gaze, detection of a face etc. These functions are expected to extend over many cortical regions. Face perception also includes subcortical mechanisms such as amygdala, superior colliculus and pulvinar. Aharon et al (2001) demonstrated that discrete categories of beautiful faces activate the reward system in the brain circuitry of human subjects. This activation was differentially based on category differences of beautiful faces such as gender differences. According to their results, reward circuitry including the nucleus accumbens, is getting activated when when subjects were passively viewing beautiful faces in fMRI. A widely distributed neural model (Haxby et al. 2000) which involves a large continuous area along with the previously mentioned face responsive area is proposed to explain all these processes involved in face perception. Moreover, face perception is not always equally bilateral between genders. Evehart et. al (2001) showed that male subjects used their right hemisphere for face processing while female subjects used their left hemisphere.

On the other hand, symmetry information is not solely presented in local features as well. It requires more complicated perceptual processes like large range integration of scene features (Tyler et al., 2005). Simultanagnosia (a visual agnosia) patients can identify local elements but they have difficulties about making relations between the objects. These patients have lesions in the occipito-parietal portions of their brains (Farah, 1990). This case represents a good example of how perception of a feature of an object is separated from the object recognition itself. Such cases might also account for symmetry perception of faces.

In a study conducted with dots but not faces, Tyler et al. (2005) questioned whether a specific region is allocated for symmetry perception. Comparison of the activation for random dot patterns versus symmetric dot patterns showed that the areas activated by the presence of symmetry are far from the retinotopic regions but medial and posterior to the motion specific area V5/MT+. In another similar study by Sasaki et al. (2005), investigating symmetry perception with random dot and line stimuli, authors located several areas in both human and macaque visual cortex specific to symmetry perception. 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 significant, but with relatively weaker sensitivity to symmetry than humans.

2.3.1 The Lateral Occipital Cortex and Its Role in Face Perception

In their study, Malach et al. (1995) found an area that responds more strongly to the photograph of everyday objects than visual textures without obvious shapes. This region which extends to the lateral side of the fusiform gyrus is called **lateral occipital cortex (LOC)**. The LOC is a largely non-retinotopic area, activated by both the contralateral and ipsilateral visual fields (Grill-Spector et al., 1998; Tootell, Mendola, Hadjikhani, Liu & Dale, 1998). This area is located lateral and anterior to retinotopic regions and shows selectivity to both objects and object fragments (Grill-Spector et al., 1998). Anatomically, areas within LOC partially overlap with a face-selective region, called the fusiform face area or FFA (Kanwisher et al.,1997). Consistent with anatomy of this structure, in two previous studies, adaptation to faces was reported in the lateral occipital complex (LOC) (Avidan et al., 2002; Grill-Spector et al., 1999). This evidence might indicate that the LOC is also included in face processing.

Previous studies show that processing identical face images exhibit a habituation phenomena in the fusiform gyrus. However, face-selective regions within the LOC are sensitive to eye/gaze direction, emotional expression and size changes of the faces (Grill-Spector et al., 1999). Hence, LOC seems to perform more sophisticated facial processing. In addition, there are some interesting findings regarding sub-areas of LOC. For example, in the anterior regions of LOC, activity was not reduced when the objects (faces and cars) were cut into halves, either vertically or horizontally. This result indicates that the neuronal properties of LOC vary with respect to its sub-regions (Lerner et al., 2001). Moreover, in their study, Weineli and Grill-Spector (2011) searched for a limb-selective region in LO region and found that the activations have boundaries that could be classified into sub-regions. The activations also illustrated differential properties varying with position changes. Authors concluded that the category selective regions are insufficient for defining the higher level visual cortical areas. Instead, property specific analysis should be done in order to understand the functional organization of the visual cortex.

2.3.2. Sub-regions of the LOC

The two common ways to localize the LOC in the brain is retinotopic analysis and LOC localizer with different kind of stimulus such as objects and faces. However, there are many other LOC studies present in the literature having compatible localization of the LOC and its sub-regions (Larson and Heeger, 2006, Grill-Spector, 1999). LOC has been subjected to a few subdivisions as summarized below.

LO1 and LO2 (Malach et al., 1995; Grill-Spector et al., 2001):
By defining a contrast between responses given to face stimulus and object stimulus, the LOC can be divided into object-preferring posterior/dorsal region (LO2) and face-preferring anterior/ventral regions (LO1) (Grill-Spector et al., 1999, 2001; Hasson et al., 2003; Tsao et al., 2003). Results from such a localizer carried out by Larson and Heeger (2006) revealed that both LO1 and LO2 are parts of the object-selective LOC (figure 2). This finding confirms that LO1 and LO2 have similar properties with the previously defined region which is called posterior LOC. LO2 is significantly more responsive to objects than LO1. Second outcome of this study is that LO2 showed no selectivity to orientation changes while LO1 does. Finally, neither LO1 nor LO2 showed selectivity for motion perception.

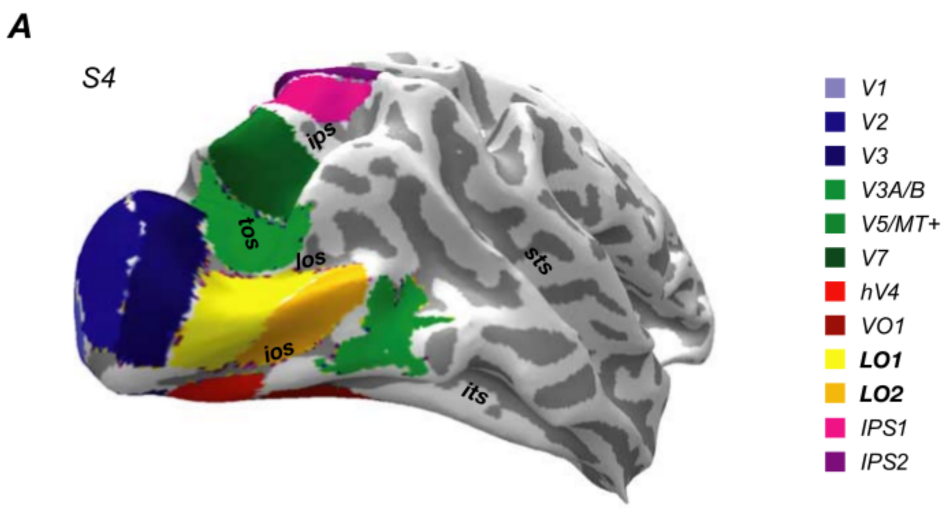

Figure 2: The localization of LO1 and LO2 inside LOC (Larson and Heeger, 2006)

Dorsal posterior vertex and ventral posterior vertex of LOC (Grill-Spector, 1999; Sawamura et al., 2005):

Posterior and dorsal parts of the LOC are more sensitive to the position and orientation changes in the stimuli compared to the anterior part.

Posterior lateral, anterior ventral LOC (Stanley and Rubin, 2005)

Stanley and Rubin (2005) divided LOC into posterior lateral part which highly responsive to the abstract 2D shapes and unknown objects while the anterior and ventral parts are more sensitive to familiar objects. Lately, a study showed that activation responsive to shape dissimilarity was present in ventral but not in the lateral parts of the LOC (Drucker, Aguirre, 2009). In contrast, a neural pattern correlated with stimulus similarity was observed in the lateral LOC while such an effect did not occur in the ventral LOC. Moreover, lateral LOC was found to be preferentially responsive to shape of the stimulus than the orientation within the shape. Similar to this aspect of lateral LOC, the LO2 region which corresponds to the lateral part of the LOC has shown a similar effect, indicating consistent results of these two studies (Larson and Heeger, 2006). These results might also indicate a hierarchical system for object perception in the LOC, since there is a spatial coding for the feature of shapes in the lateral LOC and a more focused coding of entire shape space in the ventral LOC.

To sum up, these sub-regions are highly overlapping parts of the LOC and do not show a distinguished structure. Yet, several studies have named them differently and interpreted their results according to the names they have given. For instance, it was suggested that the inverted faces are processed by the mechanism which is also involved in house perception (Haxby, 2000). These results revealed that the resources used both in the face perception and object perception may not use distinguished systems. On the other hand, later investigation of the relationship between the behavioral effect the face inversion and its neural correlates revealed different results (Kanwisher et al., 2005). According to the results of this study, behavioral face inversion effect is closely correlated with the activity in FFA but not with other face-selective or object-selective regions such as the superior temporal sulcus (f_STS) or occipital face area (OFA). The outcome of this study highlights the importance of FFA in the primary tasks like face recognition.

2.4. Neuroimaging techniques used for parcellation of FFA and LOC

Upon delivery of stimulus, a locally increased neuronal activity occurs in the responding brain area which necessitates support for neuronal metabolism through the vascular system. This change can be observed due to the increased blood flow and the oxygenated haemoglobin while the latter one is related to a decrease in the amount of deoxygenated haemoglobin (Roy and Sharrington, 1890). Since the deoxygenated haemoglobin is paramagnetic, it has a disrupting effect on the MR signal. Therefore reduced deoxygenated haemoglobin will produce a slightly increased MR signal. By using an MR pulse sequence which is called echo-planar imaging (EPI), an indirect measurement of the brain activity related to the oxygeneation at the locally responding site (Blood Oxygen Level Dependent, BOLD) can be detected with fMRI.

The entire brain scan can be obtained approximately in every 2 seconds with a resolution of 3mm on each axes. Different experimental tasks are carried out during the scan so that increased BOLD activation in different regions are associated with the localization of a function specific to that area. Typically there are few pre-processing steps being carried out before the statistical analysis of the fMRI data. Moreover, in order to increase the reliability of the results, repetition of the signal acquisition is crucial. Last but not least, superimposing the activation maps onto high-resolution anatomical images eases the localization of the functions more precisely, hence low-resolution fMR images are always complemented with a high-resolution anatomical image for which data acquisition is about 6-8 min.

The specialized locations in the brain which contain neurons with invariant properties are hard to be investigated through fMRI due to limited spatial resolution. A single voxel contains several hundred thousand of neurons. Therefore, significant activation within a group of voxels might be evoked by a heterogeneous group of generically selective neurons, as well as different sets of function specific group of neurons. For this reason, it is usually hard to infer the characteristics of the underlying neurons by the data obtained from neuroimaging techniques, especially in the higher brain areas such as LOC where complex organizational principles exist. It has been reported that a reduction of the BOLD signal in higher visual areas is observed in case the same stimulus is represented to the human subjects repeatedly. (Buckner et al., 1998; George et al., 1999; Henson, Shallice, & Dolan, 2000; James, Humphrey, Gati, Menon, & Goodale, 1999; Martin et al., 1995; Stern et al., 1996). Even though the reason for this effect is not explicitly investigated, it was suggested that this may be due to the visual priming effect (Buckner et al., 1998; Wiggs & Martin, 1998). The fMR-A paradigm takes advantage of this phenomenon to investigate the behavior of the neuronal populations in fMRI.

fMRI Adaptation (fMR-a) is a method that helps us to find the cortical area which is functionally related to the stimuli presented, by taking advantage of the cortical region becoming unattentive to the same stimuli over time (Grill-Spector & Malach, 2001). Initially, the same stimulus is presented repeatedly and as a result, high-level cortical areas show a reduction in the BOLD signal change. Later, a particular aspect of the stimulus (for ex. illumination, contrast or symmetry) is changed. If there is an increase in the signal, then we infer that there are neurons in the previously habituated cortex which are responsive to that aspect of the stimuli. This phenomenon is called **release from adaptation**. If the adaptation persists within this region, despite the change of stimulus, then this would be interpreted such that this neuronal population have no sensitivity for the altered aspect (Grill-Spector and Malach, 2001). In sum, observation of release from adaptation (i.e. an increase in BOLD signal is observed) indicates that the neurons in this area are specialized to process the altered aspect.

In a seminal study by Grill-Spector (2001), detailed characteristics of high level visual areas are revealed using fMR-a paradigm described above. Authors seek for an adaptation effect in the LOC between the repeated presentation of the same face images compared to different face images. They were able to localize a specific area showing adaptation to face stimulus.

2.5. Our motivation

Our main aim is to find whether there exists a strong activation in the LOC correlated with the symmetry changes of faces exclusively. We expect that there is a specialized region in the brain for facial symmetry perception. Moreover, this finding might help us to understand whether face processing occurs in a holistic or feature-wise manner. Finding activation in LO2 would support holistic face perception whereas LO1 would support feature based.

We could investigate this paradigm the best with fMR-adaptation method because fluctuating symmetry is a critical variation and fMR-adaptation is a decent method to investigate responses to such sensitive parameters with small variation. In order to make sure our fMR-adaptation method works, we should replicate two main studies by Tyler (2005) and Grill-Spector (2001). These studies as described earlier, investigated symmetry perception in random patches and face perception respectively. While using patch images in addition to faces, we aimed to investigate two things. First of all, depending on the previous findings we expected to observe a differential activation in LOC for symmetrical images. By using both symmetric/original face condition and random/symmetrical patch condition, we wanted to test these conditions separately. Secondly, these patch images are used to test whether the activation difference due to symmetry is evoked by any visual information reflected on the retina or evoked when a specific context, hence faces, is present.

In our experimental design,we used face stimulus possessing either fluctuating symmetry or original bilateral symmetry where the aspect of symmetry was not indicated explicitly to the subjects. While the amount of symmetry remains as an inherent aspect of the images, we seeked for a responding region in LOC. Our hypothesis is to see release from adaptation in a specific region of LOC, for the condition where original and symmetric images are intertwined. If there exists such a specific cortex, then we can deduce that face symmetry perception is a specialized function dedicated to a particular area in the brain.

CHAPTER 3

MATERIALS AND METHODS

3.1 Experiments

3.1.1 Stimuli

Face images used in this experiment are from the METU-FaceTwo Database which was developed previously by Yildirim (2010). The faces in this database are grayscale face images generated specifically to be used in psychophysics experiments.

The images were captured with uniformly distributed light and the face images are prepared so that none of the models had any external features such as earring, make-up, glasses, beard etc. The face images were also identical in terms of their positions and none of them contained mimics. The rotation of head in both vertical and horizontal positions were also controlled to be perpendicular to the ground. In addition, for standardizing the images, some pre-processing steps have been applied consisting of the following steps: cropping, head orientation tuning, relocating, resizing, intensity tuning, averaging, masking and contrast tuning. Finally, the images were morphed with their mirror-symmetric version in half ratio in order to obtain smooth full-symmetric images.

For our experiment, each face is resized by preserving the original width-height ratio in order to yield a 10° visual angle. Since the faces have different sizes and the ratio is not damaged in order to fit all the face images to the same size, the retinal size of the images had only subtle variations.

Faces of 28 people were chosen from the METU-FaceTwo Database to be used in the experiment. We paid attention to the texture of the faces and head position to be invariable in both original and symmetric versions in order to eliminate any artifacts and maid sure that the only variation between pairs of images is the symmetry. Among the 5 different versions of the face images shown in figure 3 below, we used only the DBO and DBS instances of the same face.

original (DBO), intermediate original (DBIO), symmetric (DBS), intermediate mirror (DBIM), mirror (DBM)

Figure 3: Face images at different symmetry levels by Yıldırım (2010):

For each picture used in our study, phase scrambled corresponding images that look like scrambled patches are derived (Appendix B). The patch images are generated in a way that they do not differ from the face images in terms of the information they contain. The visual information (intensity and contrast) embodied in patch images depends on the absolute values of the pixels in a gray scale face image. For this purpose, we used a piece of MatLab code for phase scrambling the face images (Olman, 2006). The code first applies Fourier transform to face images and then randomly assigns different the phase spectrum values to the signals (pixel values) while preserving the absolute values of the signals in the image. By this way, the semantic information of the images disappear while the low-level visual information remains the same. An example is shown in figure 4 below such that a DBO image and its corresponding patch is displayed.

Furthermore, since our hypotheses involved testing original versus symmetric conditions of faces versus patterns, we generated patches for the DBS images as well. It is important to note that the images used in the random-patch condition were the phase-scrambled versions of the original faces while the images in the symmetric-patch condition were the phase-scrambled images of the symmetrical face images. Symmetrical patch images were obtained via merging the phase scrambled images of the original face stimulus with their mirror symmetrical images. During this operation, opacity values are kept the same between original and symmetrical patch images. Finally, we eliminated the patch images and the corresponding face stimulus which is likely to contain a face-like pattern. In figure 4, DBS and DBO instances of the face and scrambled stimulus belonging to the same person is presented.

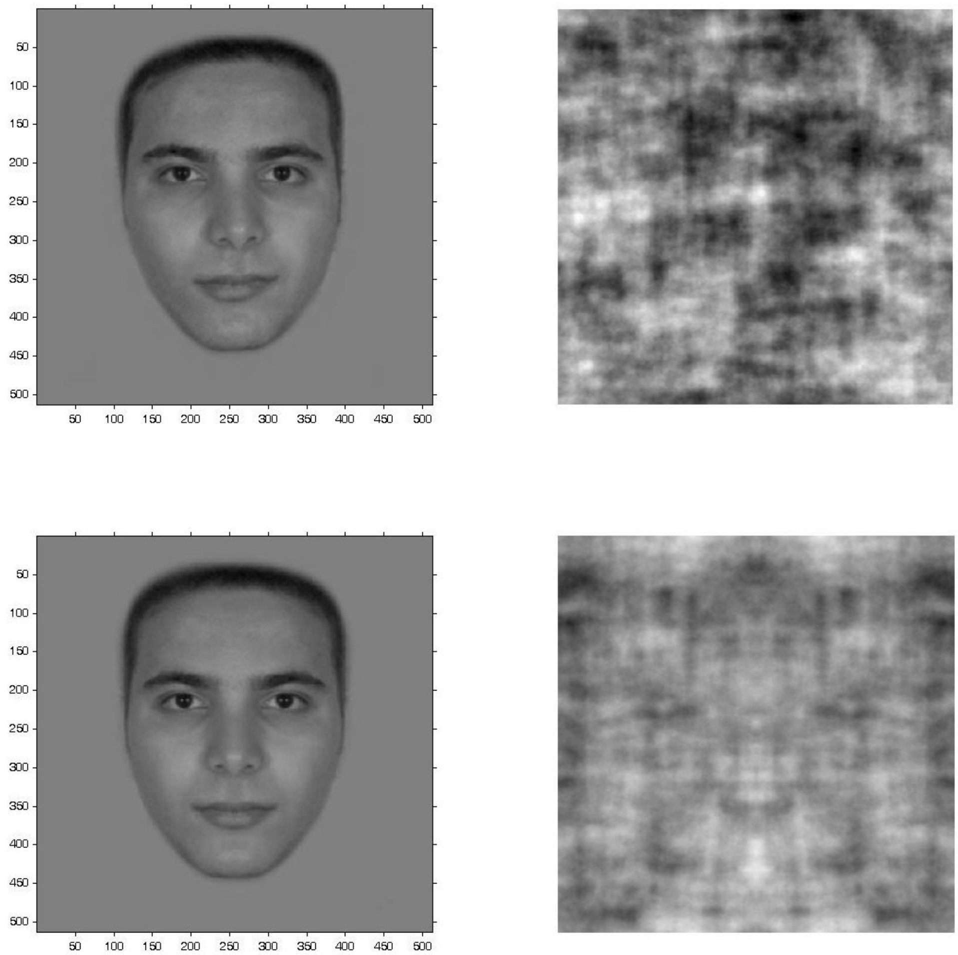

Figure 4: Phase scrambled images of the original (upper) and symmetrical (lower) face images used in the experiment.

3.2. Participants

Fourteen graduate and undergraduate students (9 male and 5 female) from Bilkent University and Middle East Technical University participated in the experiment (mean age: 25.36, stdev: 2.53). Experiments took place in the UMRAM National Magnetic Resonance Imaging Center, Cyberpark, Ankara. All participants had normal or corrected to normal vision. Since head motion was below the threshold of 5 millimeters for all subjects, no data was excluded from the study. All participants filled a consent form in accordance with the declaration of Helsinki and the local ethics committee guidelines prior to participation in our study (Appendix C).

3.3. Setup and Apparatus

Subjects were scanned at the UMRAM center for magnetic resonance imaging at Bilkent University with a Siemens MAGNETOM Trio System 3T scanner equipped with a birdcage head coil. Stimuli was projected to the screen with a NEC NP125 projector through a NuView 489MCZ900 long-throw lens by using a HP Laptop 6730b computer. The stimulus was projected on a translucent back projection screen with 1024*768 resolution. Back projected images were viewed through a first reflectance mirror (DaLite) mounted on the head coil (figure 5). Button responses were collected with a ORP 904 fMRI trigger and a 4-button response board (Current Designs). The mirror was located in such a way that the view only includes the screen and the view of each eye corresponds to equal amount of the screen. The screen view were made sure to be parallel to the floor as well as the subjects' visual field by putting colorful stripe bands as landmarks inside the scanner and by asking the subjects to adjust the edges of the mirror according to these landmarks. The head-tilt was adjusted by projecting a laser cross-hair onto subjects closed eyes and instructing the subject to move his/her head accordingly. In order to minimize the head motion, the neck of the subjects were supported by a neck protector and the head of the subjects were supported by foams. They were also provided a sponge support to lift their knees in order to make them comfortable and prevent moving their heads. The subjects were provided ear-plugs and wear headphones in order to reduce the disturbing effect of the high noise inside the scanner.

Figure 5: The MR setup with head coil, button response board and mirror

3.4.Experimental Design

The experiment was prepared using Java programming language and PsychwithJava package (Boyaci, 2006). The functional scans that each subject performed consisted of 4 different runs collected within the same session. Each run lasted for 7 minutes and 14 seconds with a break that lasted between 40-60 seconds unless the subject asked for extra time. In 2 runs the subjects were presented female face pictures whereas in the other 2 runs they were presented male face pictures. The order of the sessions were always the same for each subject. The stimuli ordering for each session was pseudo-random. The tasks were generated randomly with a computer program developed in Java by using the images in the METU FaceTwo database and later the same 4 tasks were used for every subject.

A single run contained 6 conditions presented in separate blocks of 24 seconds (figure 6). During each block, the stimulus in the current condition was presented 6 times. Each stimulus presentation lasted for 3800 ms seconds followed by a 200 ms fixation point. The presentation sequence consisting of the 6 conditions shown in figure 6 is repeated 3 times throughout each run of the experiment. For each repetition a different set of face pictures are used. As in previous fMR adaptation studies (eg. Tyler, 2005), the subjects were asked to decide whether the current image on the screen is the same with the previous one. Subjects responded with a button response board. They were instructed to press one of two buttons every time a new stimulus appeared on the screen. Subjects pressed the 'left' button if the stimuli remained the same and pressed the 'right' button in case the stimulus has changed. In total, subjects viewed 108 stimuli in each run and 432 stimulus in the total of 4 runs.

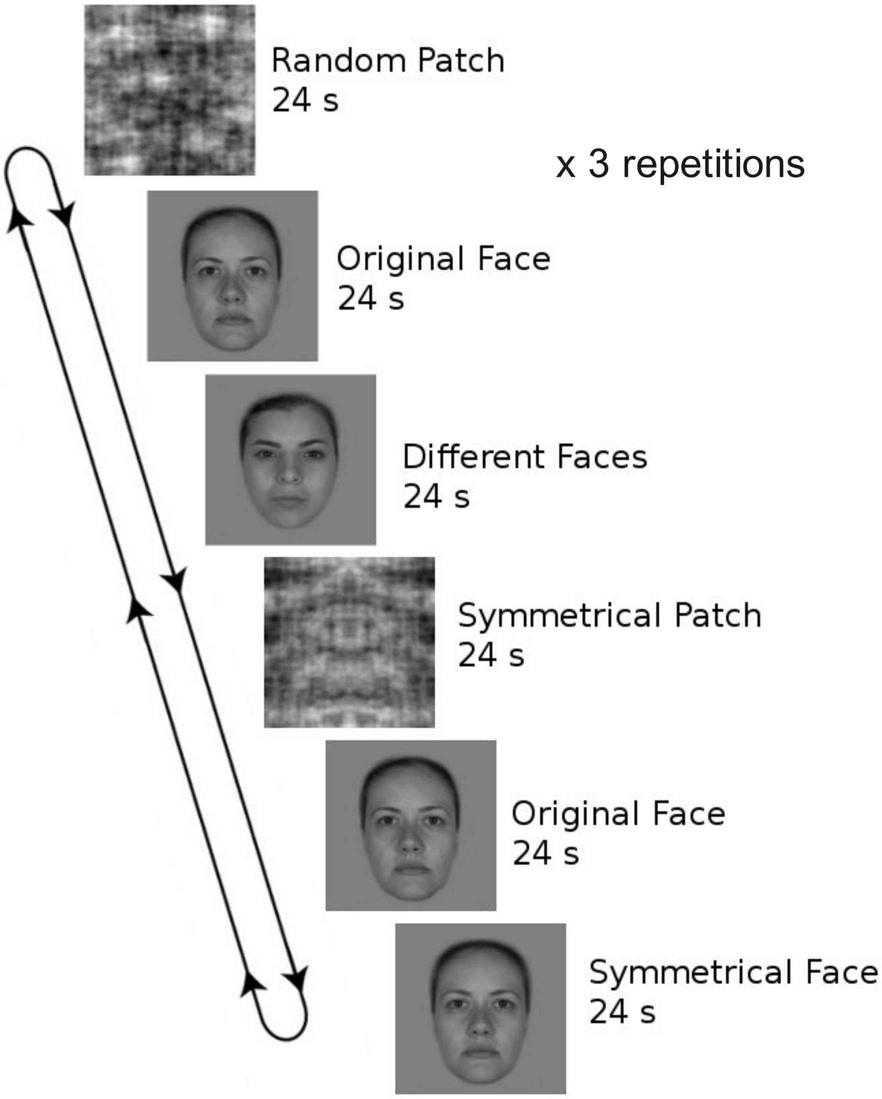

Figure 6: Blocked Design of the fMRI experiment with a total of 6 conditions (1 condition per block)

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The 6 conditions are summarized in the following.

Condition 1 (Different Asymmetric Phase Scrambled Images of Face Images):
In this condition, six different asymmetrical patch images were presented to the subjects. These patch images are the phase scrambled images of the original face images used in the same block.

Condition 2 (Adaptation: Same Original Face):
The same unmodified (original) face image drawn from the DBS instances of METU-FaceTwo is repeatedly presented to the subjects for six times.

Condition 3 (Adaptation Release 1: Different Original Faces):
Six different original face images drawn from the DBS instances of METU-FaceTwo are presented to the subjects, each of them being different from the previous face image presented in condition 2.

Condition 4 (Different Symmetric Phase Scrambled Images of Face Images):
Six different symmetrical patch images were presented to the subjects which are the phase scrambled images of the symmetrical versions of the original face images used in the same block.

Condition 5 (Adaptation: Same Original Face):
The images in this condition was identical with Condition 2.

Condition 6 (Adaptation Release 2: Symmetrical and Original Face Images):
The images used in this condition contains both original and symmetrical versions of the same face image used in the 2nd and 5th conditions (see Appendix B). First, the original version of the face image is presented followed by a symmetrical version of the same face. This pattern continues for three times in which the subjects view three times the symmetrical image and three times the original image at the end of the block.

The conditions were put in 3 pairs to make comparison with each other in order to obtain the regions responsive to the related tasks.

- Cond 1 and Cond 4: Comparison between random and symmetrical patch conditions were made in order to replicate the study of Tyler (2005). This was not a direct adaptation analysis in order to be consistent with the original study. The adaptation and release conditions which are compared with each other were in the same block but not adjacent.
- Cond 2 and Cond 3: Similar to the study of Grill-Spector (1999) we compared original and same face blocks. A direct adaptation paradigm was applied consistent with the original study.
- Cond 5 and Cond 6: Original and symmetrical faces were compared in order to investigate whether there is an adaptation release while switching from original to symmetrical faces. This phase was set as a direct adaptation paradigm. The reason that the symmetrical image was not presented to the subjects continuously is to prevent the adaptation to the symmetrical face images. Switching the stimulus between original and symmetrical faces would keep the activity of the symmetry sensitive neurons active.

3.5.fMRI Data Acquisition Procedure

All the experiments were conducted with a 3-Tesla MR Scanner Trio gradient scanner. For each participant we collected T2*-weighted gradient-echo planar imaging scans (EPIs: slice thickness = 3 mm, gap = 0.8 mm, in-plane voxel size = 3 x 3 mm, TR = 2000 ms, TE = 28 ms, flip angle = 71°, FOV = 192 x192, resolution = 64 x 64) for the fMRI analysis. The EPI-volume covered all of the cortical and sub-cortical structures in 10 subjects. In 4 subjects the most posterior part of the brain was dropped in order to keep the EPI parameters identical among all subjects. In addition, for superposition of functional maps upon brain anatomy, a high-resolution T1-weighted MP-rage anatomical scan of the whole brain was collected from each participant (MPRAGE, 176 slices, slice thickness = 1 mm, gap = 0 mm, in-plane voxel size = 1 x 1 mm, TR = 2300 ms, TE = 2.92 ms. FOV = 256 x256, resolution = 256 x 256).

After the fMRI session, each subject was debriefed and was asked about the kind of differences observed in the faces. Since the subjects were instructed to respond ‘yes’ if the “picture” on the screen is the same as the one before and ‘no’ if the “picture” is not the same as before, we do not know whether the subjects respond to the change in the face images or the change in the identity of the images. By asking the subjects about their decision, we could predict whether they were aware of the symmetry manipulation, which is our main interest. Responses collected in the last condition (symmetric versus original faces) do not necessarily give us the answer whether the subjects were aware of the change in the stimuli or not. Even if they were aware that the symmetry aspect changed, they might have evaluated the previously shown picture based on either identity of the face in the picture or features of the face image.

3.6 fMRI pre-processing

There are a series of commonly used mathematical operations for making voxel-based fMRI analysis plausible. In this thesis, the fMRI pre-processing steps are carried-out by BrainVoyager software as follows:

3.6.1. Slice Time Correction

In fMRI studies, due to technical limitations the whole brain cannot be scanned atomically but as a sequence of slices across time. For instance, for a brain volume with 30 slices and a TR[1] of 3 seconds. the scanning process of the last slice is almost 3 seconds later than the first slice. This time interval of 3 seconds is crucial because during this time the BOLD hemodynamic response evolves, leading to time differences in data analysis of consecutive voxels, especially when voxels are collected in an interleaved manner. Thus, the data needs pre-processing to synchronize data collection in the entire brain.

One way to do pre-processing is using a predictor-shifting approach. In this approach, as the prediction step, expected BOLD time course is computed using the reference time courses for that particular slice and as the shifting step, this computed BOLD time course is shifted in time proportionally to the temporal difference in scan time with respect to the reference (e.g. first) slice. Another way is using a data-shifting approach. In this approach, the data of a slice is shifted in time to match the time point that the reference slice was scanned. This approach alters the data in a way that the whole volume would have been scanned at once.

1 TR: repetition time (TR) is the time period within which a single whole-brain image sample is collected

The main difference between these two methods is that in the former method, we need slice-specific shifts of the predictors and in the latter we do not. As a consequence, in the former method every voxel should be labeled to keep which slice it belongs to. However, in the latter method, since we can use same predictor for the whole volume we do not need such labeling. It also allows us to use same predictors for the further steps (e.g. transforming slice based representation to an arbitrary space. Thus, in this thesis, we preferred data-shifting approach in pre-processing.

3.6.2. 3D motion correction

fMRI data analysis is based on the assumption that each voxel represents an unchanging and unique location on the brain over time. However there are many prohibiting factors for this assumption to hold. The head movements during fMRI scanning disrupt the time series within a voxel. For small head movements, motion correction is a useful way to correct for this type of artifact. One functional volume of the fMRI scan (most of the time, a single whole brain scan) is taken as reference for motion correction. In order to align other volumes with the reference volume, translation along the x, y and z-axes and rotation around these axes (figure 7) are performed using the motion of rigid bodies. Although the head's rigid body movement causes other non-linear artifacts such as ghosting, rigid body motion correction is still applicable in most cases. In figure 7 estimated head motion is presented on the y-axis in terms of mm.

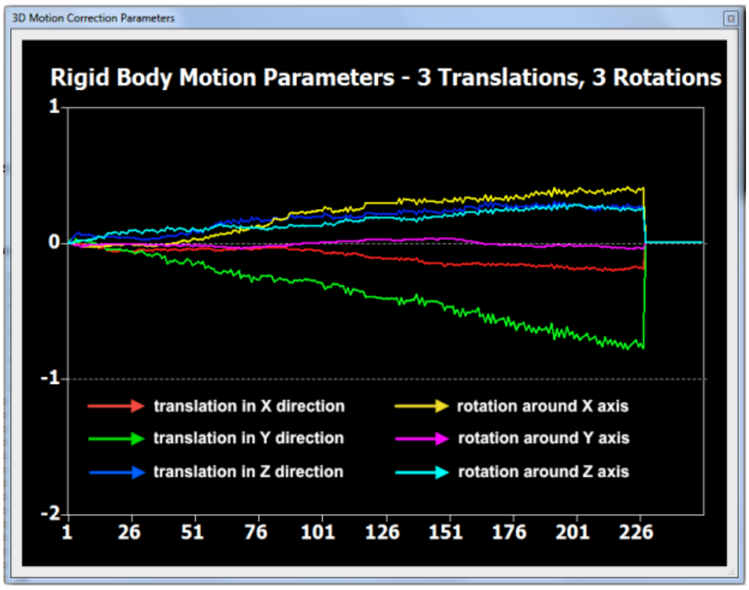

Figure 7: The motion correction tool in Brainvoyager uses the first volume obtained from the first functional scan and makes conversion of the other volumes (samples 2-226 in the figure) according to the estimated head movement in the rotation and translation in x-y-z dimensions.

3.6.3 Temporal filtering to remove signal drifts

When we deal with signals, we also deal with noises. The same argument is valid for also fMR time series. Due to physiological and physical (scanner-related) noises, voxel time courses of fMRI data often contain low-frequency drifts. These signal drifts affect statistical data analysis process and reduces its power with a significant amount. In addition, since event-related averaging expects time courses with a constant signal level, these drifts invalidate the averaging process. With these two defects considered, handling the low frequency drifts is one of the most important preprocessing steps of fMRI studies. One should be very careful when applying this preprocessing step because condition-related signal changes may accidentally be removed along with the low frequency drifts, especially when the delivery frequency of stimuli matches the low frequency noise.

Since the signal drifts are slowly rising and falling, these drifts are called low-frequency signals and can be removed by using a high-pass filter. As the name refers, high-pass filters block the low-frequency signals and let high-frequency signals (containing stimulus related activity) pass. Once the high-pass filters are applied, all low frequencies are blocked out and output signal consists of only high-frequency components of the fMR time series.

In high-pass filtering process, there exist two approaches. In the first approach, the low frequency drifts are removed from each voxel's time course as a pre-processing step. Each voxel's time course is dealt separately since the noise level for those is different. After a cleaning process, this clean data can be used for further processes (e.g. statistical data analysis and event-related averaging). In the second approach, the low frequency drifts are not removed during pre-processing step but taken into consideration and modeled as confounding effects during statistical data analysis. This approach removes low-frequency drifts implicitly during calculation of a General Linear Model (GLM). We used the former approach for our analysis.

3.6.4. Segmentation

Most of the MR data analysis software perform brain segmentation by detecting the boundary between the gray matter (GM) and white matter (WM) to build a 3D model of the brain to perform morphological analysis. The boundary between the gray matter (GM) and the cerebrospinal fluid (CSF) is also useful for brain extraction. Usually the software calculates the amount of the GM, WM and CSF and generates a diagram for enabling hand-selection of the boundaries between these structures. We primarily used the automatic segmentation option and performed manual segmentation only when necessitated after quality inspection.

3.6.5. Mesh view

Meshes are abstract representations or in other words, 3D wire models of the segmented brains. Mesh viewing option in BrainVoyager provides a better visualization of the brain. In order to enable the ease of voxel selection on the cortical surface, cortex can be inflated. During the inflation stage, the software uses the segmentation data of the boundaries between the GM and the WM to preserve the quality ratio of the 3D model. By the end of this operation, the sulcal and the gyral parts are indicated with different colors. The sulci are represented as dark blue and the gyral surface with lighter blue (figure 8).

While mapping the area of interests on the inflated surface, voxels can be adjusted due to their significance values just like the selection in classical coronal-sagittal-axial slices of the brain. It is easier to select the volume of interests from the anatomical image in this view, because we can see the continuity of the activity within sulcal areas. In this study, we selected the clusters of voxels by applying statistical criteria and extracted the mean value of the BOLD signal of these voxels throughout time course to map activities of brain regions on the inflated surface.

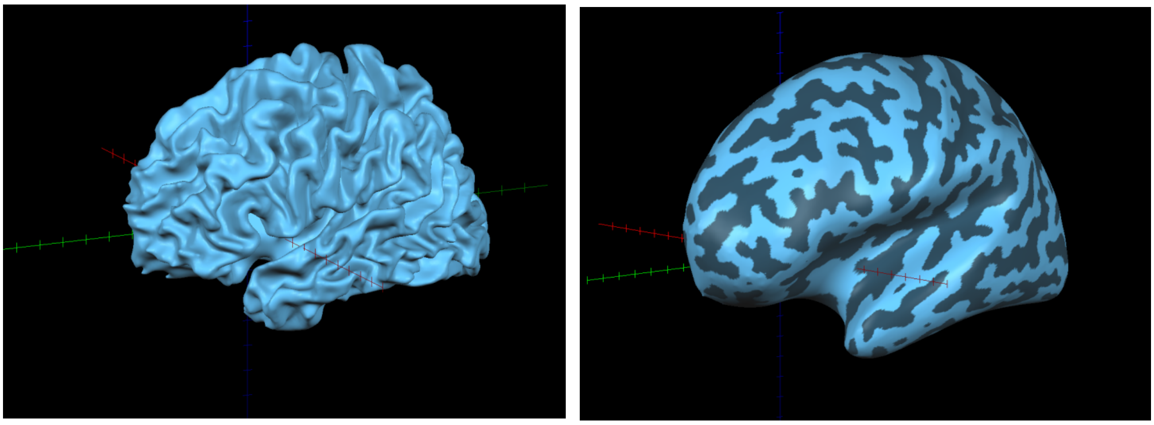

Figure 8: The segmented 3D model of the brain of subject ss003 (left) and the inflated version of the brain (right). The sulci (creeks) are shown in dark blue, gyri (crests) are shown in light blue

3.6.6. AC-PC and Talairach transformation of volumetric data

AC (Anterior comissure) and PC (posterior comissure) are two structures present in every brain and they are used to align the brain with respect to the horizontal (axial) plane to standardize the brain's rotational variability across subjects. Once the AC-PC transformation is done, Talairach transformation (Talairach and Tournoux, 1988) can be made by selecting six extreme landmarks on the brain. These are AP (Anterior Point), PP (Posterior Point), SP (Superior Point), IP (Inferior Point), RP (Right Point), LP (Left Point). The goal of the Talairach transformation is to determine these specific landmarks so that the brain of the subjects could be fit in a universal invisible 'box' in order to overlay brain activity from multiple subjects. This helps in evaluation of the data obtained from groups, and localizing a function onto an atlas-defined anatomical location even though the brain of individual subjects differ in terms of their size and shape. All the brains analyzed in this study have been transformed into Tailarach atlas coordinates.

3.6.7. Group analysis

Data obtained from 14 subjects (28 hemispheres) in four sessions (in total 56 sessions) were averaged all together via 'Multi subject, multi study' option of BrainVoyager software. The results gave us the overall contrasts values for each pair of conditions we set so that we could determine the p-value for the brain activity determined over the averaged atlas coordinates. After selecting the significant voxels from the brain atlas of 14 subjects, the Talairach voxel coordinates on this atlas were recorded for further use. It is important to note that we carried out a t-value based analysis which means that the selected voxels are significant with the same p-value ($p<0.001$) for both the group and subject level analysis. Later, we used the selected Talairach voxels to extract the time series from these regions from every individual subject's brain.

3.6.8. Statistical analysis for investigation of fMR-adaptation

In order to process on the raw fMRI data, we first extracted the BOLD values over time in each subject's brain via the BrainVoyager software. For the selected group cluster voxels in each brain, the mean time series is extracted into text files. Each file contains the intensity value for the selected cluster of voxels over time. As each run lasted for 434 seconds (432/2 = 216 TR), files containing the intensity values for each time point have 216 lines. The statistical analysis is carried out within 3 steps and all the implementation was done in Java programming language. These steps consist of (1) averaging BOLD signal over the data collected throughout the experiment and converting the values in percentage changes, (2) dividing the percentage BOLD response values into parts according to the different tasks they correspond and (3) separating values in lines for preparing the data for statistical analysis (see Appendix A).

Since the BOLD signal is very subtle (in a 3T scanner, 3-5% deviation from baseline), direct interpretation of the intensity values is not possible. A baseline value should be determined in order to prevent false-positive results. Averaging the BOLD signal values extracted from the clusters of voxels for every TR measurement gives a baseline for the entire time series within that area. Then, a percentage change in the BOLD signal can be obtained. In order to do this, the mean value of the intensities of every run (2 female + 2 male = 4 sessions) is averaged over time. By depending on this average, all the intensity values in the files are re-written as percentage values. Zero (0) represents the mean value of all run. Negative values represent the signal value being lower than the average while for the positive values it is the other way around. For instance -0.5 represents that the BOLD signal is 50 percent lower than the mean of the all time series.

In each run there are 3 repetitions of the same condition while each run contains six different conditions. In order to reach the average results, time series of the blocks that bear the same condition must be merged. In this stage of the analysis, we grouped 4 runs in total for each subject. Since there are 3 repetitions of each condition and 4 runs, we ended up with 12 time series to be merged to represent each condition. By merging the intensity value for each sample (samples are spaced TR sec apart), we obtained the overall signal value at a certain sample point for all trials. Each condition contained 12 sample points calculated in this fashion. Furthermore, to account for BOLD latency[2], we should consider a few number of previous and later sample points. Thus, additional to the 12 time samples of each block, 3 preceeding and 3 succeeding samples are also calculated and plotted for every condition. Finally, each condition is separately plotted for percentage of BOLD change over a time series of 18 samples. Paired conditions such as condition 1 and 4, condition 2 and 3, and condition 5 and 6 are analyzed together for differences. Figure 9 summarizes this fmr-adaptation analysis procedure.

2 BOLD latency: It may take some time for the brain physiology to respond in terms of oxygeneation. Therefore, the signal at a voxel which responds to the stimuli may contain a lag that takes up approximately 2-3 sample points.

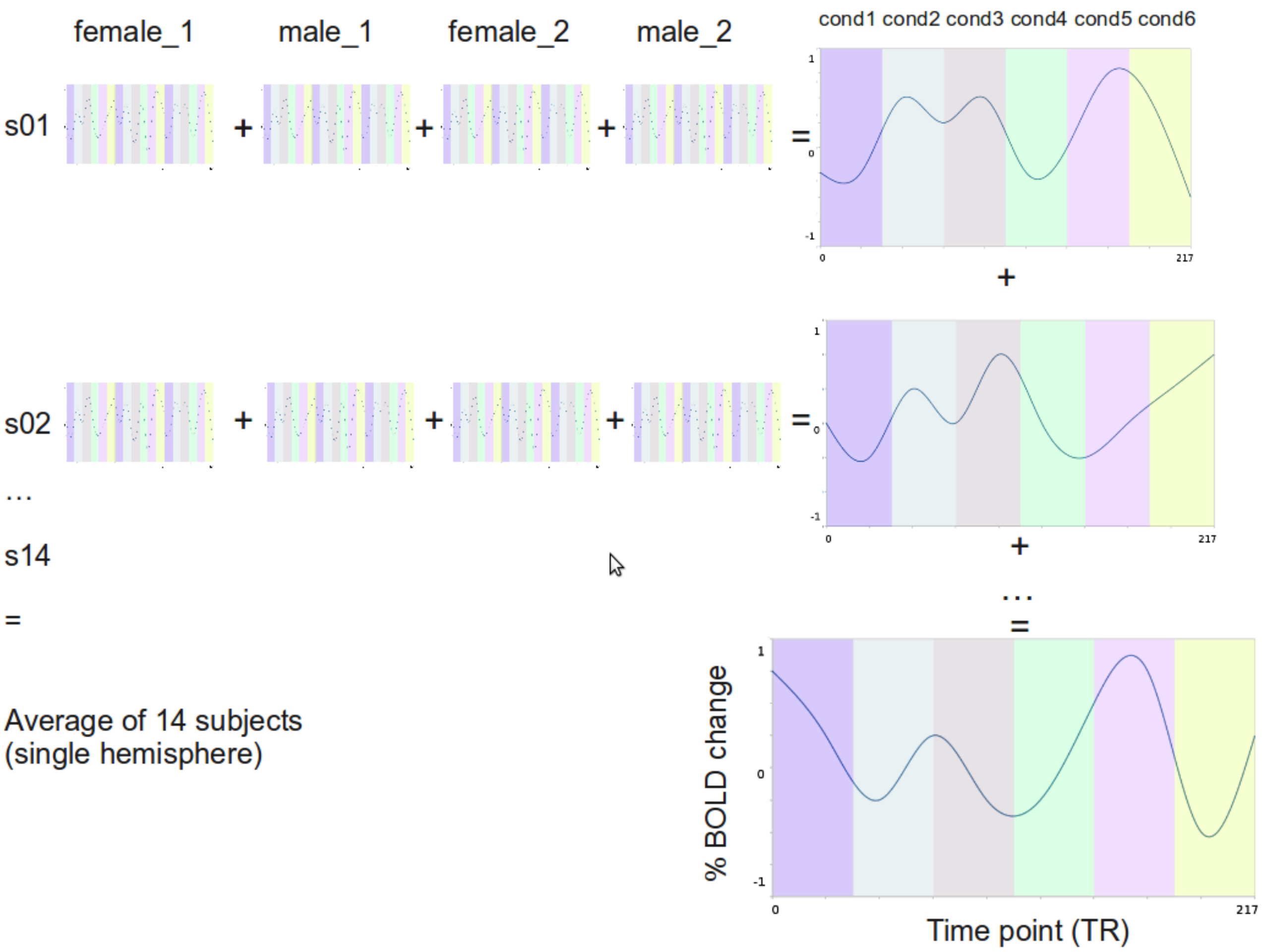

Figure 9: Chart representing the averaging operations of the data

CHAPTER 4

RESULTS

By using adaptation paradigm, the fMRI correlates were investigated separately to identify three different process-specific areas in the brain:

(1) areas that respond to different faces

(2) areas that respond to symmetrical patches

(3) areas that respond to symmetrical faces

Among these processes, the first two were investigated by Grill-Spector (2001) and Tyler (2005), and the last one is the contribution of our study.

Data analysis pipeline consisted of the following stages. Initially, statistical maps were overlaid onto the anatomical images collected from 14 subjects. Afterwards, the statistical contrasts on the group level were extracted, such that only those areas which were activated for the contrast differences were accepted for the fMR-adaptation analyses. This selection is performed separately for the three studies:

(1) Areas that respond to different faces are chosen by defining contrasts for different face versus identical faces.

(2) Areas that respond to symmetrical patches are chosen by defining contrasts for symmetrical patch versus identical patches.

(3) Areas that respond to symmetrical faces are chosen by defining contrasts for symmetrical face versus identical faces.

The extraction in all of the above three categories is done by selecting voxels as a result of a t-test between contrasts with a p value below 0.05. Finally within the selected areas, fMR-adaptation analysis is performed to determine whether adaptation and adaptation-release behaviors are exhibited.

4.1. Same face versus Different faces

We attempted to replicate the study of Grill-Spector (1999) in which an adaptation effect in the LOC between the repeated presentation of the same face compared to different faces is studied. Here, we tried to localize a specific area in the LOC which shows greater response to different face images than same face images by contrasting the different face and same face conditions (Condition 2 and Condition 3 in the experimental design).

This is achieved by the subtraction of BOLD signals elicited during the representation of the different faces from the BOLD signals during the representation of the same faces. This gives us the areas with the neuronal population responding more to different faces than viewing the same face. After extracting the voxel clusters having this aspect, we checked the behavior of the BOLD response in these areas for the related time series separately for each subject. If an adaptation for the repeated representation of the same face is observed along with a release from this adaptation in the different face condition, then this implies that the corresponding area has sensitive voxels for differentiation of faces.

Over 14 subjects, we found no adaptation for the identical face images compared to the face images belonging to different identities. The possible causes behind this will be discussed in the discussion section.

4.2 Asymmetrical versus Symmetrical Patches

In this part, we attempted to replicate the results of Tyler (2005) in which they investigated a symmetry specific response in some parts of LOC by using random-dot versus two fold and four fold patterns.

The contrast differences are investigated by the subtraction of BOLD signals elicited during the representation of the phase scrambled images of symmetrical images (symmetric patch) from the BOLD signals during the representation of the phase scrambled original faces (random patch). We obtained the areas with the neuronal population responding more to symmetric patches than viewing the random patterned patches (figure 10 and 11). After extracting the voxel clusters having this aspect, we checked the behavior of the BOLD response in these areas for the related time series separately for each subject. This is not a direct adaptation paradigm because during the course of the experiment, condition 1 and condition 4 are presented not contiguously.

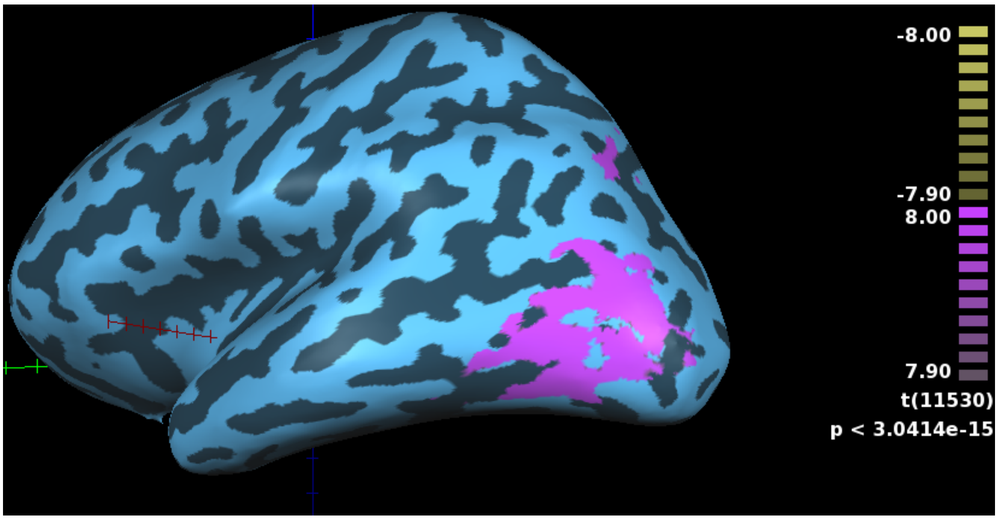

Figure 10: Voxels presenting significant activation in the symmetrical versus random patch condition in the occipital cortex of the left hemisphere. These voxels later get eliminated to determine the ones fitting inside the LOC.

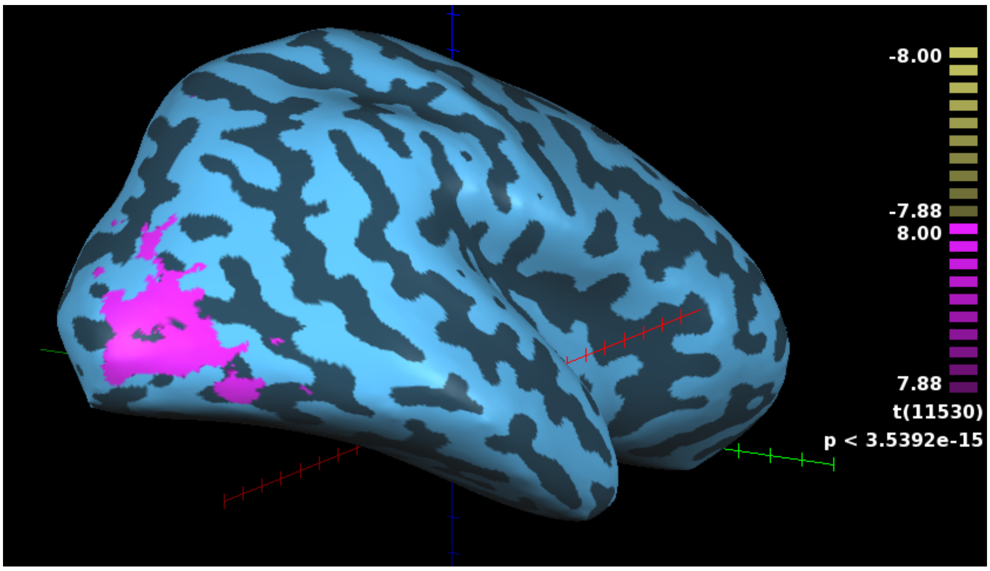

Figure 11: Voxels presenting significant activation in the symmetrical versus random patch

condition in the occipital cortex of the right hemisphere. These voxels later get eliminated to determine the ones fitting inside the LOC.

Note that by subtracting the signals which are collected both during patch representation, the task irrelevant signals obtained from other areas such as the motor response evoked due to the button responses of the subjects are eliminated.

Result graphs from ROI voxels of all subjects could be found in Appendix F. While we could not observe adaptation effect in some subjects (e.g. Subject 9 and Subject 10) some others presented well adaptation to this task (e.g. Subject 4 and Subject 14). Regardless of this, we included all subjects in the group analyses.

Previous studies revealed that the LOC consists of two parts responding to different aspects of visual stimuli. These two regions are referred as dorsal posterior and ventral posterior vertex (Table 2) in some studies (e.g. Grill-Spector, 1999) while they are classified as LO1 and LO2 (Table 1) in some of the recent studies (Larson and Heeger, 2006).

In the current paradigm which investigates a symmetry specific region for the patches in the LOC, we found activation both in LO1 and LO2 of the LOC.

Table 1. Talairach coordinates of the centroids of LO1 and LO2 (mean ± SD and range across all 15 subjects), based on boundaries defined by atlas fitting procedure (see Materials and Methods)

	Left hemisphere			Right hemisphere		
	x	*y*	*z*	*x*	*y*	*z*
LO1						
Mean	−31 ± 3.9	−90 ± 5.2	1.4 ± 6.9	32 ± 4.2	−89 ± 5.1	2.6 ± 6.5
Range	(−37, −26)	(−101, −82)	(−12, 11)	(24, 38)	(−98, −81)	(−8, 13)
LO2						
Mean	−38 ± 3.4	−83 ± 6.4	−0.1 ± 7.1	38 ± 4.4	−82 ± 5.1	0.6 ± 7.2
Range	(−43, −31)	(−92, −67)	(−13, 11)	(32, 46)	(−89, −72)	(−13, 12)

Table 1: Talairach coordinates of LO1 and LO2 (Larson and Heeger, 2006)

Table 1. Talairach Coordinates

	Left			Right		
	X	Y	Z	X	Y	Z
LO	−41 ± 5mm	−77 ± 6mm	3 ± 7mm	40 ± 6mm	−72 ± 7mm	2 ± 5mm
	−36 ± 7mm	−71 ± 7mm	−13 ± 5mm	37 ± 5mm	−69 ± 7mm	−10 ± 4mm
PF/LO_a	−38 ± 5mm	−50 ± 6mm	−17 ± 5mm	33 ± 4mm	−47 ± 6mm	−14 ± 4mm

Talairach coordinates (Talairach and Tournoux, 1988) of four subjects whose individual foci are depicted in Figure 6c. They were derived from regions located lateral to retinotopic areas V4/V8 that showed significant preference for objects compared to noise patterns in the face and face and car experiments (see red contour in Figure 6c). The LO complex can be described by three vertices: the first row corresponds to the dorsal posterior vertex, the second to the ventral posterior vertex, and the third to the ventral anterior vertex. The first two vertices bound LO, and the third vertex defined the center of PF/LO_a in Talairach space. Values represent the mean ± standard deviation in mm.

Table 2: Talairach coordinates of the ventral posterior vertex (first row) and dorsal posterior vertex (second row) (Grill-Spector, 1999)

Talairach coordinates of the patch symmetry specific activation (Table 3) are checked to assure that they match with previously defined regions by Larson and Heeger (Table 1) and the regions corresponding to LO2 (Figure 12) and LO1 (Figure 13) are presented in below.

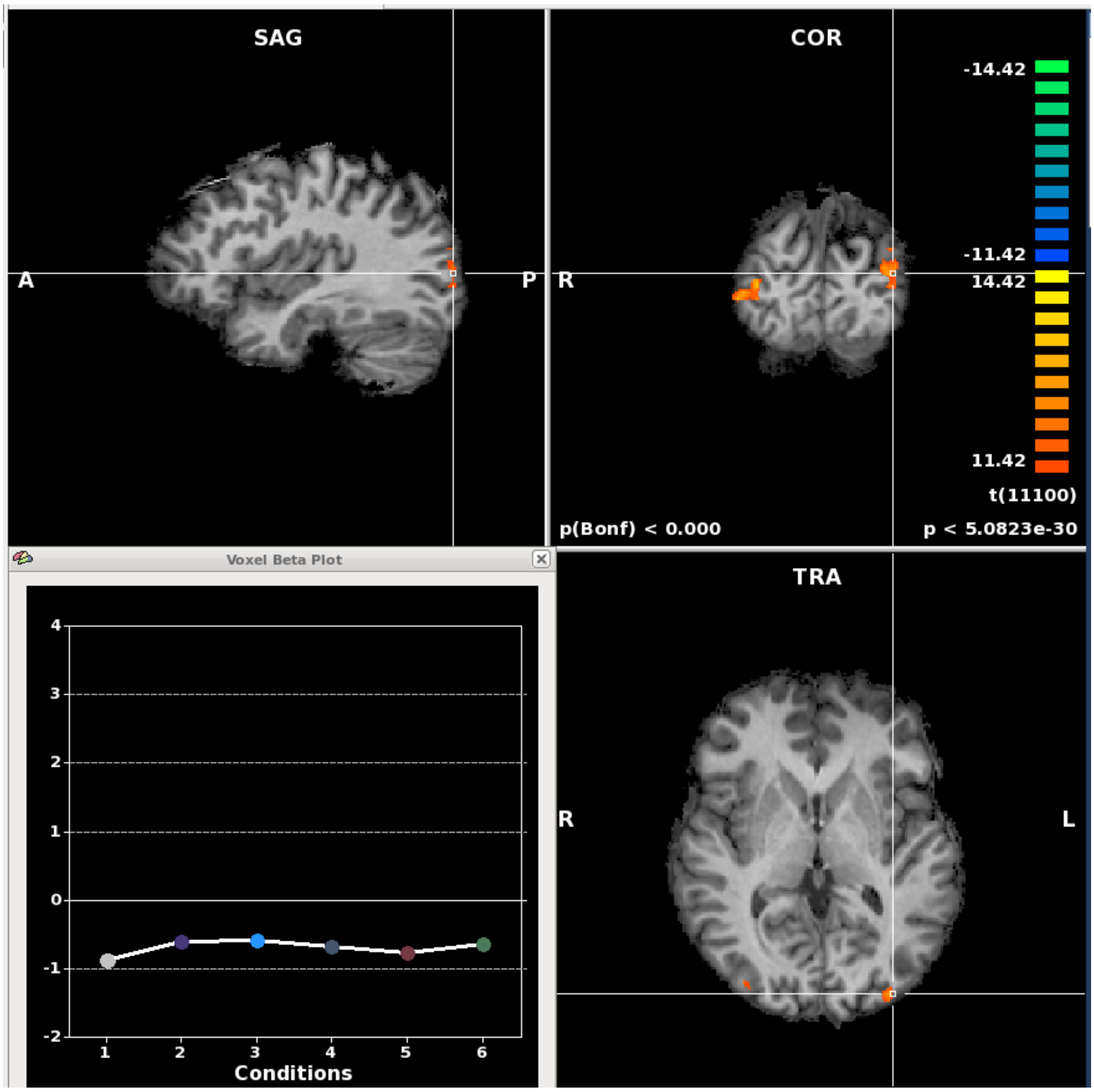

Figure 12: The symmetry specific activation in the dorsal posterior vertex of the group analysis of fourteen subjects. The p value is assigned less than 0.01.

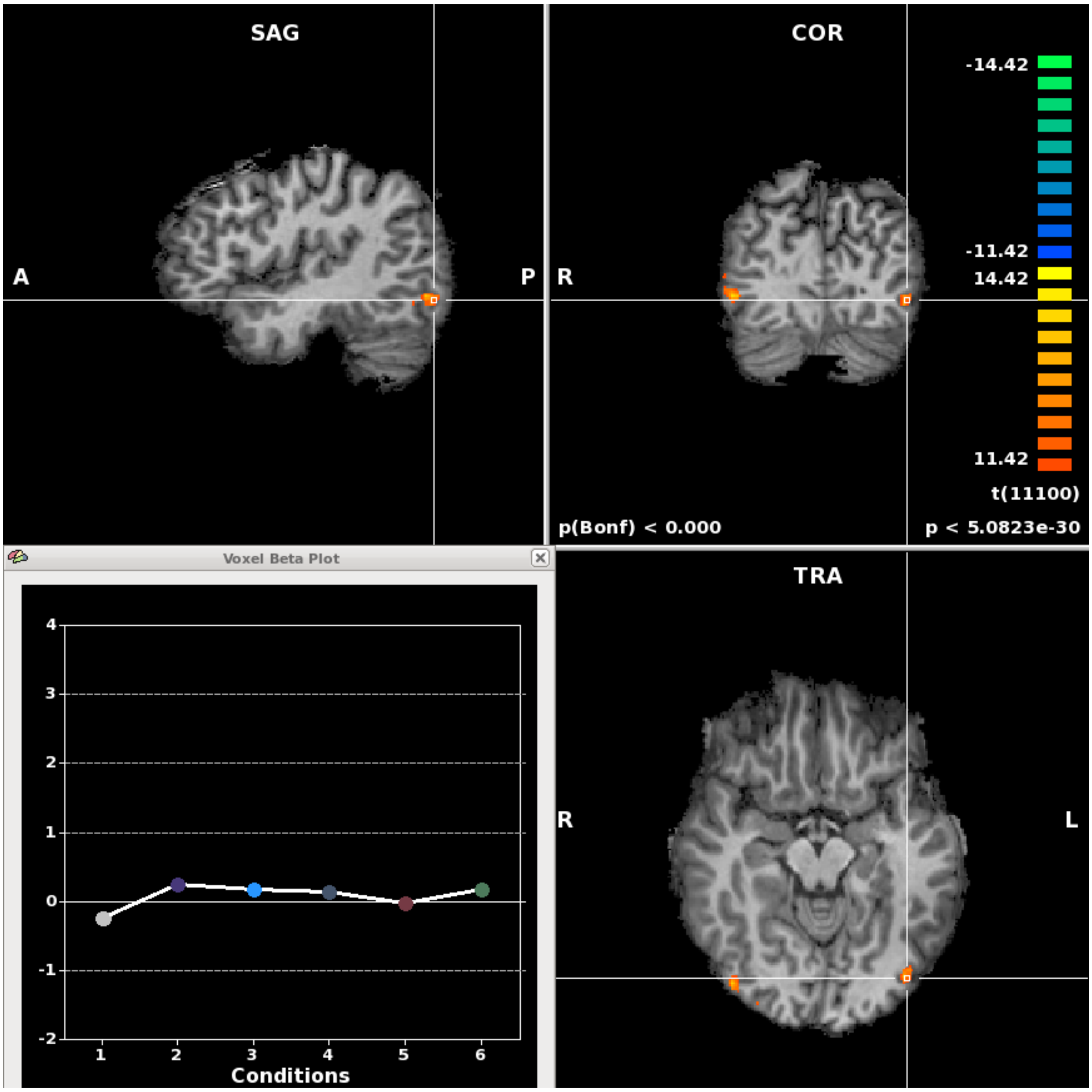

Figure 13: The symmetry specific activation in the ventral posterior vertex of the group analysis of fourteen subjects. The p value is assigned less than 0.01.

Over all subjects, average of the voxels within the LOC border showed a clear adaptation effect (figure 14-a and 14-b) for same face stimulus while showing release from adaptation when symmetrical face images are presented.

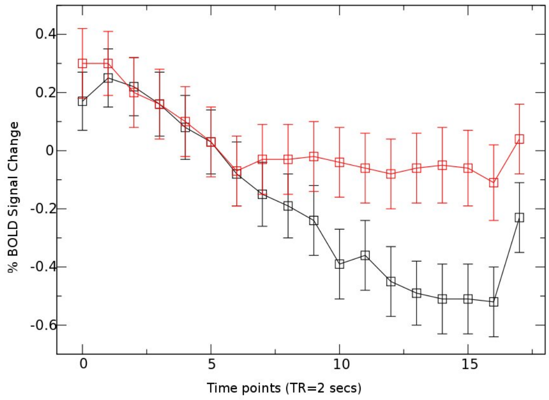	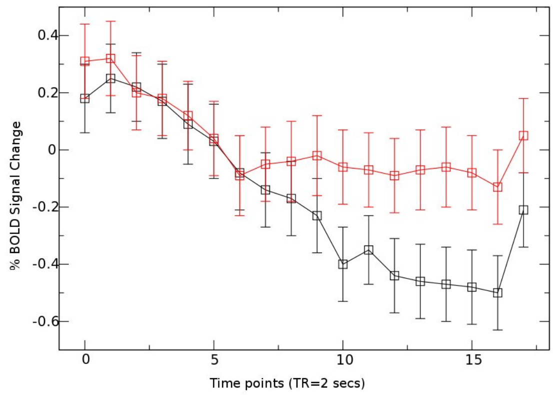
Figure 14-a: fMRI signals from random patch and symmetrical patch conditions were plotted as a function of TR values averaged over the left hemispheres of 14 subjects, $p < 0.05$. Error bars represent SEM	Figure 14-b: fMRI signals from random patch and symmetrical patch conditions were plotted as a function of TR values averaged over the right hemispheres of 14 subjects, $p < 0.05$. Error bars represent SEM

Patch Symmetry Responsive			
Left	Hemisphere		
x		-39	-30
y		-87	-80
z		1	10
Right	Hemisphere		
x		32	36
y		-81	-77
z		2	4
Left	Hemisphere		
x		-47	-39
y		-77	-68
z		-13	-7
Right	Hemisphere		
x		25	47
y		-87	-73
z		-12	0

Table 3: Talairach coordinates of the areas presenting symmetry specific activity for patch images as a results of the group analysis of fourteen subjects.

4.3 Symmetrical Face Adaptation

By using a combination of the previously mentioned paradigms, in other words a similar adaptation analysis of Grill-Spector (1999) and a research question similar to Tyler (2004), we found a face-symmetry specific response in the sub regions (LO1 and LO2) of LOC (figures 15-a, 15-b and 15-c).

Contrast for original face images and symmetrical face images: This contrast is the subtraction of BOLD signals elicited during the representation of the symmetrical face images from the BOLD signals during the representation of the original face images. This gives us the areas with the neuronal population responds more to symmetric faces than viewing the original faces. After extracting the voxel clusters having this aspect, we checked the behavior of the BOLD response in these areas for the related time series separately for each subject. If an adaptation for the repeated representation of the original face is observed while a release from this adaptation in the symmetric face condition is observed, then this implies that the corresponding area has sensitive voxels for symmetrical faces.

By subtracting the signals which are both collected during face representation, the task irrelevant signals obtained from other areas such as FFA and motor areas evoked from the button responses of the subjects would be eliminated. Result graphs from ROI voxels of all subjects could be found in Appendix F. While we could not observe an adaptation effect in some subjects (e.g. Subject 4 and Subject 9) some others presented well adaptation to this task (e.g. Subject 2 and Subject 8). Regardless of this, we included all subjects in the group analyses. (figure 16-a and 16-b)

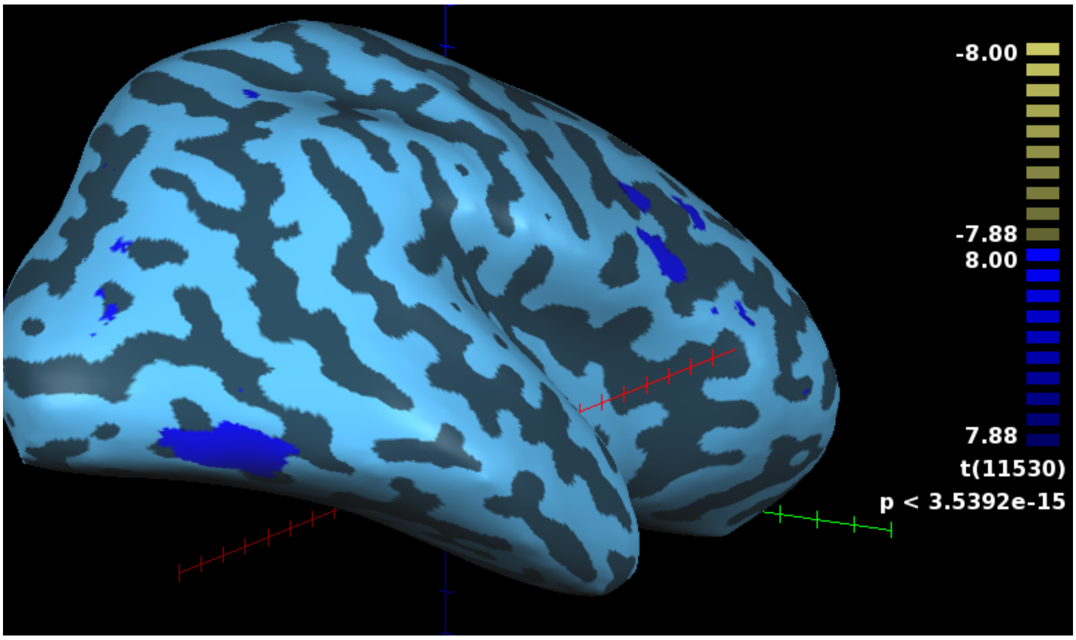

Figure 15-a: The symmetry specific activation in the right hemisphere as a result of the group analysis of fourteen subjects. The p value is assigned less than 0.01.

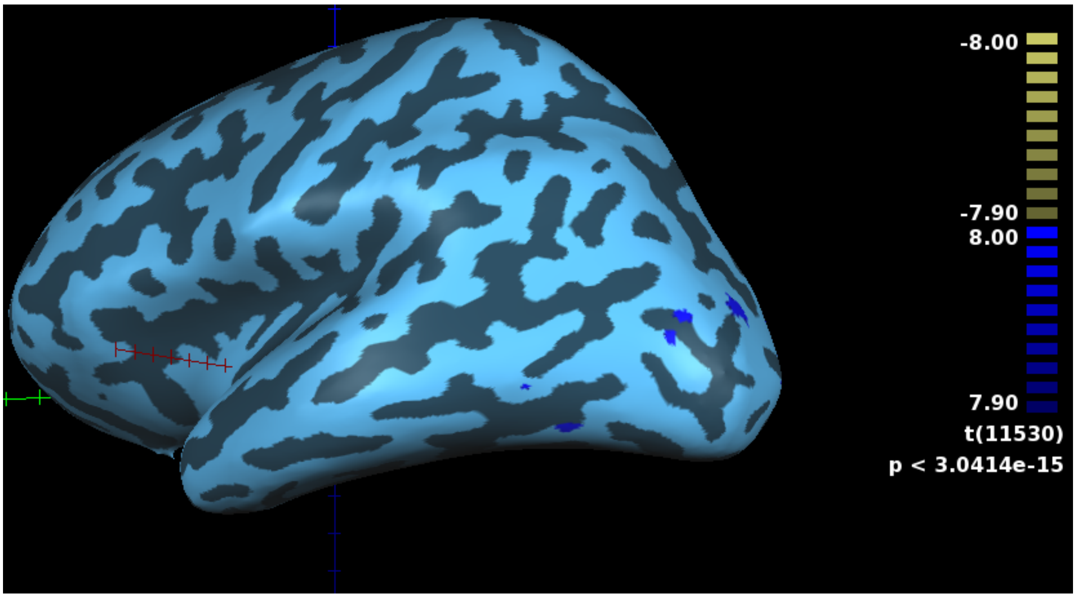

Figure 15-b: The symmetry specific activation in the left hemisphere as a result of the group analysis of fourteen subjects. The p value is assigned less than 0.01.

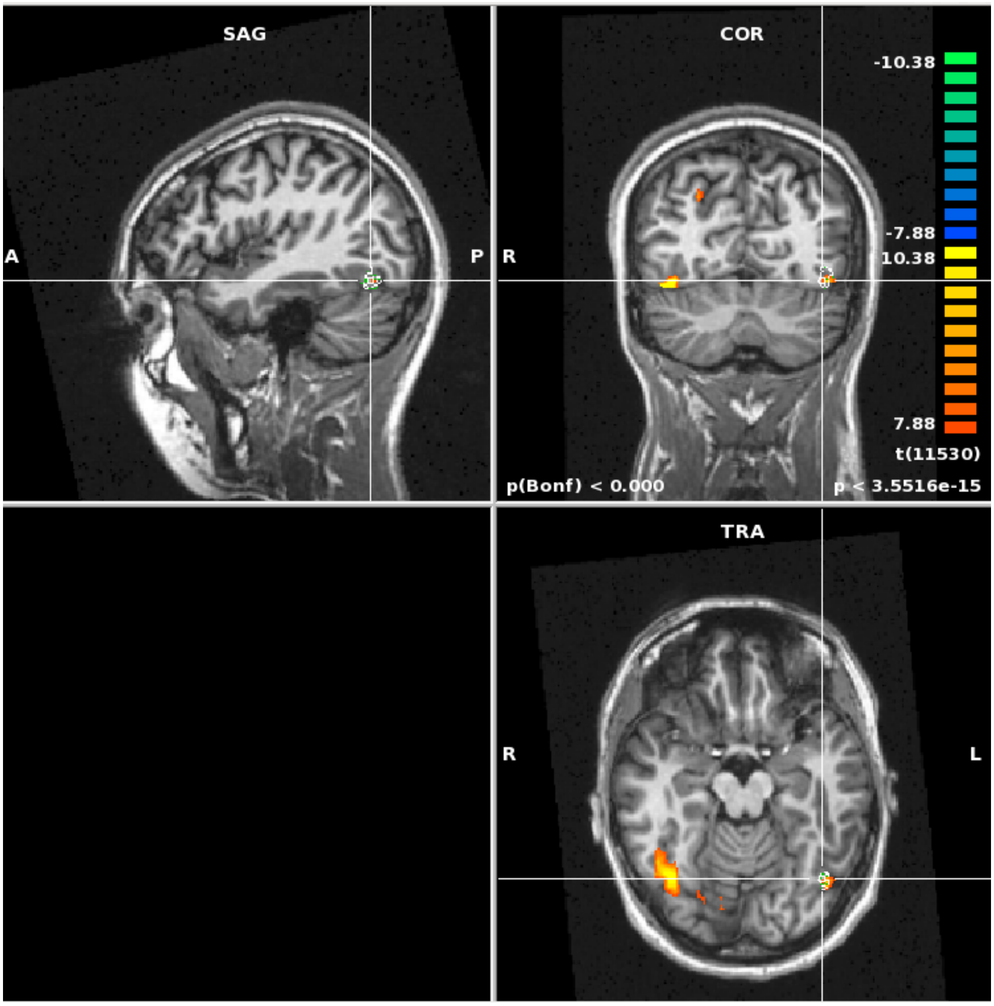

Figure 15-c: The symmetry specific activation in the ventral posterior vertex of the group analysis of fourteen subjects. The p value is assigned less than 0.01.

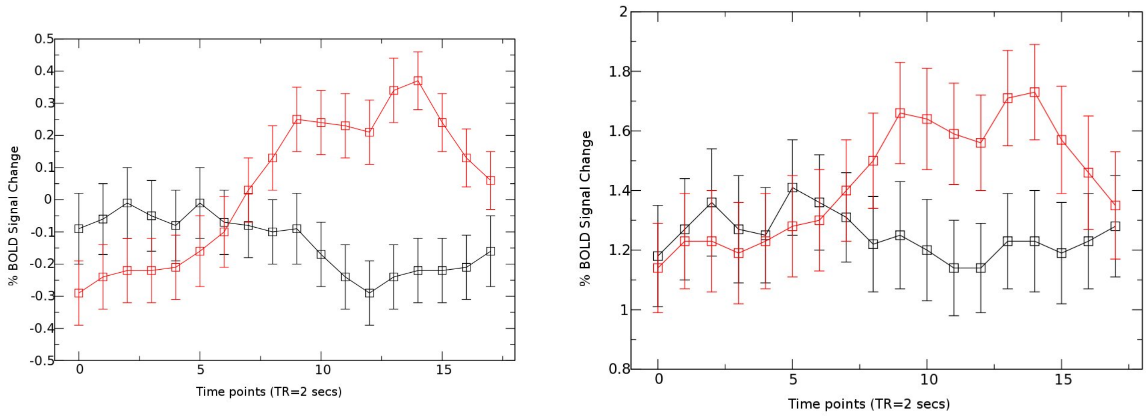

Figure 16-a (left) and 16-b (right): fMRI signals from original face and symmetrical face conditions were plotted as a function of TR values averaged over the left (16-a) and right (16-b) hemispheres of 14 subjects, $p < 0.05$. Error bars represent SEM

In the current paradigm which investigates a symmetry specific region for the faces in the LOC, we were able to localize such an area in the ventral posterior vertex of the LO (Grill-Spector, 1999) and LO2 according to another classification methodology (Larson and Heeger, 2006).

4.4. Activations in other Areas

Other than the face-symmetry responsive region in the LOC, there was also significant amount of activation in the low-level visual areas: V1, V2, V3 and V3a/b (figure 17). Even though the total amount of visual information between original and symmetrical face images were preserved, the entropy values between original face images (M=4.076, Std=0.1753) and symmetrical face images (M=3.869, Std=0.1519) in the database differ significantly from each other ($p<0.01$).

Since V1 responds to such low-level information, activation in V1 is not surprising. Other areas V2, V3 and V3ab sample information from each other in a certain hierarchy, eventually forming cortico-cortical mappings in the visual cortex. A differentiating activation is expected in these areas whenever there is a change in the stimulus. As the stimulus has changed between the symmetrical and original face conditions often in our experiment, such activation in the low-level visual areas are also expected. Besides, a majority of the subjects declared during de-briefing that they became aware of the symmetry manipulation. Such conscious cognitive processing can be attributed to higher-level visual areas.

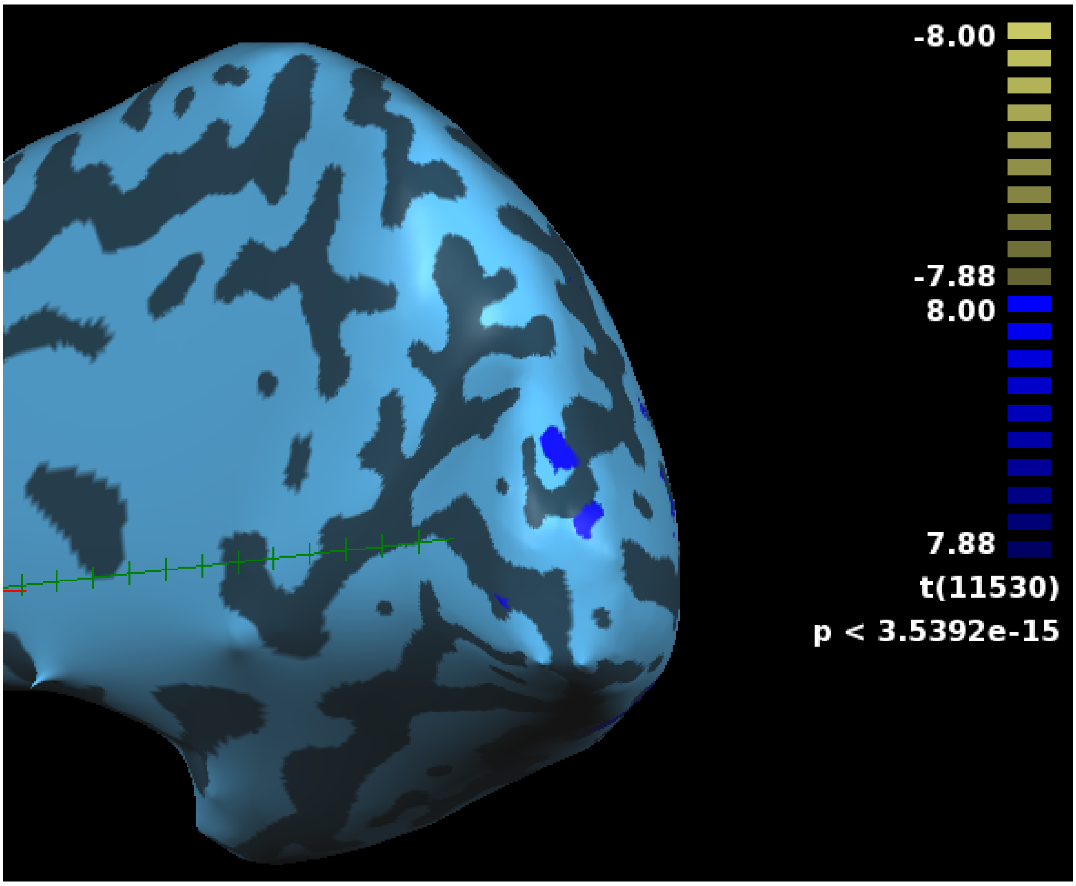

Figure 17: Retinotopic areas presenting significantly more activation in the symmetrical face condition than in the original face condition.

Another region where we observed a significant activation across the subjects is the dorsalateral prefrontal cortex (DLPFC) (figure 18) which is known to be active in online maintenance and manipulation of information such as working memory tasks (Mars and Grol, 2007). Previous functional neuroimaging studies revealed that this area is also active during response selection (Rowe et al., 2000). In our task, during the representation of the same face stimuli, the workload of the working memory is low. In the symmetrical face condition the faces images are not identical. This would cause an extra activation in the symmetrical face condition compared to the same face condition and this should be the cause of the contrast activation that we found.

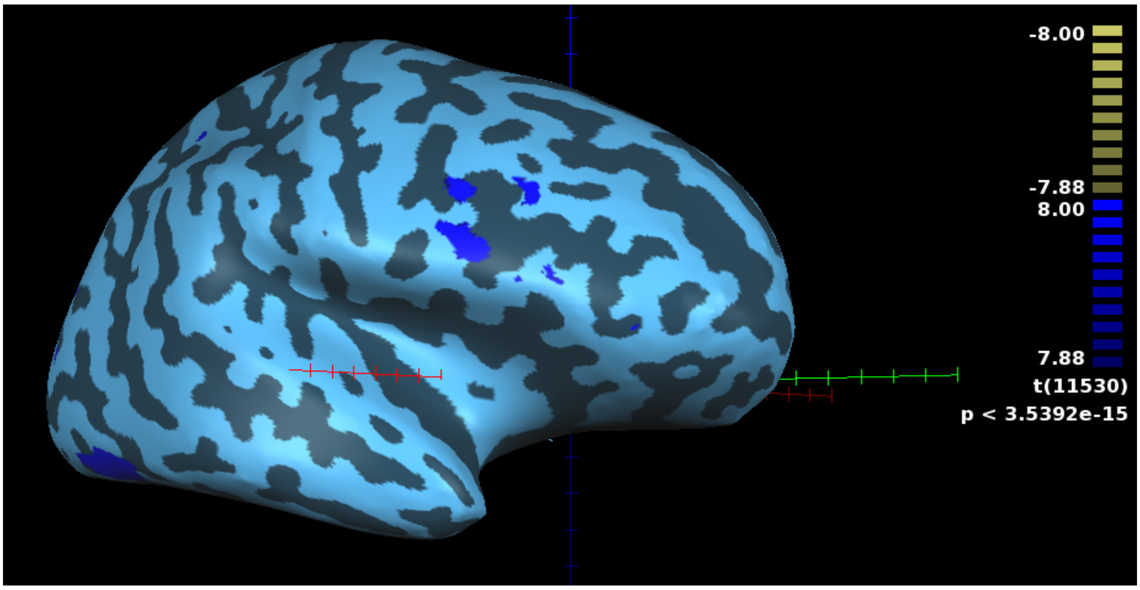

Figure 18: Areas presenting significantly more activation in the symmetrical face condition than in the original face condition.

Moreover, a delay-related activity occurs in this area is especially when a response should be given at the beginning of the delay interval (Pochon et al., 2001). Even though our task did not necessarily require to give a response at the beginning of the stimulus presentation, the subjects had a relatively short time to respond (less than 4 seconds). Thus the activation in the DLPFC can also be explained by the working memory/response selection task.

CHAPTER 5

DISCUSSION AND CONCLUSION

Humans not only make objective quantification of faces but also they use faces to make plenty of subjective inferences. The impact of the facial symmetry perception on the subjective judgments are issue to many research. When faces are used as stimuli, it has been shown that attractiveness, trustworthiness, and even recognition memory performance is related to facial symmetry.

Previous studies showed that the facial symmetry is perceived very accurately and fast by humans (Dövencioğlu, 2008; Yildirim, 2010). Because we make lots of inferences from the visual world, not only the lately developed frontal lobe but also the visual cortex attained a high-level structure compared to those of other creatures. Therefore it is curious whether humans have developed specialized cortices for face symmetry perception, a cognitive ability which is highly robust across several human populations.

So far, the neural correlates of face perception, especially face versus object identification and face recognition are studied in a broad sense. Regardless of the vast literature on the mirror symmetry amount that a face possesses (Chapter 2), and how this information is perceived by human observers, neural correlates of face symmetry perception has not been investigated yet.

In this study, we used an imaging analysis method called fMRI adaptation (fMR-

A) to determine the area in the brain which plays role in the perception of facial symmetry. In a nutshell, fMRI-A suggests that the higher level visual areas become less responsive to repeatedly presented stimuli over time. Then, upon presentation of the same stimulus which is manipulated by changing only a specific, the areas which are responsive to the changed aspect of the stimulus will show a release from adaptation. Prior to testing our main hypothesis we also replicated some findings in the literature which forms the core of our motivation.

First, an experimental design has been carefully set up by using a controlled stimuli in order to prevent the confusion evoked by the conflicting results in the literature. The previously developed METU-FaceTwo database was used which contains normalized face images with original and symmetrical versions. In three control conditions, all inserted in the same blocked fMRI design, we tested our main hypothesis and the outcomes of two previous studies. Both face images and scrambled patch images were presented to the subjects. In order to generate patch images, face images are converted to their phase scrambled version and presented as phase-scrambled vs symmetrical phase-scrambled images. These conditions aimed to limit the outcoming effects to only be related to facial symmetry but not to object symmetry.

For three conditions, we carried out three different comparisons where each comparison was made between two different experiment blocks. First, a contrast between same face and different face conditions was defined. Second, we compared the responses evoked by the random patch stimulus and symmetric patch stimulus. Finally, for our main hypothesis we compared the original face images with symmetrical faces. We checked the adaptation trend in the regions where the general linear model (GLM) of the voxels behavior is higher for one condition to the other (different faces>same face, symmetric patch>random patch, symmetrical face>original face). Contrasts one and two aimed to replicate the results of the studies Grill-Spector (1999) and Tyler (2005).

The results for the same versus different faces adaptation task did not agree with fMR-adaptation paradigm. Data taken from the LOC region where the activation during the different face presentation are not higher than the viewing of same face.

Thus, we failed to find an adaptation effect for same versus different faces. In the literature, some controversies have been raised regarding the use of fMR-adaptation for same versus different faces, houses, tools, etc. (Simmons et al., 2007; Baker et al., 2007). Mainly due to the subtlety of fMR-adaptation release magnitude, it has been reported that fMR-adaptation effects may be misclassified (Grill-Spector et al., 2006; Grill-Spector et al., 2007). Probably in our study there may be some confounds related with the observations in the literature.

Results for the random patch vs. symmetrical patch patterns presented highly reliable outcomes. Data taken from the LOC region revealed that 11 out of 14 subjects showed an adaptation to the repeatedly presented random patch stimuli and all 10 subjects showed a release from adaptation while they view the symmetric patch stimuli.

Entropy differences between both original face images vs (M=4.0761, =0.1753) original patch images (M=7.2400, Std = 0.1034), and symmetrical face (M=3.8693, Std= 0.1519) vs symmetrical patch (M= 6.8111, Std = 0.1234) images are significantly different from each other. Even though the amplitude of the signals in these images are preserved with the Fourier transformed phase scrambled versions, the difference of the entropy values indicate that low level visual processes between the original versus scrambled pictures may differ. Hence the activations that we found in primary visual cortex is due to this type of change in the stimulus, but not due to high level changes such as symmetry manipulation.

Last but definitely not least, we questioned whether a specific area for perceiving facial symmetry is localized in the human brain. Through the verbal feedback collected from subjects (Appendix D), it is possible to understand that the subjects reported some minor differences in the facial aspects, while some of them were explicitly aware of the symmetry manipulation in the stimuli and some were not. Yet, none of them reported that the identity of the person has changed while only the symmetry aspect of the faces has changed. Additionally, some subjects reported that the faces are perceived as they are rotating around a vertical axis. In order to assure that our findings are not evoked by viewing difference of the same faces, we compared the results of our study with a related study. In Chen et al. (2006), the authors investigated the responsive areas to the viewpoint change of faces and the study revealed that intraoccipital sulci (IOS) (Talairach coordinates: left -24, -95, 19 and Right 36, -75, 23) and middle occipital gyrus (MOG) (Talairach coordinates: left -37, -76, 0 and right: 33, -79, 0) showed viewpoint change responsive activity. However, none of these regions are overlapping with out finding in the LOC regions. Thus, we know that any change evoked in the cognitive response between original and symmetrical face stimulus indicates an activity corresponding to the symmetry aspect change. Data taken from the LOC region where the activation during the different face presentation are higher than the viewing of same face revealed that all 14 subjects showed an adaptation trend in at least one hemisphere to the repeatedly presented random original face images while in all these hemisphere we could observe a release from adaptation while subjects view the symmetric face stimuli.

To the best of our knowledge, this is the first study which shows that an area in the LOC region shows a symmetry specific response for faces. The activation was not always bilateral between subjects. Seeking for a biased perception through facial symmetry, Table 4 shows that right hemisphere responds more to the facial symmetry task compared to the left hemisphere. Furthermore, even though the responding voxels fall into the predefined regions of LO1 and LO2, it is possible to observe that facial symmetry perception is largely presented inside the boundaries of LO2 (Table 4). According to the literature, LO2 is more responsive to objects than LO1. Moreover, LO1 was found to show orientation selectivity to the stimulus while LO2 did not show significant response to this kind of change (Larsson and Heeger, 2006). However, such activation differences could be observed also in the random vs symmetrical patches condition in our experiment, which indicates that our findings may not be specific to the symmetry perception of faces but objects in a general sense. Overall, our results not only point out a symmetry responsive area for faces but also contributes to the literature related to the sub regions of LOC. We introduced that the symmetrical specific activation of faces are located more on the right hemisphere, while studies in the literature suggest different hemisphere bias effects involved in face perception (De Renzi et al., 1994; Evehart et al.,2001).

		RH	LH
face sym.	LO1	2485	20
	LO2	4069	92
patch sym.	LO1	2260	3876
	LO2	4067	7403

Table 4: Number of significantly responsive voxels to the symmetrical vs original faces condition (top rows) and random vs symmetrical patches condition.

Although we also observed other areas presenting significant activation for the facial symmetry perception in different subjects, normalizing the data in overall 14 subjects caused a high reduction of activation in these areas. There were only a few more active areas remained other than LOC, such as the low-level retinotopic areas and the dorso-lateral prefrontal cortex. These can be explained by the pixel-wise changes in the stimulus and the differences between the memory load of the task carried out (1-back is not the same when you repeat the same stimulus and when the stimulus keeps changing).

Overall, LOC is an accurate anatomical structure for looking into the details of semantic meaning of visual stimulus. LOC builds a bridge between how we perceive the visual world and how they make sense to us, how do we make inferences out of the visual world. This region is crucial to in terms of forming a center where the visual stimulus leads memories, emotions, learning, etc. By utilizing the fMR-A paradigm to investiagate the facial features, we showed that more facial measurements and judgments might be investigated using this method in the brain. For instance, the correlations between the decision making parameters which are known to have effect on each other such as symmetry and attractiveness can be studied in more detail.

5.1. Limitations

Subjective judgments should have been taken into account and several group analyses could have been applied according to subjective perceptual differences.

Besides, the use of eye-tracker in the MR scanner might provide a better analysis of the subject data to be extracted to the study based on attentional differences. The lack of the adaptation behavior observed in a few subjects might be due to the difference in where the subjects paid attention.

Most importantly, the method we followed for extracting single subject results has some shortcomings. We picked the region of interests from each subjects' brain by using the Talairach coordinates we obtained from the group analysis. However there might be unrelated areas within these voxels whose behavior is meaningful when averaged over all subjects but not by itself for individual subjects. Moreover, we used ROI borders from the literature while determining the LOC. A better way to do this might be picking LOC specifically for each subject, perhaps through the use of high-level visual localizers. However when we try to base our findings on the same amount of statistical significance (setting the same p value) for each subject, there is huge amount of variance in cluster sizes. This is a common problem in literature. This problem has two common solutions; basing the analysis on either cluster size or p-value. We picked the latter because the former one requires to set different p values for each subject which gives less reliability in terms of statistics.

Finally, although the number of subjects in this study is consistent with the amount of subjects required to study high-level visual areas via fMRI, adding more subjects would increase the reliability of the results.

5.2. Further Study

Decision making processes about the fluctuating symmetry amount and other features of faces should be investigated in more detailed both in terms of behavioral and neurological bases. Collecting more data about the relationship between facial features such as attractiveness, familiarity, trustworthiness, symmetry, etc. and studying their anatomical correlates is important.

These processes might be based on hierarchical decision making processes. We showed that the perception of the symmetry feature of the faces might be accurate and fast due to the neurological channels assigned for this function. As symmetry is a low-level and quantitative feature compared to other emotional and subjective features, it is expected that humans perceive this feature based on reliable biological sources. Other high level subjective decisions about the facial appearance might be due to the use of this mechanism and the decisions might be made accordingly. In other words, there might be a hierarchical decision making processing going from the objective judgments to subjective judgments. The neural correlates of this framework should be investigated in a more detailed fashion. Localization of different decision making processes in the brain via accurate imaging techniques would help to understand if such a network exists or not. Some current studies based on the perception of the pleasing scenes (Aharon et al., 2001) reveal that viewing attractive faces may cause an activation in the reward mechanism, nucleus accumbens particularly. As attractiveness is a higher level process it should be processed in higher than visual areas. These kind of subjective judgments are expected to be processed in the emotional network.

Since we only investigated the perception of the mirror symmetry of the faces in this study, the effect of the horizontal reversal effect still remains unknown. Investigating this parameter through fMRI should add more to understanding the functioning of LOC.

To conclude we can say that, the combination of the results derived from the second and third parts of this study, where we seek for neural correlates of the symmetry perception in non-face objects and faces, made it explicit that the symmetry aspect of the faces not only get processed like a non-face object but also is localized to a distinct area in LOC. To the best of our knowledge, our study is the first to demonstrate the localization of face-symmetry processing in the brain. Our findings may lead to several future studies as briefly mentioned above.

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APPENDICES

APPENDIX A: PROGRAMS USED IN STATISTICAL ANALYSIS

percentageConverter.java

```
//calculates the mean percentage value for each scan by averaging
all the values during that session

import java.io.BufferedReader;
import java.io.BufferedWriter;
import java.io.FileReader;
import java.io.FileWriter;
import java.io.FileNotFoundException;
import java.io.IOException;
import java.util.Random;


public class percentageConverter {

  public void readFile() {

    BufferedReader br = null;
    String[] fileName = new String[2];
    double[] numbers = new double[5000];
    double[] percArray = new double[5000];
    int j = 0;
    double total = 0;
    double mean = 0;
    double perc;
    fileName[0]="fs003_LH";
    fileName[1]="fs003_RH";

    for(int fn=0; fn<2; fn++){
          try {

            br = new BufferedReader(new FileReader(fileName[fn]));
            String line = null;

            while ((line = br.readLine()) != null) {
```

```
            String[] values = line.split("\n");

            //Do necessary work with the values, here we just
print them out
            for (String str : values) {
                  numbers[j] = Double.parseDouble(str.trim());
                  total += numbers[j];
                  //System.out.println(numbers[j]);
                  j++;
            }
             }
            mean = total/j;
            System.out.println(mean);
            for (int i=0; i<j; i++){
                  perc=((numbers[i]-mean)/mean)*100;
                  //System.out.println("("+numbers[i] + "-" + mean
+ ")/" + mean+ ")*100="+ perc);
                  percArray[i]=perc;
            }

            try {
                BufferedWriter out = new BufferedWriter(new
FileWriter(fileName[fn]+"-percentage"));
                System.out.println("written to the file");
            for (int f=0; f<j; f++)
                out.write(percArray[f] + "\n");
                out.close();
            } catch (IOException e) {
            }
          }
          catch (FileNotFoundException ex) {
            ex.printStackTrace();
          }
          catch (IOException ex) {
            ex.printStackTrace();
          }
          finally {
            try {
            if (br != null)
              br.close();
            }
            catch (IOException ex) {
            ex.printStackTrace();
            }
          }
    }//for filenames close
  }

  public static void main(String[] args) {
    percentageConverter test = new percentageConverter();
    test.readFile();
  }
}
```

pickup.java

//divides the stream of values into six groups where every group represents a single condition

```
import java.io.BufferedReader;
import java.io.BufferedWriter;
import java.io.FileReader;
import java.io.FileWriter;
import java.io.FileNotFoundException;
import java.io.IOException;
import java.util.Random;
import java.lang.Long;
import java.io.InputStream;
import static java.lang.Math.*;

import java.util.*;

public class pickup {

  public static void main(String[] args) {

    BufferedReader br = null;
    String[] fileName = new String[4];
    double[] numbers = new double[2000];
    double[] scr_orig_face = new double[2000];
    double[] same_face = new double[2000];
    double[] same_face2 = new double[2000];
    double[] dif_faces = new double[2000];
    double[] scr_sym_face = new double[2000];
    double[] sym_face = new double[2000];
    long temp =0;
    int j = 0;
    int i = 0;
    int n = 0;
    int s = 0;
    int m = 0;
    int scrorigface=0;
    int sameface=0;
    int sameface2=0;
    int diffaces=0;
    int scrsymface=0;
    int symface=0;
    int limit, pause;
    int randomInt, randomInt2, randomInt3;
    fileName[0] = "fs003_LH-percentage";
    fileName[1] = "fs003_RH-percentage";

    for(int fn=0; fn<2; fn++){
          try {

      /*      br = new BufferedReader(new FileReader(fileName));
            String line = null;

            while ((line = br.readLine()) != null) {

            String[] values = line.split("\n");

            //Do necessary work with the values, here we just
print them out
            for (String str : values) {
                  numbers[j] = Long.parseLong(str.trim());
                  //System.out.println(numbers[j]);
                  j++;
```

```
            }
              }*/
            InputStream task = 
pickup.class.getResourceAsStream(fileName[fn]);
            Scanner sc = new Scanner(task);
            while (sc.hasNext()) {
              numbers[s]=sc.nextDouble();
              s++;
      //System.out.println(numbers[s]);
            }
              while (i<864){
                    for (int a = 0; a<6; a++){
                                for (int d = 0; d<12; d++){
                                      if (d==0){
                                            if(a!=0){

      scr_orig_face[scrorigface]=numbers[i-3];//take three TR 
before and after

      scrorigface=scrorigface+1;

      scr_orig_face[scrorigface]=numbers[i-2];

      scrorigface=scrorigface+1;

      scr_orig_face[scrorigface]=numbers[i-1];

      scrorigface=scrorigface+1;
                                                  }
                                            else{

      scr_orig_face[scrorigface]=0;//take three TR before and 
after

      scrorigface=scrorigface+1;

      scr_orig_face[scrorigface]=0;

      scrorigface=scrorigface+1;

      scr_orig_face[scrorigface]=0;

      scrorigface=scrorigface+1;
                                                  }
                                            }

      scr_orig_face[scrorigface]=numbers[i];
                                      scrorigface=scrorigface+1;
                                      if (d!=11)
                                            i=i+1;
                                      if (d==11){

      scr_orig_face[scrorigface]=numbers[i+1];

      scrorigface=scrorigface+1;

      scr_orig_face[scrorigface]=numbers[i+2];

      scrorigface=scrorigface+1;
```

```
	scr_orig_face[scrorigface]=numbers[i+3];

	scrorigface=scrorigface+1;
						i=i+1;}
				}
				for (int e = 0; e<12; e++){
					if (e==0){

	same_face[sameface]=numbers[i-3];//take three TR before and
after
						sameface=sameface+1;;

	same_face[sameface]=numbers[i-2];
						sameface=sameface+1;

	same_face[sameface]=numbers[i-1];
						sameface=sameface+1;
						}
					same_face[sameface]=numbers[i];
					sameface=sameface+1;
					if (e!=11)
						i=i+1;
					if (e==11){

	same_face[sameface]=numbers[i+1];
						sameface=sameface+1;

	same_face[sameface]=numbers[i+2];
						sameface=sameface+1;

	same_face[sameface]=numbers[i+3];
						sameface=sameface+1;
						i=i+1;}
				}
				//i=i+1;
				for (int f = 0; f<12; f++){
					if (f==0){

	dif_faces[diffaces]=numbers[i-3];//take three TR before and
after
						diffaces=diffaces+1;;

	dif_faces[diffaces]=numbers[i-2];
						diffaces=diffaces+1;

	dif_faces[diffaces]=numbers[i-1];
						diffaces=diffaces+1;
						}
					dif_faces[diffaces]=numbers[i];
					diffaces=diffaces+1;
					if (f!=11)
						i=i+1;
					if (f==11){

	dif_faces[diffaces]=numbers[i+1];
						diffaces=diffaces+1;

	dif_faces[diffaces]=numbers[i+2];
						diffaces=diffaces+1;
```

```
	dif_faces[diffaces]=numbers[i+3];
						diffaces=diffaces+1;
						i=i+1;}
				}
				for (int g = 0; g<12; g++){
					if (g==0){

	scr_sym_face[scrsymface]=numbers[i-3];//take three TR before
and after
						scrsymface=scrsymface+1;;

	scr_sym_face[scrsymface]=numbers[i-2];
						scrsymface=scrsymface+1;

	scr_sym_face[scrsymface]=numbers[i-1];
						scrsymface=scrsymface+1;
						}

	scr_sym_face[scrsymface]=numbers[i];
					scrsymface=scrsymface+1;
					if (g!=11)
						i=i+1;
					if (g==11){

	scr_sym_face[scrsymface]=numbers[i+1];
						scrsymface=scrsymface+1;

	scr_sym_face[scrsymface]=numbers[i+2];
						scrsymface=scrsymface+1;

	scr_sym_face[scrsymface]=numbers[i+3];
						scrsymface=scrsymface+1;
						i=i+1;}
				}
				for (int p = 0; p<12; p++){
					if (p==0){

	same_face2[sameface2]=numbers[i-3];//take three TR before
and after
						sameface2=sameface2+1;;

	same_face2[sameface2]=numbers[i-2];
						sameface2=sameface2+1;

	same_face2[sameface2]=numbers[i-1];
						sameface2=sameface2+1;
						}

	same_face2[sameface2]=numbers[i];
					sameface2=sameface2+1;
					if (p!=11)
						i=i+1;
					if (p==11){

	same_face2[sameface2]=numbers[i+1];
						sameface2=sameface2+1;

	same_face2[sameface2]=numbers[i+2];
						sameface2=sameface2+1;
```

```
      same_face2[sameface2]=numbers[i+3];
                                          sameface2=sameface2+1;
                                          i=i+1;}
                                }
                                for (int o = 0; o<12; o++){
                                      if (o==0){

      sym_face[symface]=numbers[i-3];//take three TR before and
after
                                          symface=symface+1;;

      sym_face[symface]=numbers[i-2];
                                          symface=symface+1;

      sym_face[symface]=numbers[i-1];
                                          symface=symface+1;
                                          }
                                      sym_face[symface]=numbers[i];
                                      symface=symface+1;
                                      if (o!=11)
                                          i=i+1;
                                      if (o==11){

      sym_face[symface]=numbers[i+1];
                                          symface=symface+1;

      sym_face[symface]=numbers[i+2];
                                          symface=symface+1;

      sym_face[symface]=numbers[i+3];
                                          symface=symface+1;
                                          i=i+1;}
                                }
                          //}
                          //if (i>375) break;
                    }
            }//get out from while (i<4400)
      //start flick pause

            try {
                System.out.println("written to the file");
                BufferedWriter out = new BufferedWriter(new
FileWriter(fileName[fn] + "-scr_orig_face"));
                BufferedWriter out2 = new BufferedWriter(new
FileWriter(fileName[fn] + "-same_face"));
                BufferedWriter out3 = new BufferedWriter(new
FileWriter(fileName[fn] + "-dif_faces"));
                BufferedWriter out4 = new BufferedWriter(new
FileWriter(fileName[fn] + "-scr_sym_face"));
                BufferedWriter out5 = new BufferedWriter(new
FileWriter(fileName[fn] + "-same_face_2"));
                BufferedWriter out6 = new BufferedWriter(new
FileWriter(fileName[fn] + "-sym_face"));


            for (int h=0; h<216; h++){
                  System.out.println(h);
                          out.write(scr_orig_face[h] + "\n");
                          out2.write(same_face[h] + "\n");
                          out3.write(dif_faces[h] + "\n");
```

```
                    out4.write(scr_sym_face[h] + "\n");
                    out5.write(same_face2[h] + "\n");
                    out6.write(sym_face[h] + "\n");
          }
                    out.close();
                    out2.close();
                    out3.close();
                    out4.close();
                    out5.close();
                    out6.close();
     j = 0;
     i = 0;
     n = 0;
     s = 0;
     m = 0;
     scrorigface=0;
     sameface=0;
     sameface2=0;
     diffaces=0;
     scrsymface=0;
     symface=0;

      } catch (IOException e) {
      }
    }
  /*  catch (FileNotFoundException ex) {
      ex.printStackTrace();
    }
    catch (IOException ex) {
      ex.printStackTrace();
    }*/
    catch (NumberFormatException nfe) {
      System.out.println("number format exception");
    }
    finally {
      try {
      if (br != null)
        br.close();
      }
      catch (IOException ex) {
      ex.printStackTrace();
      }
    }
  }//for filenames close
 }

/*  public static void main(String[] args) {
    pickup test = new pickup();
    test.reasamefaceile();
  }*/
}
```

lineSeperator.java

//takes a text file where every line has a single value and put them in groups of 18 in every line. This operation is necessary for the Grace software to generate graphs.

```
import java.io.BufferedReader;
```

```
import java.io.BufferedWriter;
import java.io.FileReader;
import java.io.FileWriter;
import java.io.FileNotFoundException;
import java.io.IOException;
import java.util.Random;
import java.lang.Long;
import java.io.InputStream;
import static java.lang.Math.*;

import java.util.*;

public class lineSeperator {

  public static void main(String[] args) {

    BufferedReader br = null;
    double[] numbers = new double[50000];
    String[] fileNameArr = new String[160];
    long temp =0;
    int clusterNo = 18; //# of numbers exist in a line
    int j = 0;
    int i = 0;
    int n = 0;
    int s = 0;
    int sf=0;
    int df=0;
    int sb=0;
    int db=0;
    int limit, pause;
    int randomInt, randomInt2, randomInt3;

    fileNameArr[0] = "fs003_LH-percentage-dif_faces";
    fileNameArr[1] = "fs003_LH-percentage-same_face";
    fileNameArr[2] = "fs003_LH-percentage-same_face_2";
    fileNameArr[3] = "fs003_LH-percentage-scr_orig_face";
    fileNameArr[4] = "fs003_LH-percentage-scr_sym_face";
    fileNameArr[5] = "fs003_LH-percentage-sym_face";
    fileNameArr[6] = "fs003_RH-percentage-dif_faces";
    fileNameArr[7] = "fs003_RH-percentage-same_face";
    fileNameArr[8] = "fs003_RH-percentage-same_face_2";
    fileNameArr[9] = "fs003_RH-percentage-scr_orig_face";
    fileNameArr[10] = "fs003_RH-percentage-scr_sym_face";
    fileNameArr[11] = "fs003_RH-percentage-sym_face";


    //String fileName = "flick_R6_V4-percentage-dynamic_front-
dynamic_front";
    for(int ef=0;ef<12;ef++){
    try {

/*      br = new BufferedReader(new FileReader(fileName));
      String line = null;

      while ((line = br.readLine()) != null) {

        String[] values = line.split("\n");

        //Do necessary work with the values, here we just print
them out
```

```
        for (String str : values) {
            numbers[j] = Long.parseLong(str.trim());
              //System.out.println(numbers[j]);
            j++;
        }
       }*/

          String fileName = fileNameArr[ef];

          InputStream task =
lineSeperator.class.getResourceAsStream(fileName);
          Scanner sc = new Scanner(task);
          while (sc.hasNext()) {
            numbers[s]=sc.nextDouble();
            s++;
          }
//System.out.println("0");
            try {
                System.out.println("written to the file");
                BufferedWriter out = new BufferedWriter(new
FileWriter(fileName + "-line-seperated"));

            for (int a = 0; a<(s/clusterNo); a++){
                  for (int b = 0; b<clusterNo; b++){
                        out.write(numbers[i] + " ");
                        i=i+1;
                  }
                        out.write("\n");
            }
                out.close();
                i=0;
                s=0;

            } catch (IOException e) {
            }
          }
      /*    catch (FileNotFoundException ex) {
            ex.printStackTrace();
          }
          catch (IOException ex) {
            ex.printStackTrace();
          }*/
          catch (NumberFormatException nfe) {
            System.out.println("number format exception");
          }
    finally {
      try {
        if (br != null)
          br.close();
      }
      catch (IOException ex) {
        ex.printStackTrace();
      }
    }
    }//for fileNameArr[29] close
  }

/*  public static void main(String[] args) {
    pickup test = new pickup();
    test.readFile();
```

```
  }*/
}
```

taskGenerator.java

//generates a random task from the images in the database by writing the order of the stimulus in the array into a text file

```
import java.io.BufferedReader;
import java.io.BufferedWriter;
import java.io.FileReader;
import java.io.FileWriter;
import java.io.FileNotFoundException;
import java.io.IOException;
import java.util.Random;


public class taskGenerator {

  public void readFile() {

    BufferedReader br = null;
    int[] numbers = new int[4400];
    int j = 0;
    int i = 0;
    int n = 0;
    int s = 0; //skipping line
    int limit, pause;
    int randomInt, randomInt2, randomInt3;

    try {

      br = new BufferedReader(new FileReader("dene.txt"));
      String line = null;

      while ((line = br.readLine()) != null) {

        String[] values = line.split("\n");

        //Do necessary work with the values, here we just print
them out
        for (String str : values) {
            numbers[j] = Integer.parseInt(str.trim());
              //System.out.println(numbers[j]);
            j++;
        }
       }

      while (i<4400){
            for (int a = 0; a<20; a++){
            i = i+1;
            }
            Random randomGenerator = new Random();
            randomInt = randomGenerator.nextInt(6);
            //System.out.println("0-6 "+randomInt);
            for (int p = 0; p<randomInt; p++) {
                  i++;

            }
            Random randomGenerator2 = new Random();
```

```
            randomInt2 = randomGenerator2.nextInt(2);
            //System.out.println("0-1 "+randomInt2);
            for (int k=0; k<4; k++) {
                  if (i>=4400)//prevents outofArrayIndex exception
                        break;
                  i++;
                  if(randomInt2 == 0){
                        if(numbers[i]==1){
                              numbers[i]=11;
                              }
                        if(numbers[i]==2){
                              numbers[i]=21;
                              }
                        if(numbers[i]==3){
                              numbers[i]=31;
                              }
                        if(numbers[i]==4){
                              numbers[i]=41;
                              }
                        if(numbers[i]==5){
                              numbers[i]=51;
                              }
                        if(numbers[i]==6){
                              numbers[i]=61;
                              }
                        if(numbers[i]==7){
                              numbers[i]=71;
                              }
                        if(numbers[i]==8){
                              numbers[i]=81;
                              }
                  }
                  if(randomInt2 == 1){
                        if(numbers[i]==1){
                              numbers[i]=12;
                              }
                        if(numbers[i]==2){
                              numbers[i]=22;
                              }
                        if(numbers[i]==3){
                              numbers[i]=32;
                              }
                        if(numbers[i]==4){
                              numbers[i]=42;
                              }
                        if(numbers[i]==5){
                              numbers[i]=52;
                              }
                        if(numbers[i]==6){
                              numbers[i]=62;
                              }
                        if(numbers[i]==7){
                              numbers[i]=72;
                              }
                        if(numbers[i]==8){
                              numbers[i]=82;
                              }
                  }
            }
      }//get out from while (i<4400)
```

```
int s2=0;
s = s+200;
for (int fx = 0 ; fx < 10; fx++) {
      s2 = s + 200; //interval
      while (s < s2) {
            if ((s2-s)>70){
                  s = s + 70;
                  Random randomGenerator3 = new Random();
                  randomInt3 = randomGenerator3.nextInt(60);
                  if ((s2-s) > randomInt3) {
                        s = s+randomInt3;
                        if ((s2-s) >= 5){
                              if (numbers[s]==2) {
                                    for (int p=0; p<5; p++){
                                          s = s+1;
                                          numbers[s] = 20;
                                    }
                              }
                              else if (numbers[s]==3) {
                                    for (int p=0; p<5; p++){
                                          s = s+1;
                                          numbers[s] = 30;
                                    }
                              }
                              else if (numbers[s]==5) {
                                    for (int p=0; p<5; p++){
                                          s = s+1;
                                          numbers[s] = 50;
                                    }
                              }
                              else if (numbers[s]==6) {
                                    for (int p=0; p<5; p++){
                                          s = s+1;
                                          numbers[s] = 60;
                                    }
                              }
                              else if (numbers[s]==21) {
                                    for (int p=0; p<5; p++){
                                          s = s+1;
                                          numbers[s] = 210;
                                    }
                              }
                              else if (numbers[s]==22) {
                                    for (int p=0; p<5; p++){
                                          s = s+1;
                                          numbers[s] = 220;
                                    }
                              }
                              else if (numbers[s]==31) {
                                    for (int p=0; p<5; p++){
                                          s = s+1;
                                          numbers[s] = 310;
                                    }
                              }
                              else if (numbers[s]==32) {
                                    for (int p=0; p<5; p++){
                                          s = s+1;
                                          numbers[s] = 320;
                                    }
                              }
```

```
                else if (numbers[s]==51) {
                        for (int p=0; p<5; p++){
                                s = s+1;
                                numbers[s] = 510;
                        }
                }
                else if (numbers[s]==52) {
                        for (int p=0; p<5; p++){
                                s = s+1;
                                numbers[s] = 520;
                        }
                }
                else if (numbers[s]==61) {
                        for (int p=0; p<5; p++){
                                s = s+1;
                                numbers[s] = 610;
                        }
                }
                else if (numbers[s]==62) {
                        for (int p=0; p<5; p++){
                                s = s+1;
                                numbers[s] = 620;
                        }
                }
        }
        else {
                if (numbers[s]==2) {
                        for (int p=0; p<(s2-s); p++){
                                s = s+1;
                                numbers[s] = 20;
                        }
                }
                else if (numbers[s]==3) {
                        for (int p=0; p<(s2-s); p++){
                                s = s+1;
                                numbers[s] = 30;
                        }
                }
                else if (numbers[s]==5) {
                        for (int p=0; p<(s2-s); p++){
                                s = s+1;
                                numbers[s] = 50;
                        }
                }
                else if (numbers[s]==6) {
                        for (int p=0; p<(s2-s); p++){
                                s = s+1;
                                numbers[s] = 60;
                        }
                }
                else if (numbers[s]==21) {
                        for (int p=0; p<(s2-s); p++){
                                s = s+1;
                                numbers[s] = 210;
                        }
                }
                else if (numbers[s]==22) {
                        for (int p=0; p<(s2-s); p++){
                                s = s+1;
                                numbers[s] = 220;
```

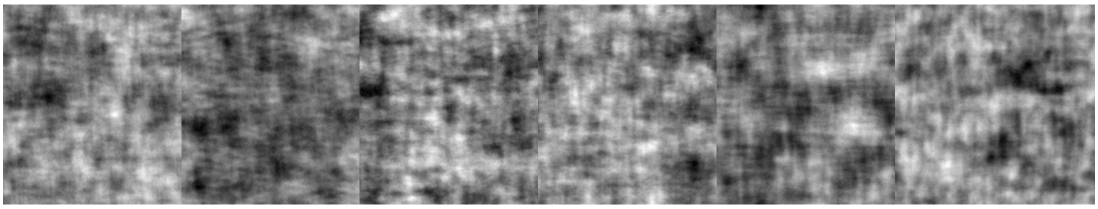
```
                        }
                    }
                    else if (numbers[s]==31) {
                        for (int p=0; p<(s2-s); p++){
                            s = s+1;
                            numbers[s] = 310;
                        }
                    }
                    else if (numbers[s]==32) {
                        for (int p=0; p<(s2-s); p++){
                            s = s+1;
                            numbers[s] = 320;
                        }
                    }
                    else if (numbers[s]==51) {
                        for (int p=0; p<(s2-s); p++){
                            s = s+1;
                            numbers[s] = 510;
                        }
                    }
                    else if (numbers[s]==52) {
                        for (int p=0; p<(s2-s); p++){
                            s = s+1;
                            numbers[s] = 520;
                        }
                    }
                    else if (numbers[s]==61) {
                        for (int p=0; p<(s2-s); p++){
                            s = s+1;
                            numbers[s] = 610;
                        }
                    }
                    else if (numbers[s]==62) {
                        for (int p=0; p<(s2-s); p++){
                            s = s+1;
                            numbers[s] = 620;
                        }
                    }
                }
            }
            else {
                s=s2;
            }
        }
        else {
            s=s2; // saturation
        }
    }
    if (fx!= 10)
        s=s+240;
}
//flick pause finish

    try {
        System.out.println("written to the file");
        BufferedWriter out = new BufferedWriter(new
FileWriter("yaz"));
    for (int f=0; f<4400; f++)
        out.write(numbers[f] + "\n");
        out.close();
```

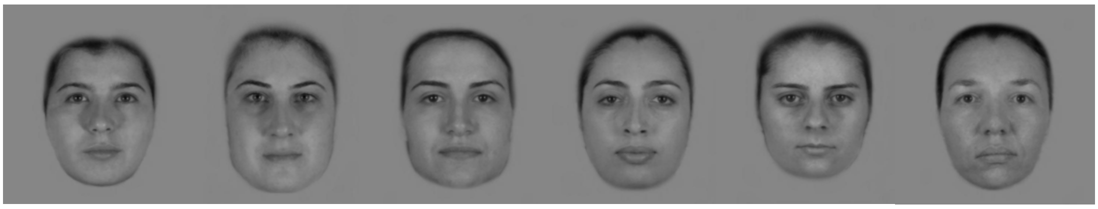
```
      } catch (IOException e) {
      }
    }
    catch (FileNotFoundException ex) {
      ex.printStackTrace();
    }
    catch (IOException ex) {
      ex.printStackTrace();
    }
    finally {
      try {
        if (br != null)
          br.close();
      }
      catch (IOException ex) {
        ex.printStackTrace();
      }
    }
  }

  public static void main(String[] args) {
    taskGenerator test = new taskGenerator();
    test.readFile();
  }
}
```

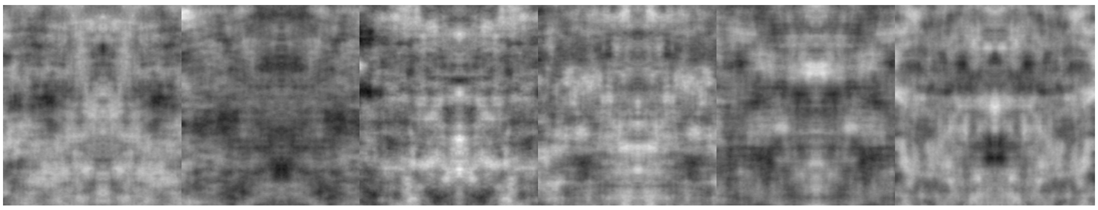
APPENDIX B: ALL STIMULUS USED IN THE EXPERIMENT

Run 1

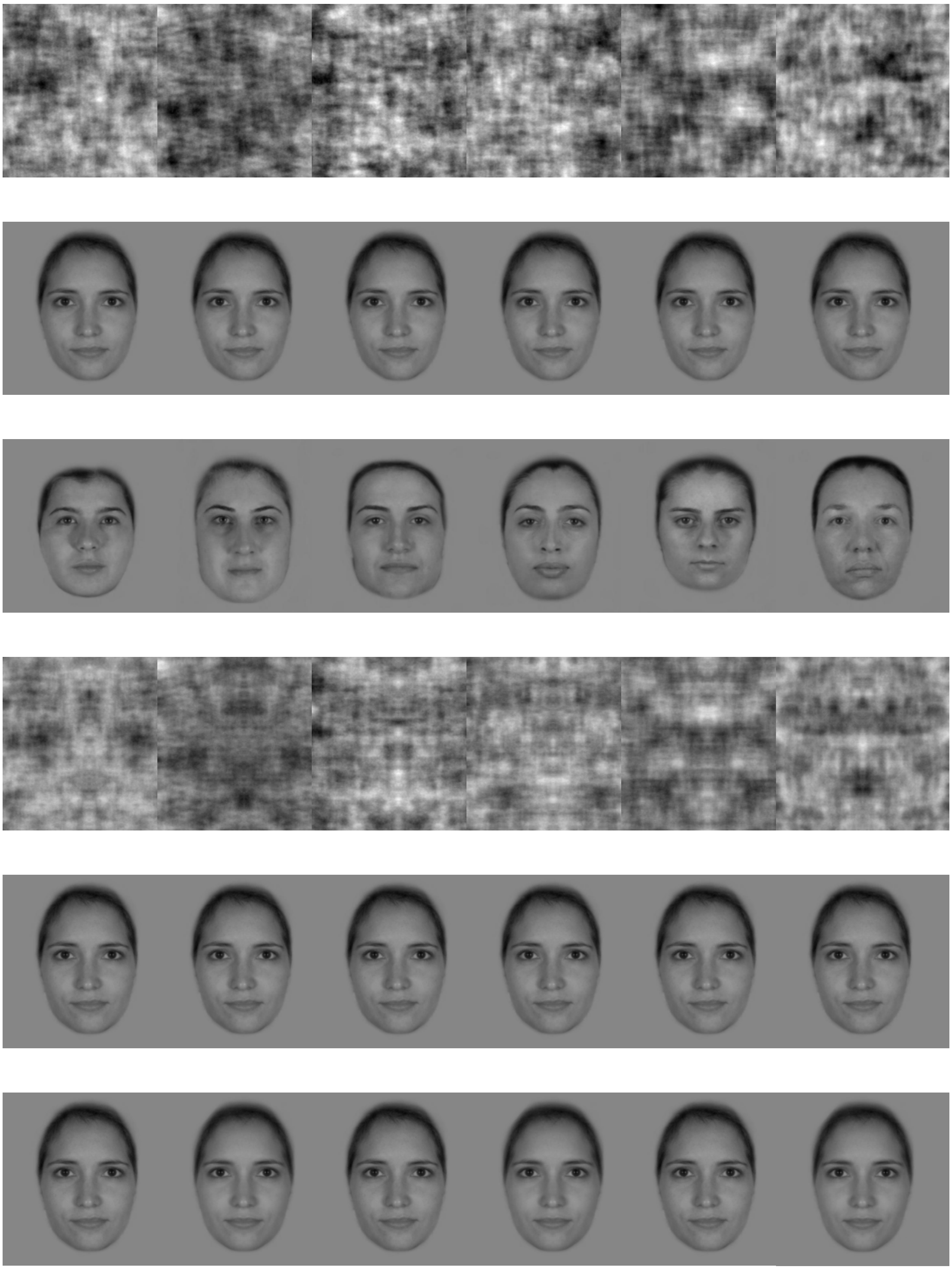
Repetition 1



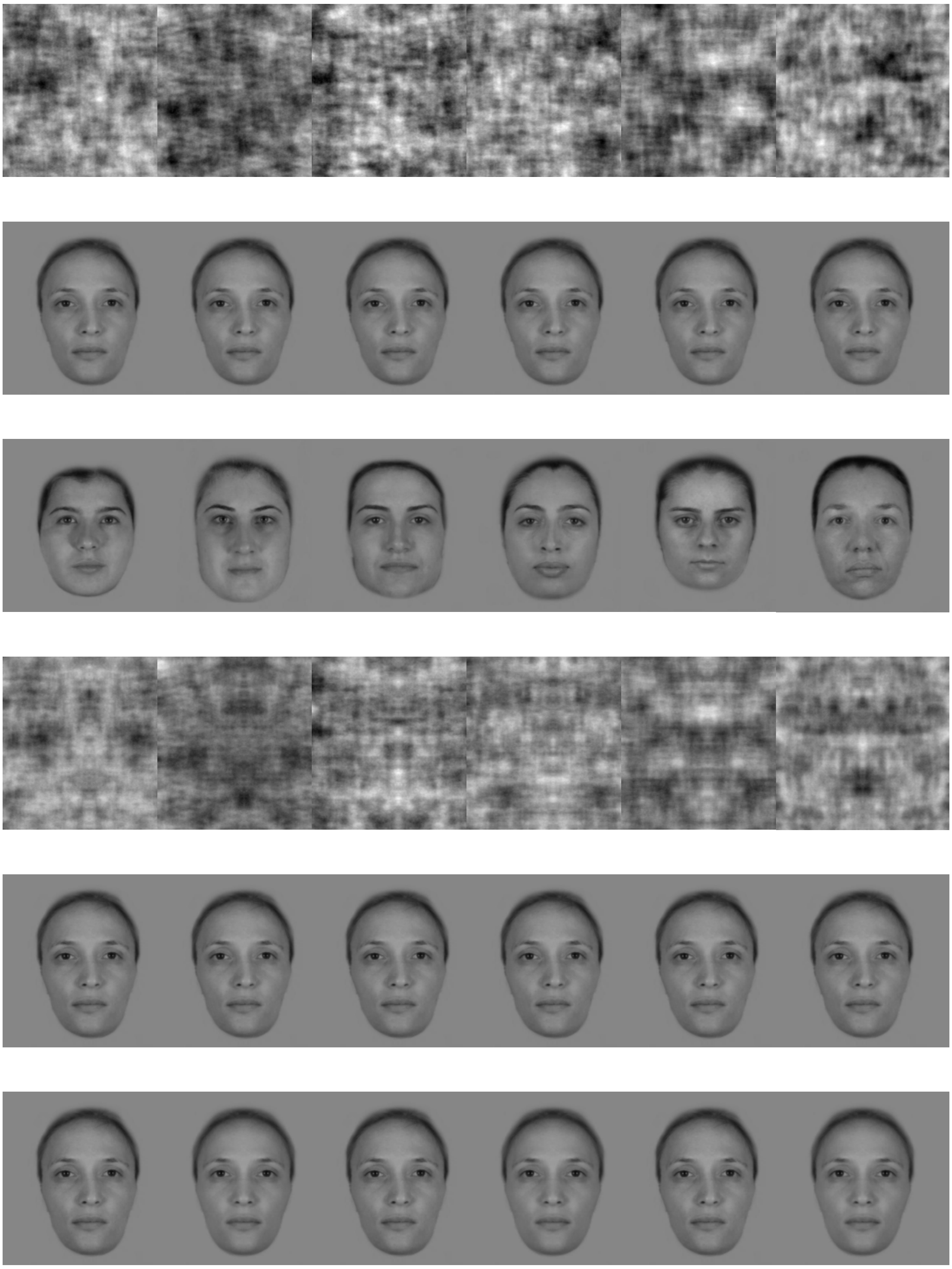




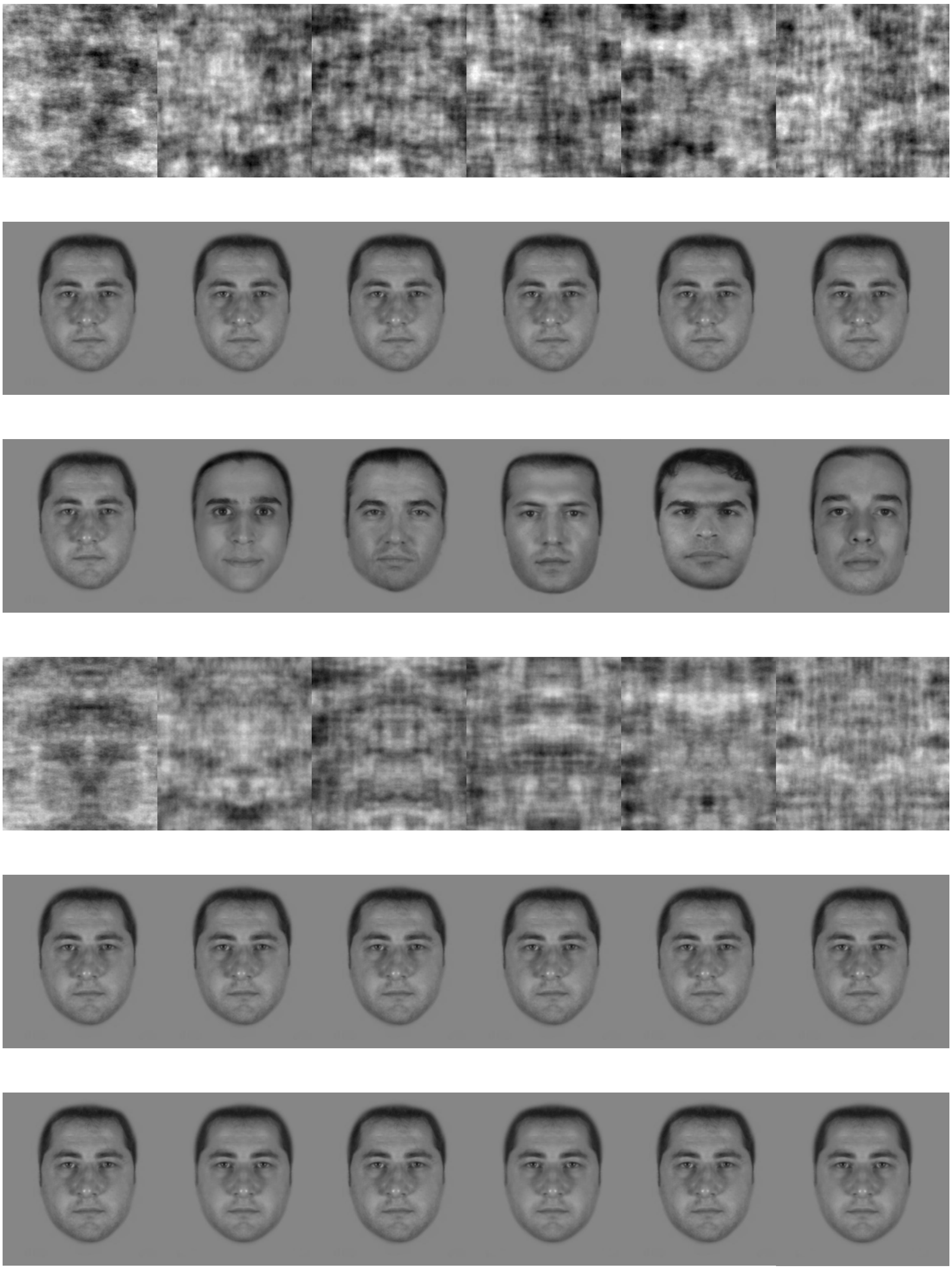
Repetition 2



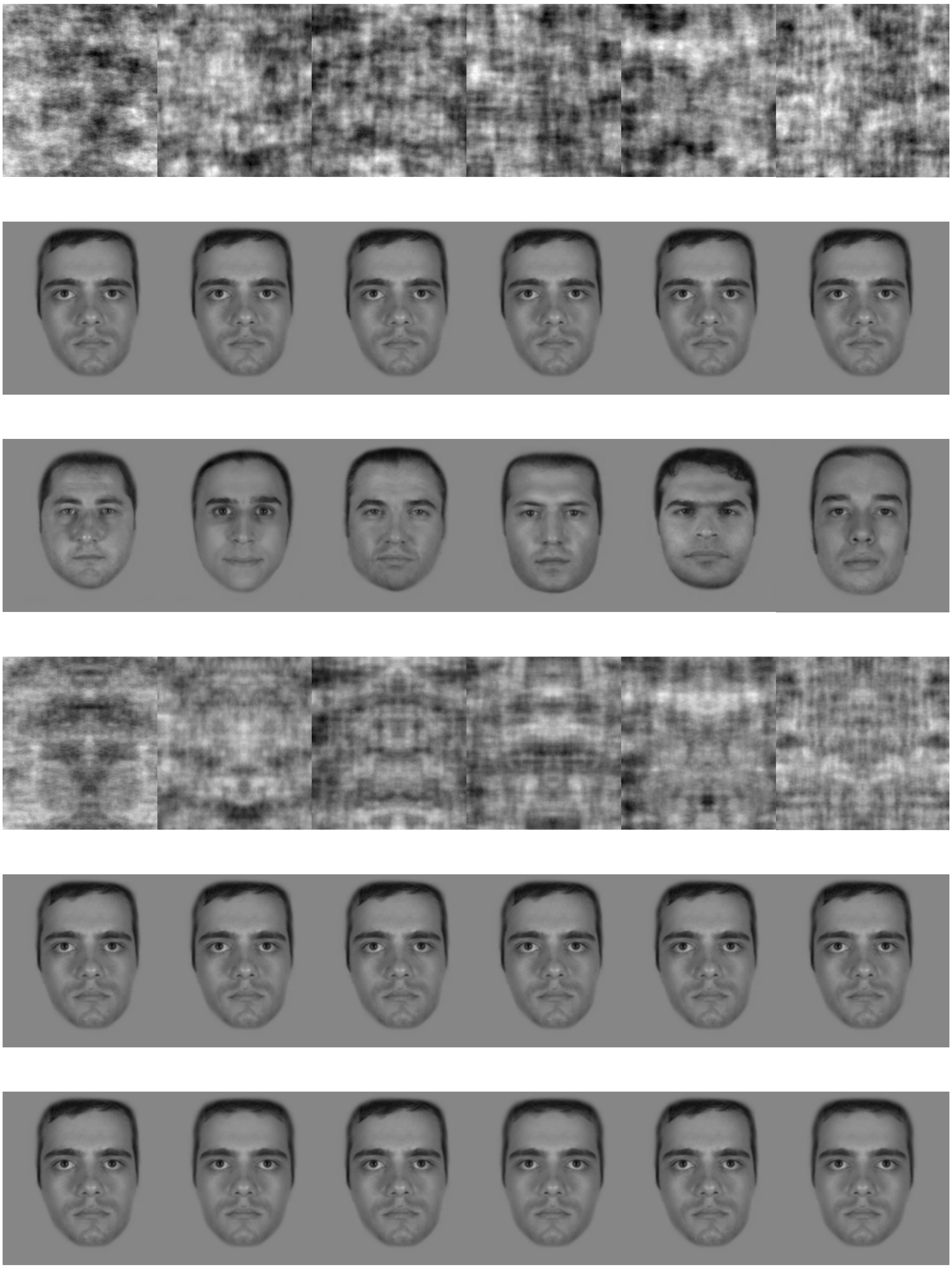
Repetition 3



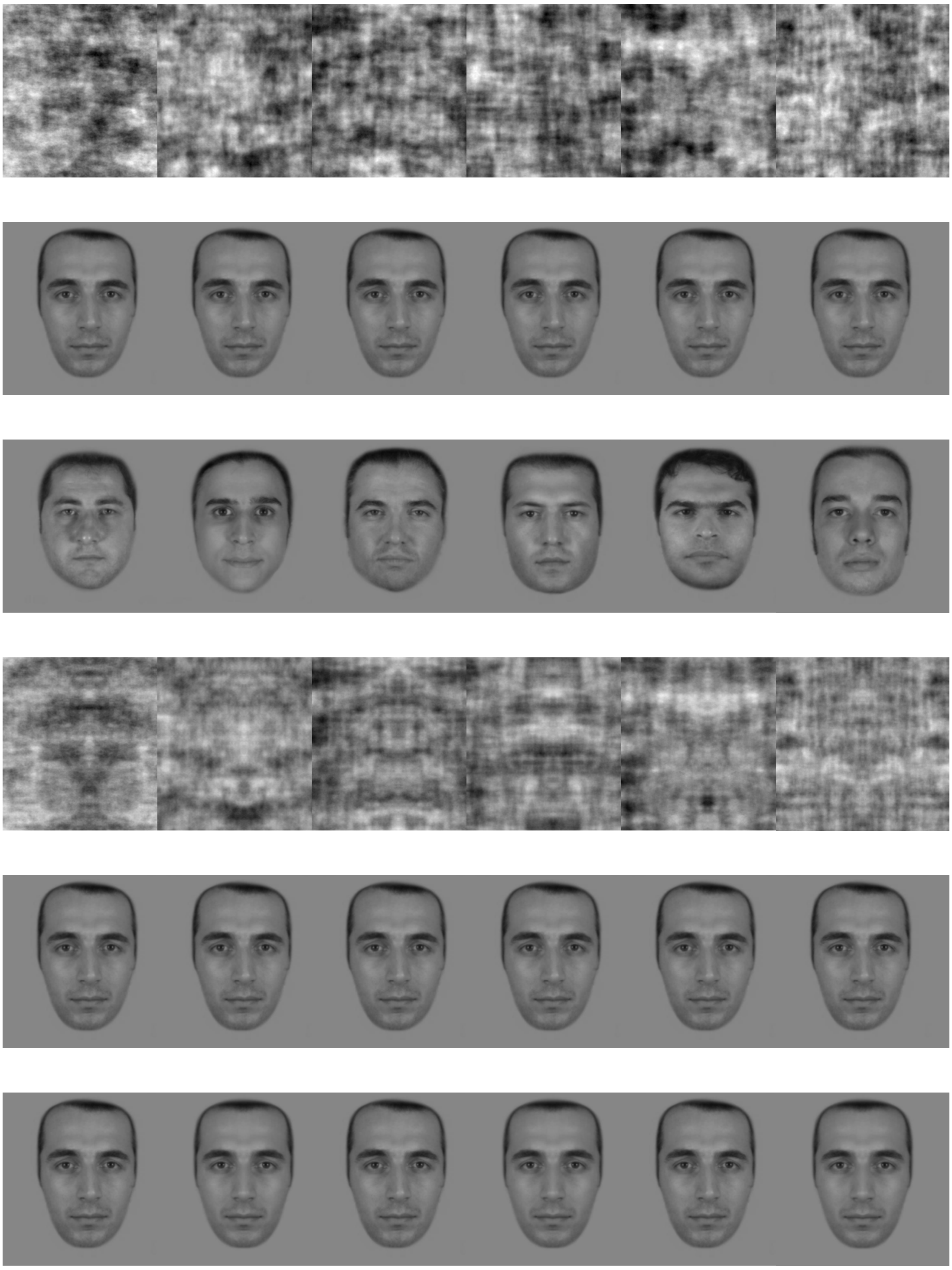
Run 2
Repetition 1



Repetition 2

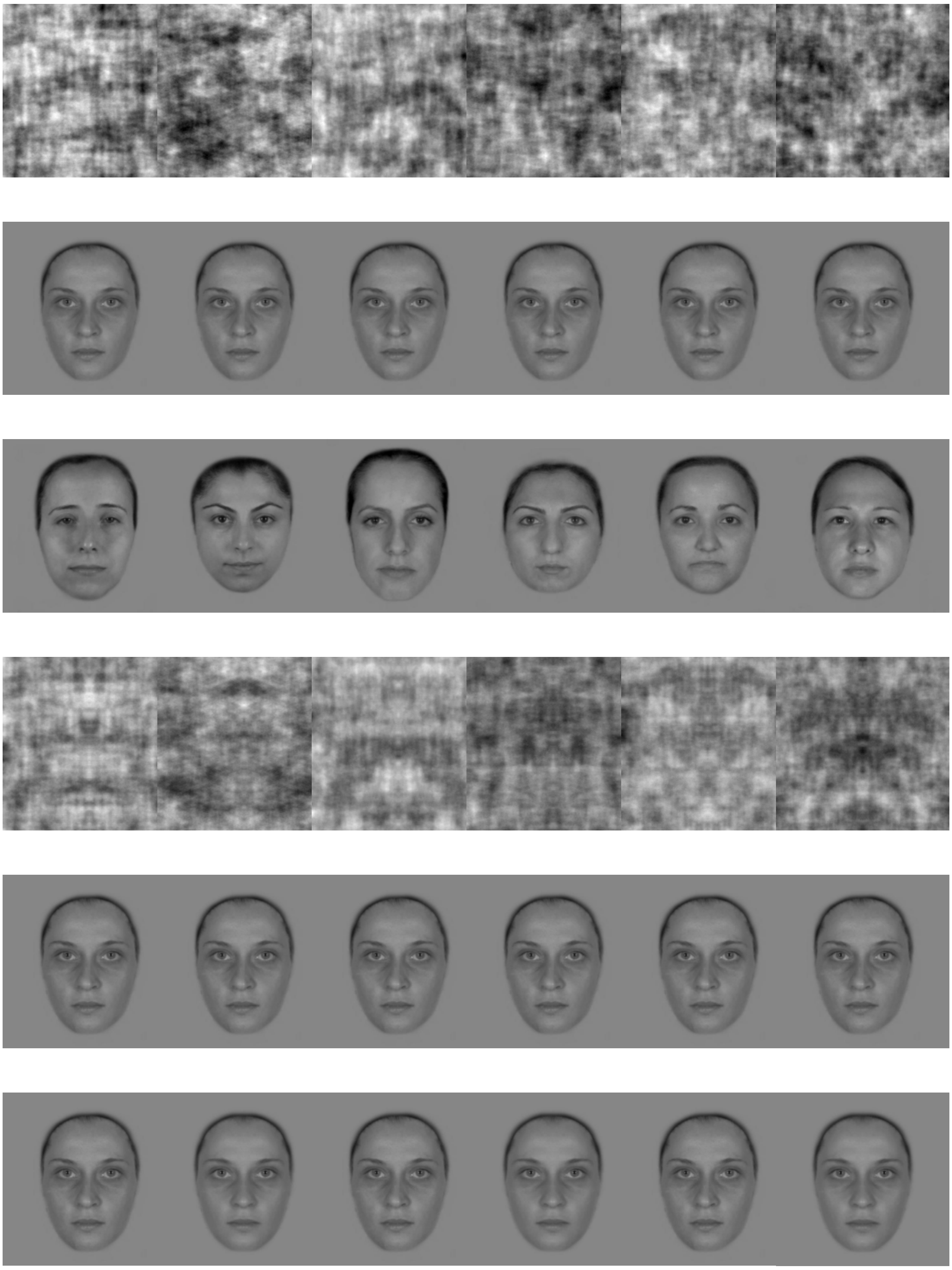


Repetition 3

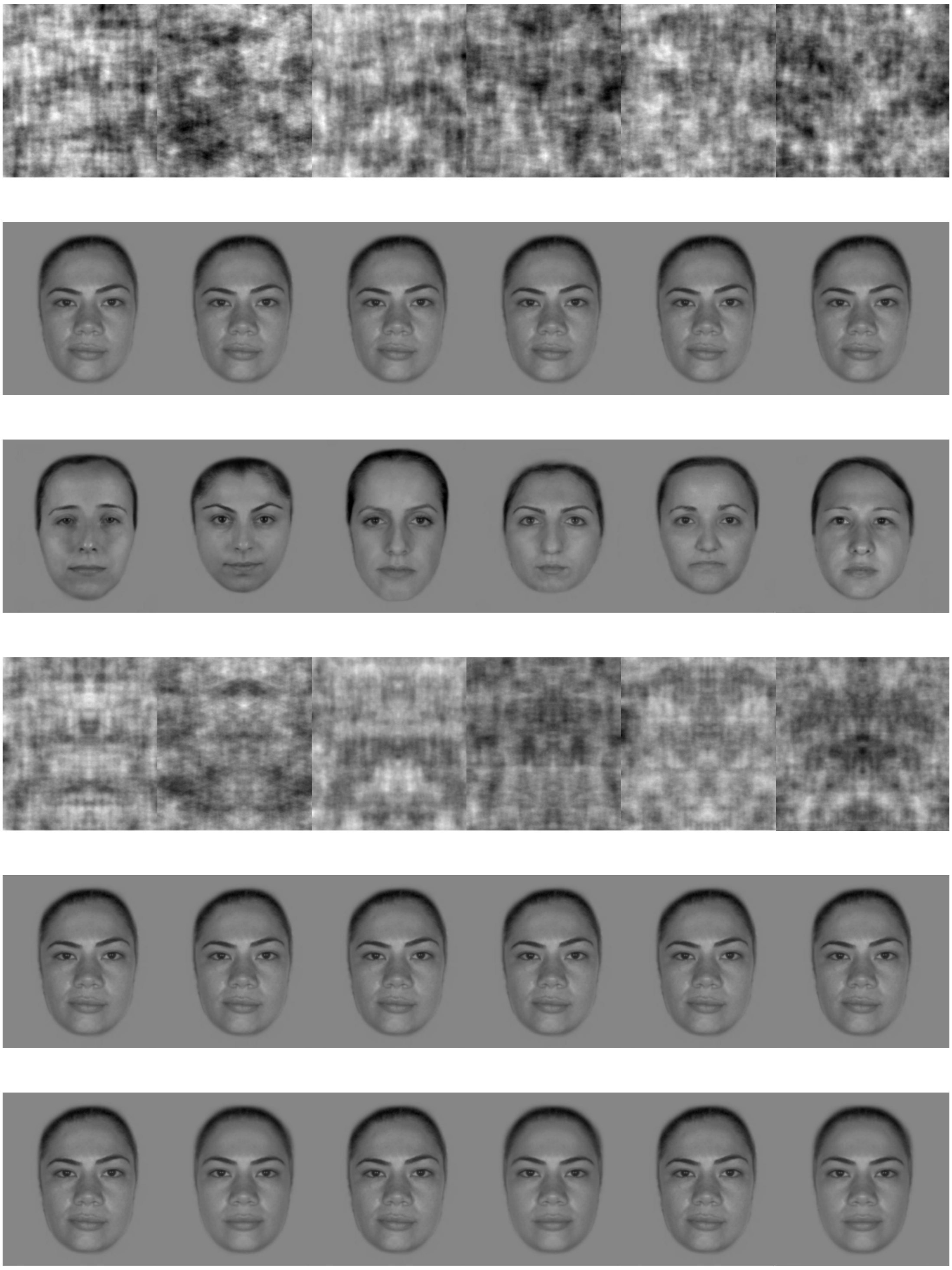


Run 3
Repetition 1

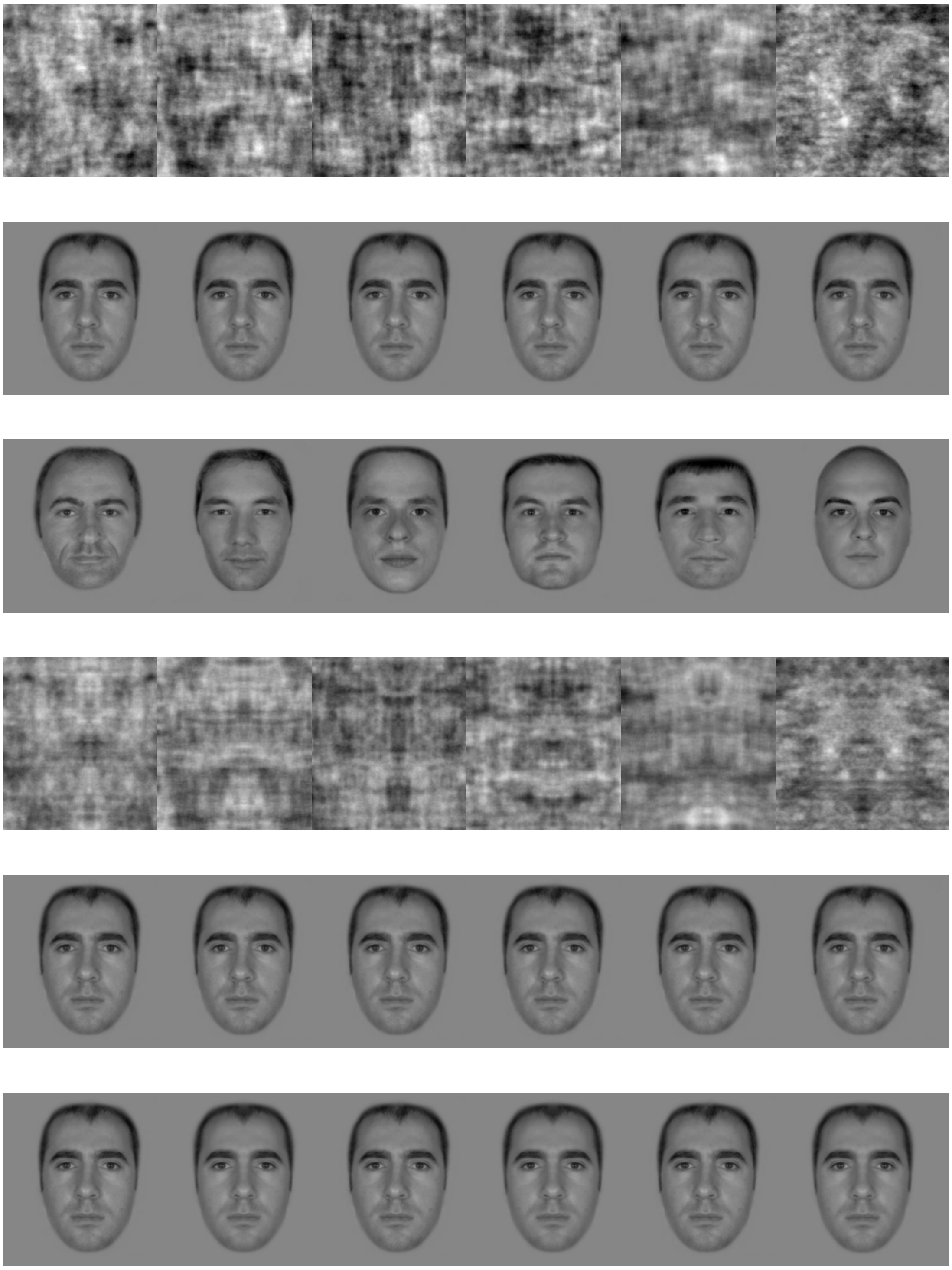
Repetition 2



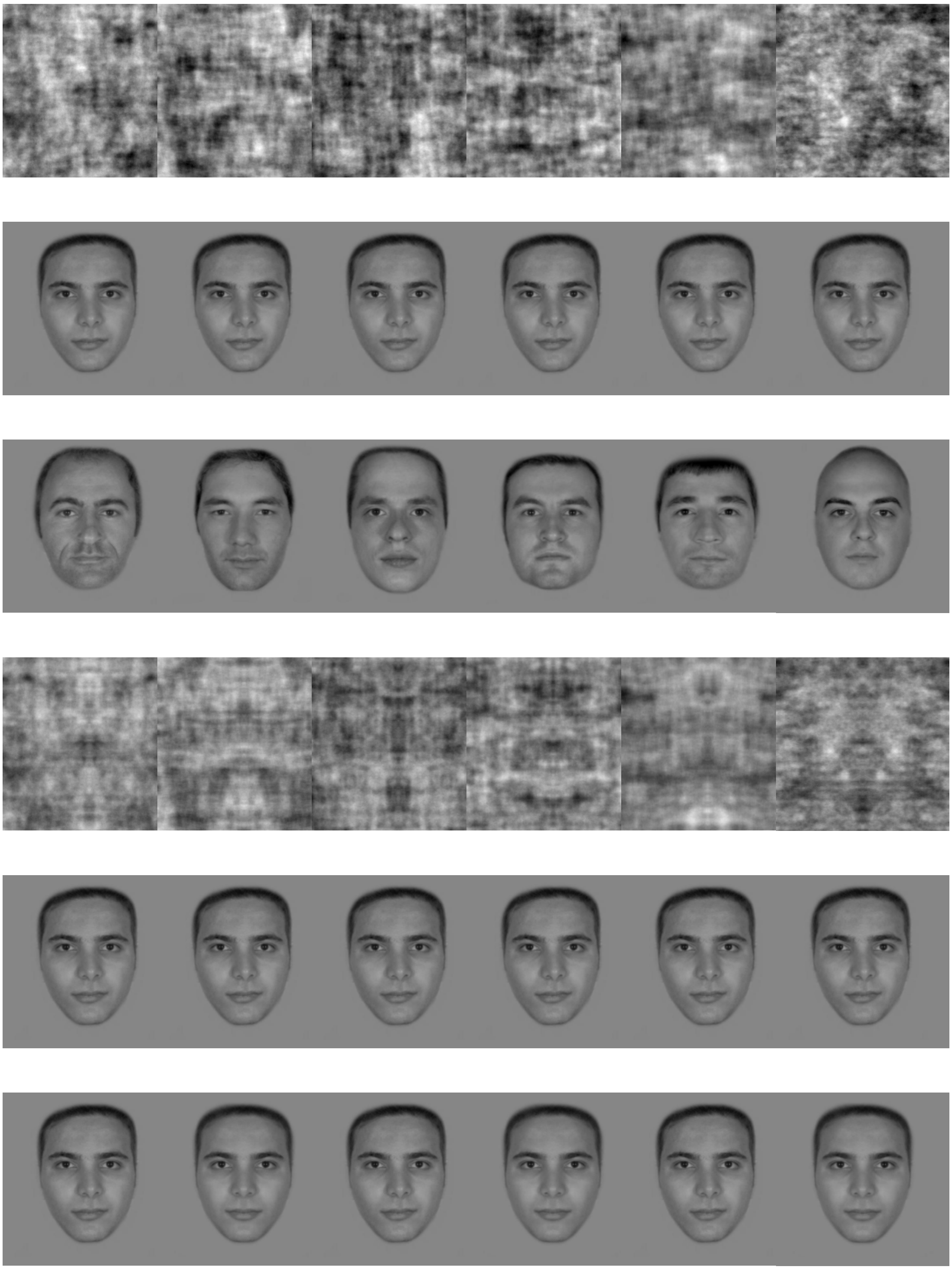
Repetition 3



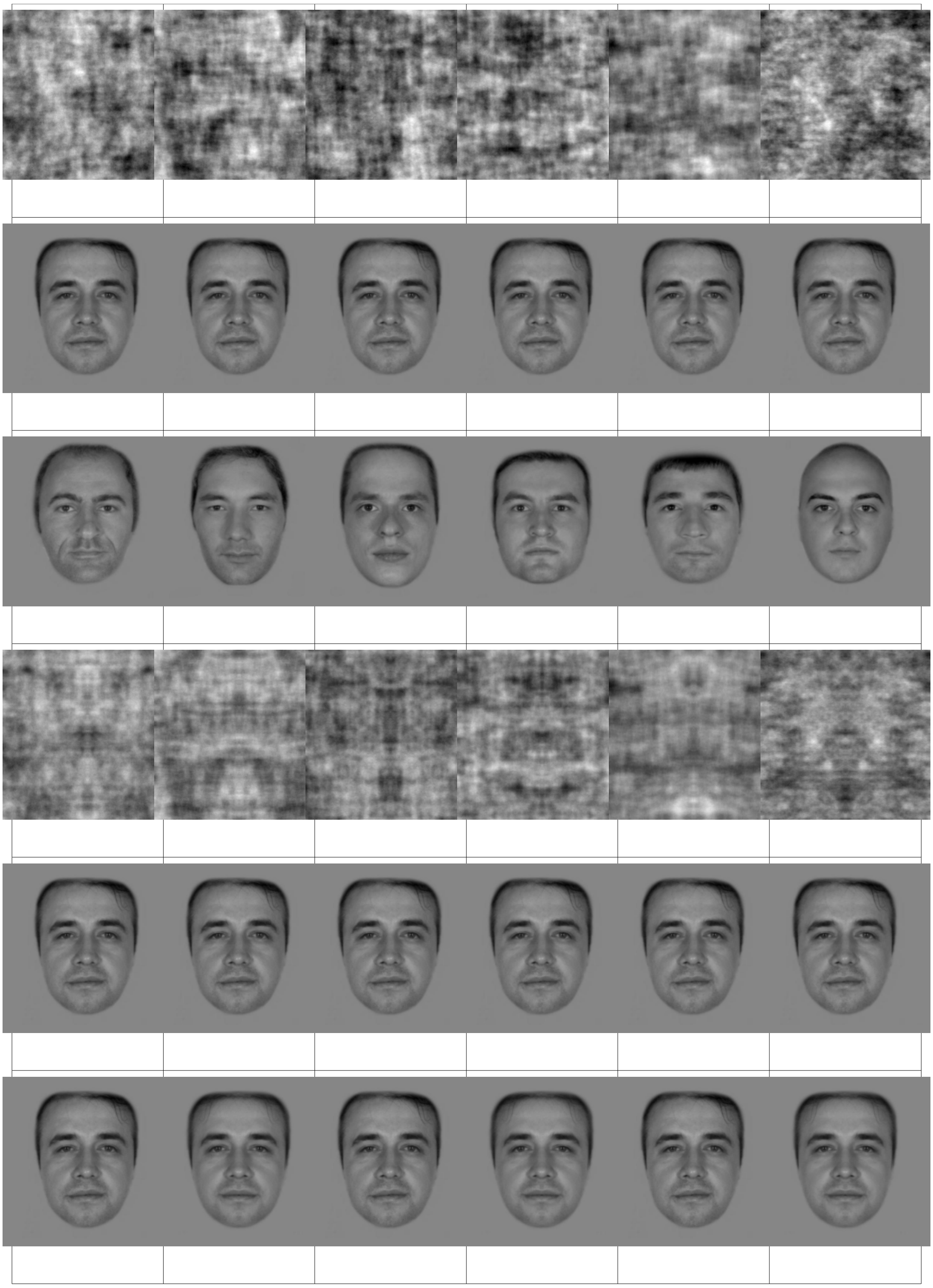
Run 4
Repetition 1



Repetitition 2



Repetition 3



APPENDIX C: WRITTEN CONSENT FORM

BİLGİLENDİRİLMİŞ GÖNÜLLÜ OLUR FORMU

Araştırmanın adı: FONKSİYONEL MAGNETİK REZONANS GÖRÜNTÜLEME İLE YÜZ SİMETRİSİ ALGISININ ANALİZİ

Sorumlu araştırmacı: Yard. Doç. Dr. Didem Gökçay

Araştırmanın yapılacağı yer: ODTÜ Enformatik Enstitüsü, Bilkent UMRAM MR Merkezi

Orta Doğu Teknik Üniversitesi Enformatik Enstitüsü Bilişsel Bilimler bölümü yüksek lisans öğrencisi Funda Yıldırım tarafından, yine Orta Doğu Teknik Üniversitesi Enformatik Enstitüsü Öğretim Üyelerinden Yrd. Doç. Dr. Didem Gökçay'ın danışmanlığındaki yüksek lisans tezi kapsamında, yüz algılama sırasında ortaya çıkan beyin aktivitesini değerlendirmek için planlanan bu araştırma projesine katılmak için davet edilmektesiniz. Çalışma sadece sağlıklı yetişkinleri kapsamaktadır ve çalışmaya 30 gönüllü katılacaktır.

Beyin görüntülemesi UMRAM MR Merkezi'nde bulunan ve beyin kan akımını ölçmeye yarayan MR cihazı yardımıyla yapılacaktır ve herhangi bir potansiyel risk içermemektedir. MR cihazında bilindiği üzere, herhangi bir radyoaktif madde ya da X-ışını kullanılmaz, klinik olarak günlük hayatımızda pek çok uygulamaları vardır.

Katılımcılardan yatar pozisyonda başlarına bir aygıt giydirilerek, MR içerisindeki aynaya yansıtılan görsellere yanıt vermeleri istenmektedir. Deneyde MR cihazı içerisinde gözünüzün yaklaşık 15 cm uzağına bir ayna düzeneği yerleştirilecektir. Bu düzenek sayesinde ekrandan yansıtılan resimleri görebilecek ve değerlendirebileceksiniz. Ekranda peşpeşe yüz resimleri yada karışık gri renkli dikdörtgenler gösterilecektir. Sizden, görmekte olduğunuz resim bir önceki resimle aynı ise sağ, farklı ise sol tuşa basmanız basmanız istenecektir. Bu değerlendirmeyi ekrana gelen her resim için yapmanız gerekecektir.

Bu uygulama yaklaşık olarak 40dk sürecek olup, size herhangi bir fiziksel zarar vermeyecektir. MR çekimi, uygun önlemler alındığı takdirde zararsız bir işlemdir. Ancak hamile olan, kapalı yer korkusu olan, ya da vücudunda metal protez, kalp pili ve benzeri cihazlar bulunan kişilerin MR cihazına girmesi sakıncalıdır. MR çekimi başladığında ritmik sesler duyacaksınız. Personel bu sesi azaltmak için size kulak tıkacı temin edecektir. Cihazın içerisinde, iletişim yapabilmeniz için yerleştirilmiş bir ses sistemi bulunmaktadır. Bu vesileyle teknisyen ile konuşmanız mümkündür. Çekim süresince hiçbir kafa hareketi olmaması gerekmektedir. Öksürme, boğazı temizleyecek şekilde yutkunma gibi hareketler çekim kalitesini düşürdüğünden, bazı çekimlerin tekrarlanması gerekebilir. Bu nedenle mümkün olduğunca kafanızı kıpırdatmamanız gerekmektedir.

Bu çalışmada hakkınızda edinilen tüm bilgiler gizli tutulacak ve sadece araştırmacıların bilgisine sunulacaktır. Bu çalışmadan herhangi bir rapor veya yayın yapılması halinde okuyucuların sizleri tanımasına yol açacak hiçbir kişisel bilgi bulunmayacaktır.

Deney, genel olarak kişisel rahatsızlık verecek unsurlar içermemektedir. Ancak, katılım sırasında herhangi bir nedenden ötürü kendinizi rahatsız hissederseniz yanınızda duracak mikrofona sesli komut vererek deneyi yarıda bırakıp çıkmakta serbestsiniz. Araştırmaya katılımınız tamamıyla gönüllülük çerçevesinde olup, istediğiniz zaman, hiçbir yaptırım veya cezaya maruz kalmadan, hiçbir hak kaybetmeksizin araştırmaya katılmayı reddedebilir veya araştırmadan çekilebilirsiniz. Çalışmaya katılmamayı da seçebilirsiniz.

Deney sonunda, bu çalışmayla ilgili sorularınız cevaplanacaktır. Bu çalışmaya katıldığınız için şimdiden teşekkür ederiz. Çalışma hakkında daha fazla bilgi almak için veya herhangi bir sorunuz olduğunda, ODTÜ Enformatik Enstitüsü Öğretim Üyesi Yrd. Doç. Dr. Didem Gökçay (Oda: A-216, Tel: 03122103750, E-posta: didemgokcay@ii.metu.edu.tr) ile iletişim kurabilirsiniz.

Bilgilendirilmiş Gönüllü Olur Formu'ndaki tüm açıklamaları okudum. Yukarıda konusu ve amacı belirtilen araştırma ile ilgili tüm yazılı ve sözlü açıklama aşağıda adı belirtilen araştırmacı tarafından yapıldı. Bu çalışmaya tamamen gönüllü olarak katılıyorum ve istediğim zaman gerekçeli veya gerekçesiz olarak yarıda kesip çıkabileceğimi veya kendi isteğime bakılmaksızın araştırmacı tarafından araştırma dışı bırakılabileceğimi biliyorum. Verdiğim bilgilerin bilimsel amaçlı yayınlarda isim bilgilerim olmadan kullanılmasını, görüntü kayıtlarıma sadece araştırmacı veya etik kurul tarafından gizli tutulmak kaydıyla erişilebilmesini kabul ediyorum. Kendi özgür irademle, hiçbir baskı ve zorlama olmadan "FONKSİYONEL MAGNETİK

REZONANS GÖRÜNTÜLEME İLE YÜZ SİMETRİSİ ALGISININ ANALİZİ" adlı çalışmaya katılmayı kabul ettiğimi ve bu formun bir kopyasının bana verildiğini aşağıdaki imzamla beyan ederim.

Gönüllü:

Adı Soyadı:	Tarih ----/----/-----	İmza

Adres ve telefon:

Tanıklık Eden Yardımcı Araştırmacı:

Adı Soyadı:	Tarih ----/----/----	İmza

APPENDIX D: VERBAL FEEDBACK OF SUBJECTS ABOUT THE ORIGINAL FACES VERSUS SYMMETRICAL FACES CONDITIONS (cond 5 and cond 6)

FS002:	'Some facial features has changed.'
FS003:	'Some facial features has changed.'
FS004:	Symmetry aspect detected
FS005:	Symmetry aspect detected
FS006:	Symmetric faces differ from originals (realized only in later stages of the task)
FS007:	'Head orientation change. Hair shape change.'
FS008:	'Attractiveness changing in sym vs orig. The disoriented nose being fixed. Beard getting clean'
FS009:	'Faces getting blurry.' Symmetry aspect detected.
FS010:	'Disoriented nose getting fixed'
FS011:	'Spots disappearing.' Thought images were made symmetric by copying one part to the other.
FS012:	Thought they were mirror images
FS013:	Symmetry aspect detected. 'Faces are getting disoriented on purpose. Hair, mouth and nose are changing.'
FS014:	Symmetry aspect detected
FS015:	Symmetry aspect detected

APPENDIX E: ETHICAL COMMITTEE APPROVAL

ANKARA ÜNİVERSİTESİ TIP FAKÜLTESİ KLİNİK ARAŞTIRMALAR ETİK KURUL KARARI

BAŞVURU BİLGİLERİ	ARAŞTIRMANIN AÇIK ADI	Fonksiyonel magnetik rezonans görüntüleme ile yüz simetrisi algısının analizi			
	ARAŞTIRMA PROTOKOL KODU				
	KOORDİNATÖR/SORUMLU ARAŞTIRMACI UNVANI/ADI/SOYADI	Yrd.Doç.Dr.Didem Gökçay			
	KOORDİNATÖR/SORUMLU ARAŞTIRMACININ UZMANLIK ALANI	Bilgisayar Enformasyon Bilimi ve Mühendisliği			
	KOORDİNATÖR/SORUMLU ARAŞTIRMACININ BULUNDUĞU MERKEZ	ODTÜ Enformatik Enstitüsü Bilişsel Bilimler Bölümü			
	DESTEKLEYİCİ				
	DESTEKLEYİCİNİN YASAL TEMSİLCİSİ				
	ARAŞTIRMANIN FAZI	FAZ 1	☐		
		FAZ 2	☐		
		FAZ 3	☐		
		FAZ 4	☐		
	ARAŞTIRMANIN TÜRÜ	Yeni Bir Endikasyon	☐		
		Yüksek Doz Araştırması	☐		
		Diğer ise belirtiniz: Laboratuar Tarama Çalışması			
	ARAŞTIRMAYA KATILAN MERKEZLER	TEK MERKEZ ☐	ÇOK MERKEZLİ ☒	ULUSAL ☒	ULUSLARARASI ☐

Hasan TUNA
A. Ü. Tıp Fakültesi
İdari Personel Bürosu Şefi

DEĞERLENDİRİLEN BELGELER	Belge Adı	Tarihi	Versiyon Numarası	Dili
	ARAŞTIRMA PROTOKOLÜ			Türkçe ☐ İngilizce ☐ Diğer ☐
	BİLGİLENDİRİLMİŞ GÖNÜLLÜ OLUR FORMU			Türkçe ☐ İngilizce ☐ Diğer ☐
	OLGU RAPOR FORMU			Türkçe ☐ İngilizce ☐ Diğer ☐
	ARAŞTIRMA BROŞÜRÜ			Türkçe ☐ İngilizce ☐ Diğer ☐

DEĞERLENDİRİLEN DİĞER BELGELER	Belge Adı		Açıklama
	TÜRKÇE ETİKET ÖRNEĞİ	☐	
	SİGORTA	☐	
	ARAŞTIRMA BÜTÇESİ	☐	
	BİYOLOJİK MATERYEL TRANSFER FORMU	☐	
	HASTA KARTI/GÜNLÜKLERİ	☐	
	İLAN	☐	
	YILLIK BİLDİRİM	☐	
	SONUÇ RAPORU	☐	
	GÜVENLİLİK BİLDİRİMLERİ	☐	
	DİĞER:	☐	

KARAR BİLGİLERİ	**Karar No:13-417-12**	**Tarih: 27 Ağustos 2012**
	Yukarıda bilgileri verilen klinik araştırma başvuru dosyası ile ilgili belgeler araştırmanın gerekçe, amaç, yaklaşım ve yöntemleri ile bilgilendirilmiş gönüllü olur formu incelenmiş çalışmanın başvuru dosyasında belirtilen merkezlerde gerçekleştirilmesinde etik ve bilimsel sakınca bulunmadığına toplantıya katılan Etik Kurul üye tam sayısının salt çoğunluğu ile karar verilmiştir.	

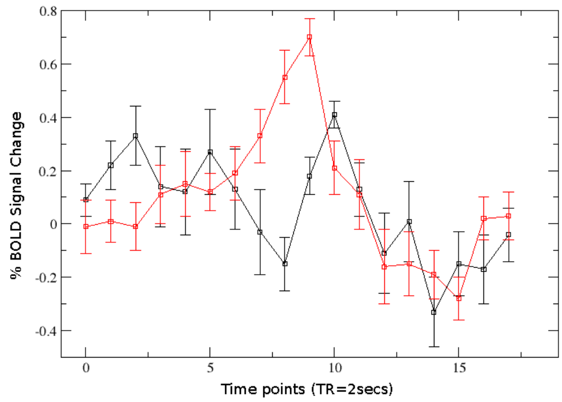
ANKARA ÜNİVERSİTESİ TIP FAKÜLTESİ KLİNİK ARAŞTIRMALAR ETİK KURULU

ÇALIŞMA ESASI	Klinik Araştırmalar Hakkında Yönetmelik, İyi Klinik Uygulamaları Kılavuzu
BAŞKANIN UNVANI / ADI / SOYADI:	Prof.Dr.Mehmet MELLİ

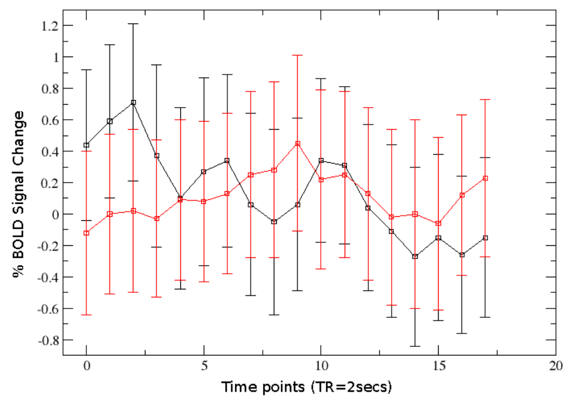
APPENDIX F: Individual Subject Results

Symmetric versus Asymmetric patches

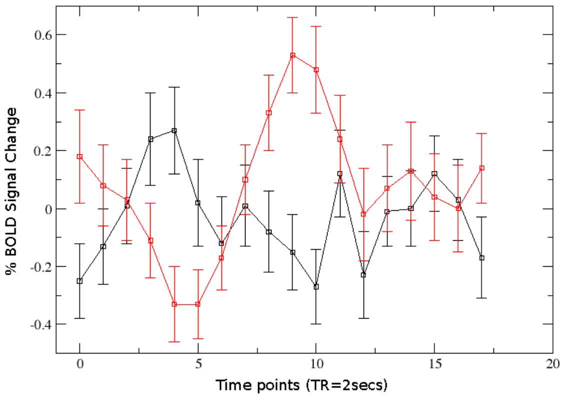
LO1



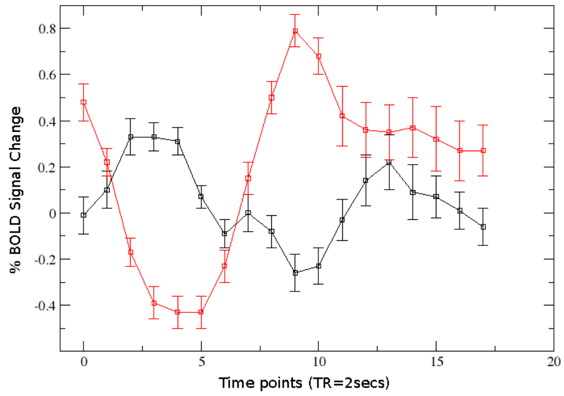
Subject 1 - LH



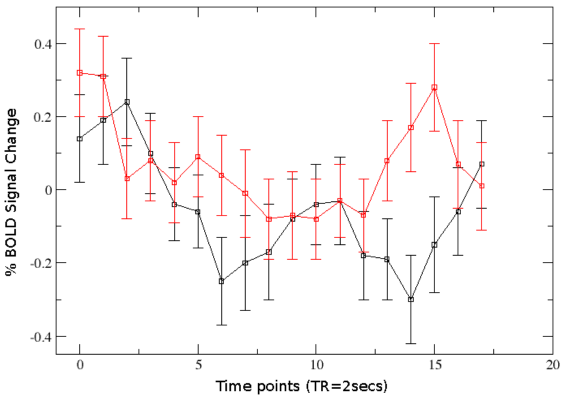
Subject 1 - RH



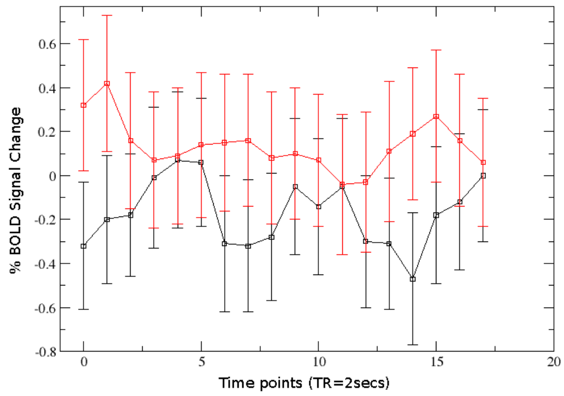
Subject 2 - LH



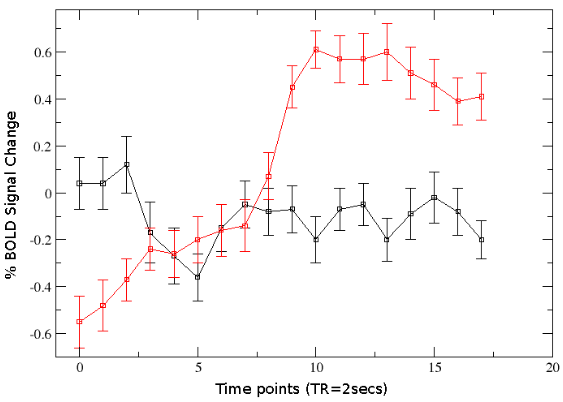
Subject 2 - RH



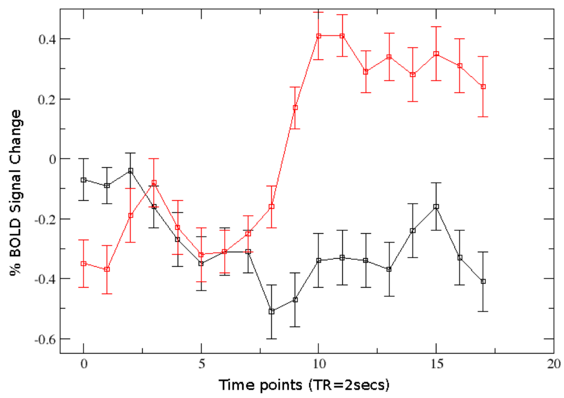
Subject 3 - LH



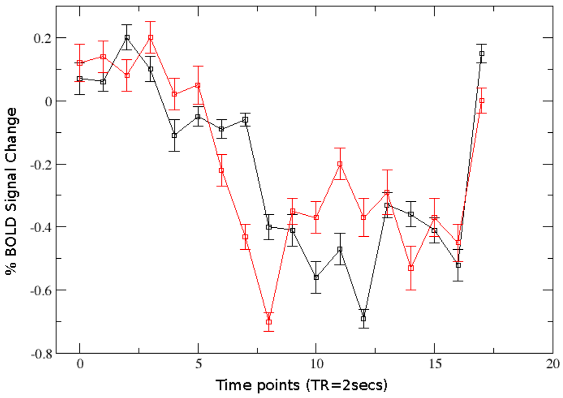
Subject 3 - RH



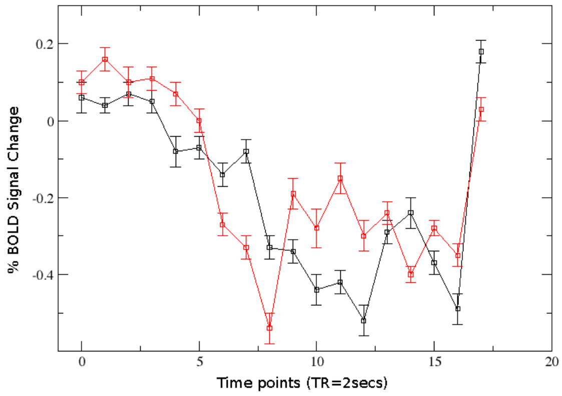
Subject 4 - LH



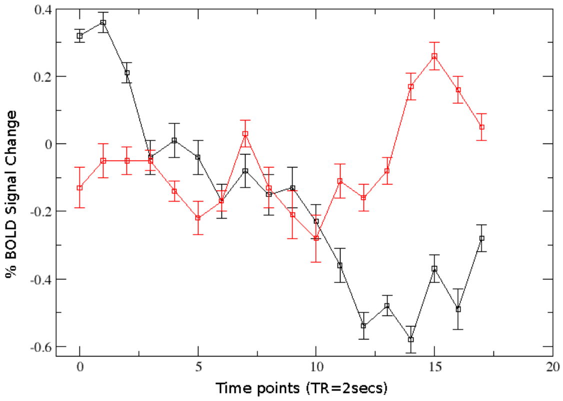
Subject 4 - RH



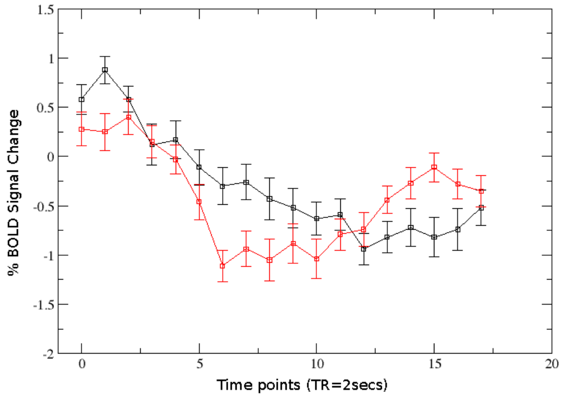
Subject 5 - LH



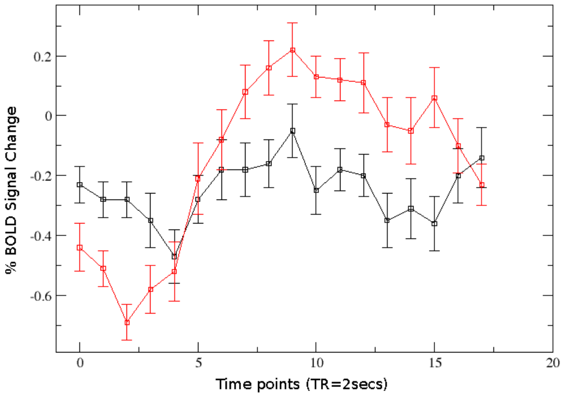
Subject 5 - RH



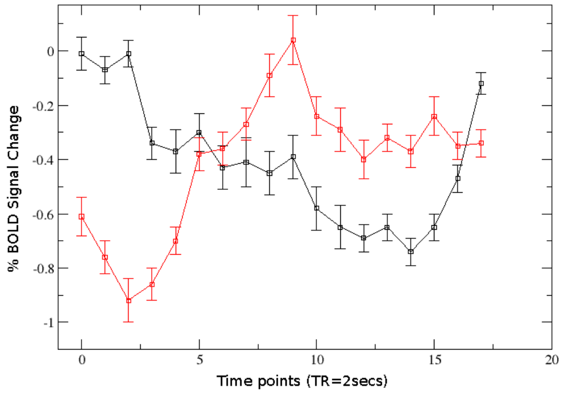
Subject 6 - LH



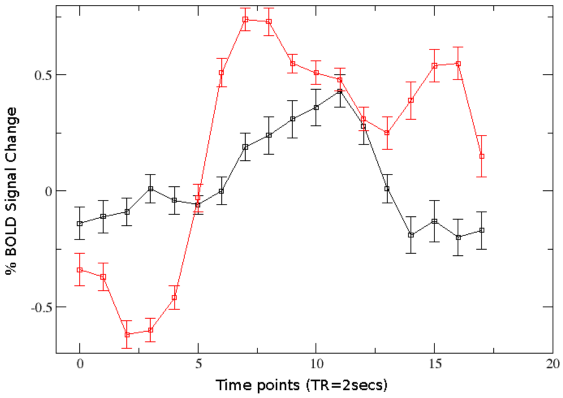
Subject 6 - RH



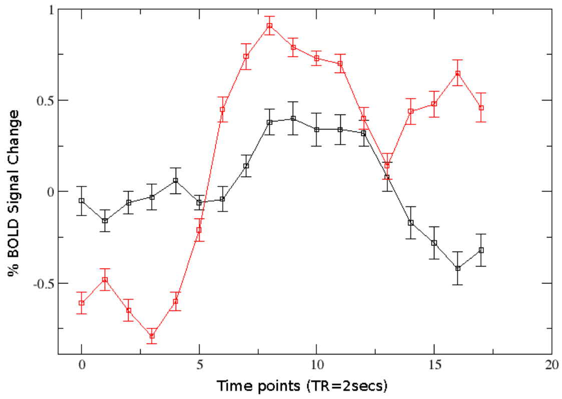
Subject 7 - LH



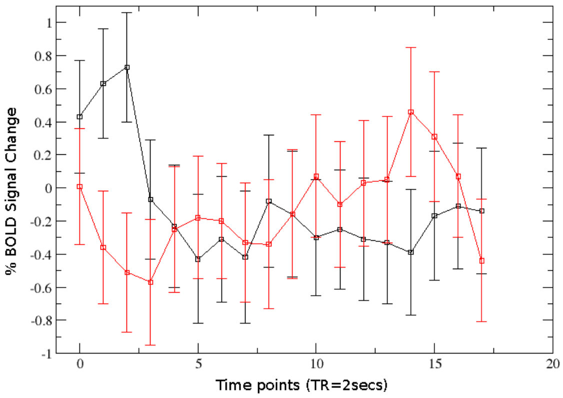
Subject 7 – RH



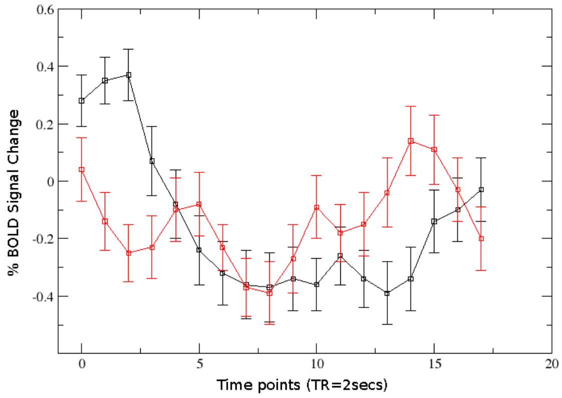
Subject 8 - LH



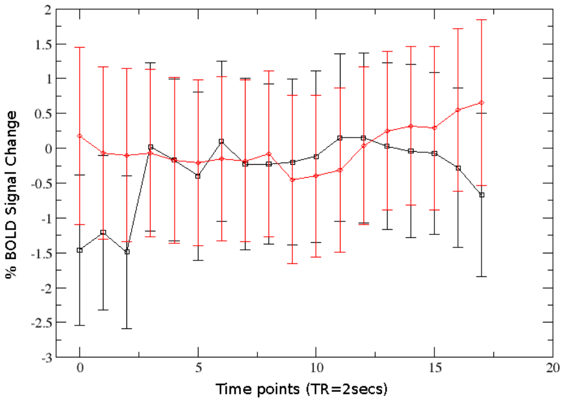
Subject 8 - RH



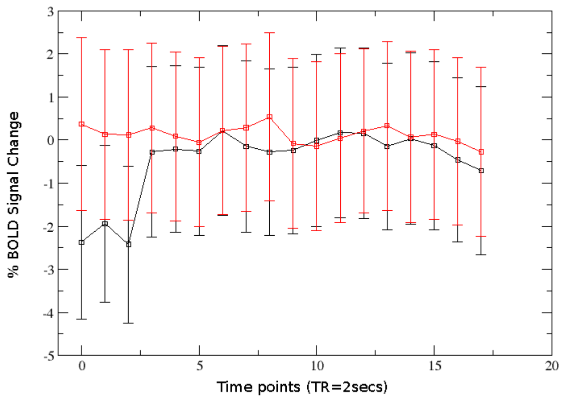
Subject 9 - LH



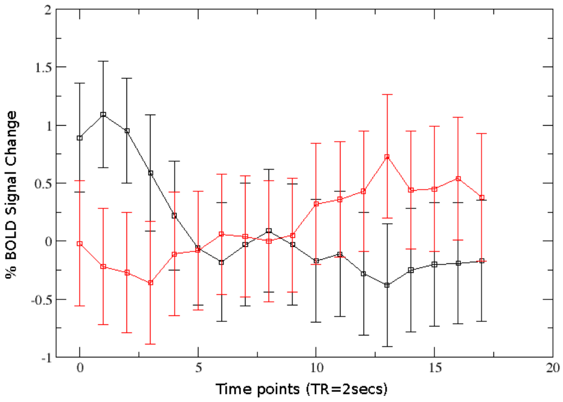
Subject 9 - RH



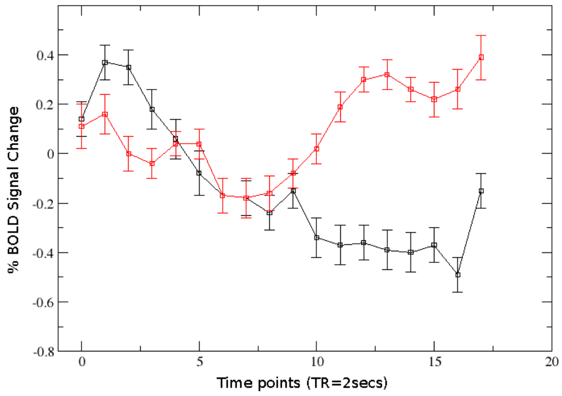
Subject 10 - LH



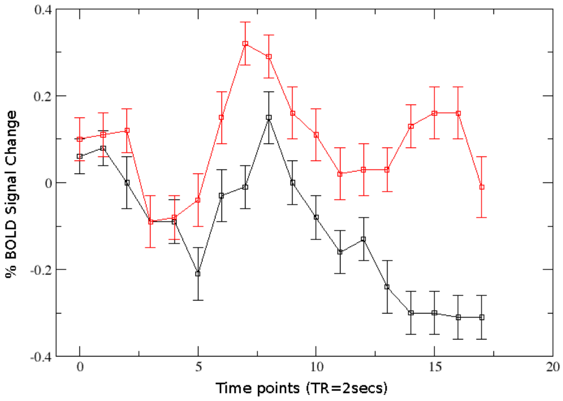
Subject 10 - RH



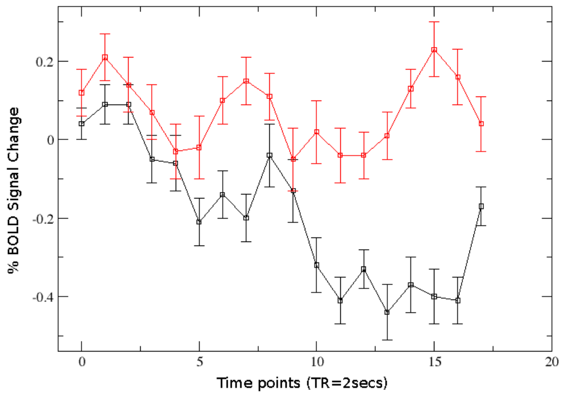
Subject 11 - LH



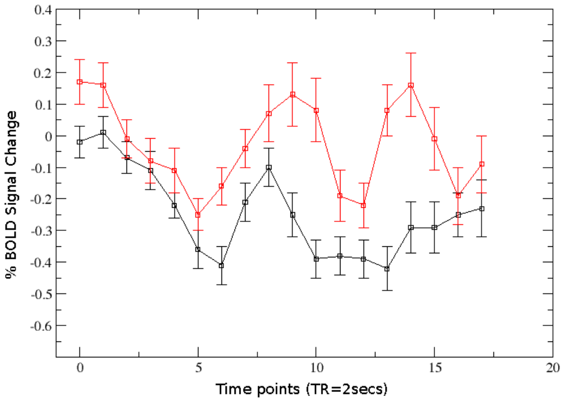
Subject 11 - RH



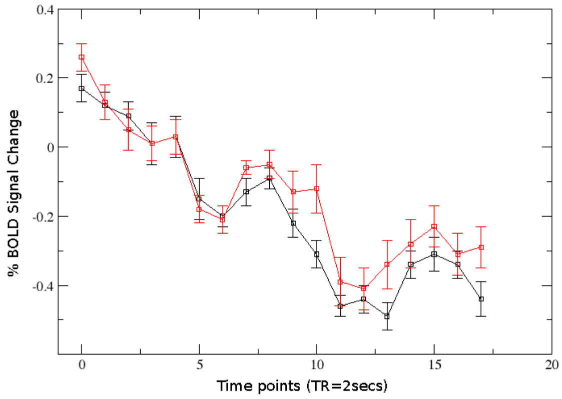
Subject 12 - LH



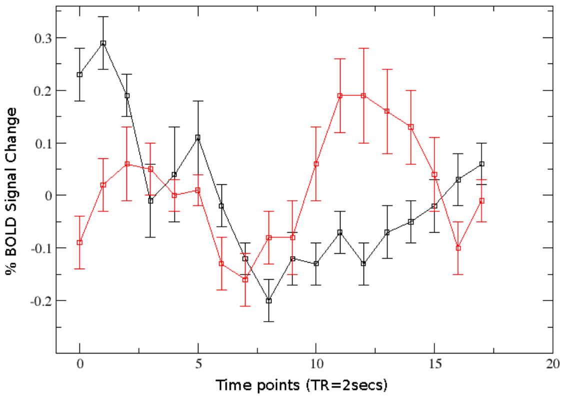
Subject 12 - RH



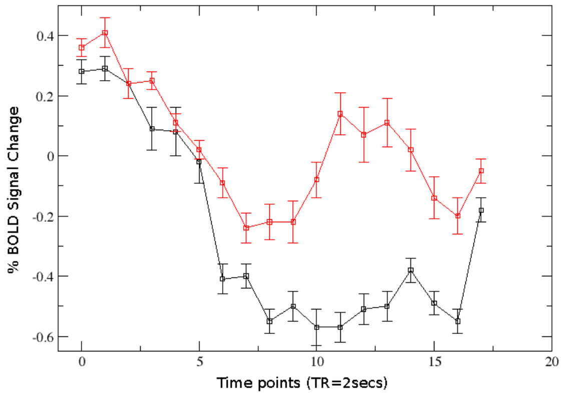
Subject 13 - LH



Subject 13 - RH

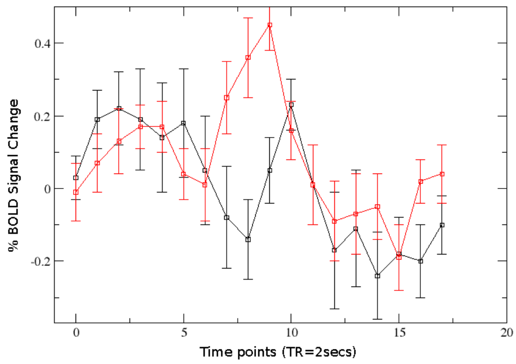


Subject 14 - LH

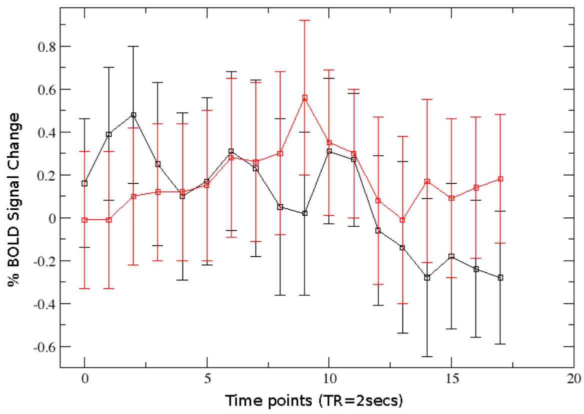


Subject 14 - RH

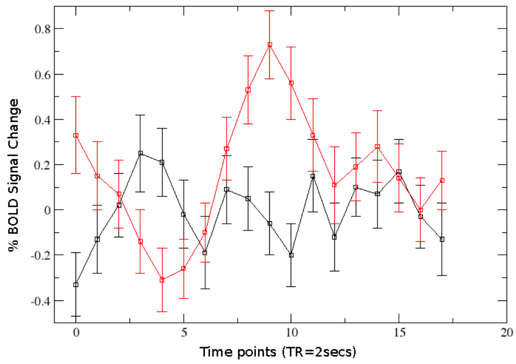
LO2 Results



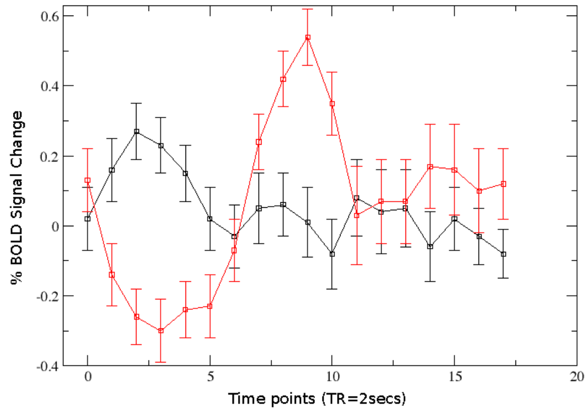
Subject 1 - LH



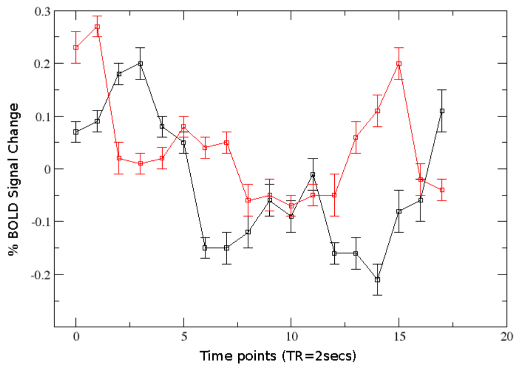
Subject 1 - RH



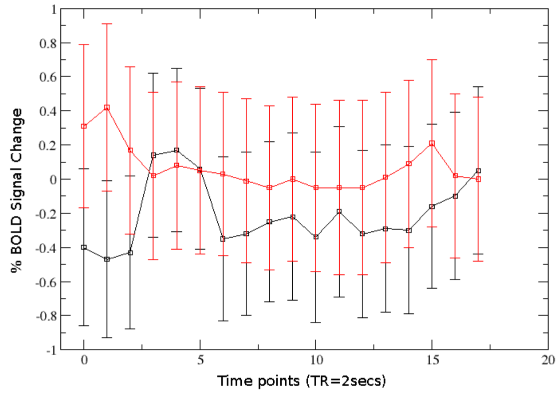
Subject 2 - LH



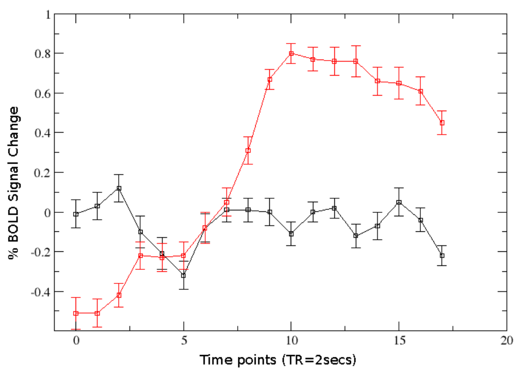
Subject 2 - RH



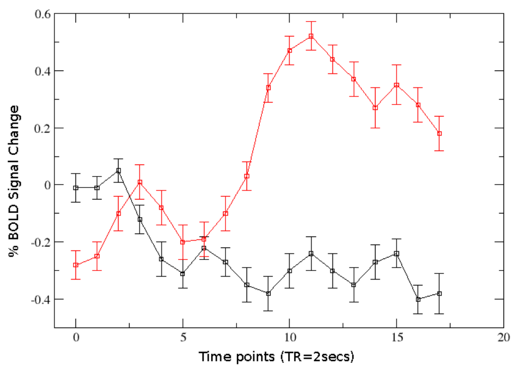
Subject 3 - LH



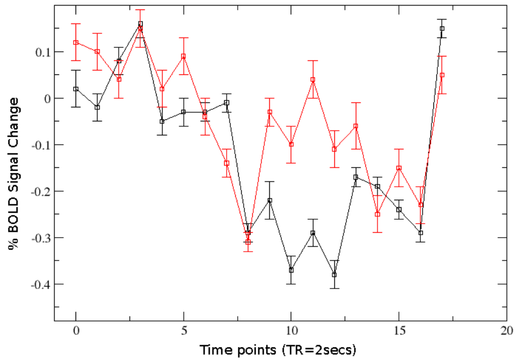
Subject 3 - RH



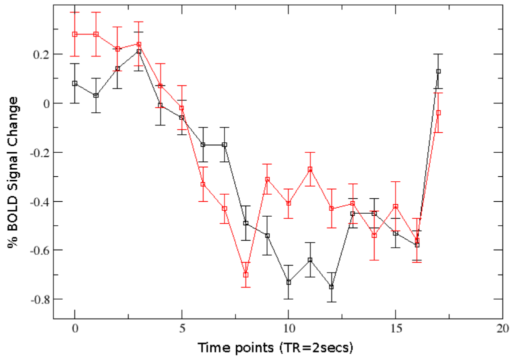
Subject 4 - LH



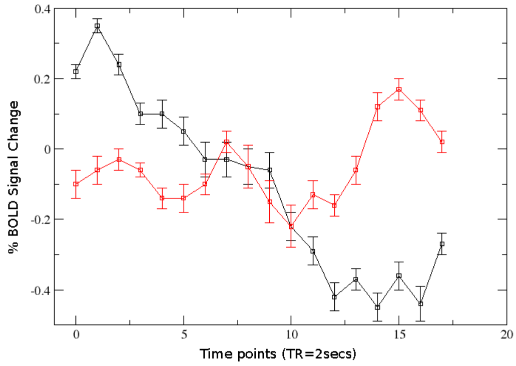
Subject 4 - RH



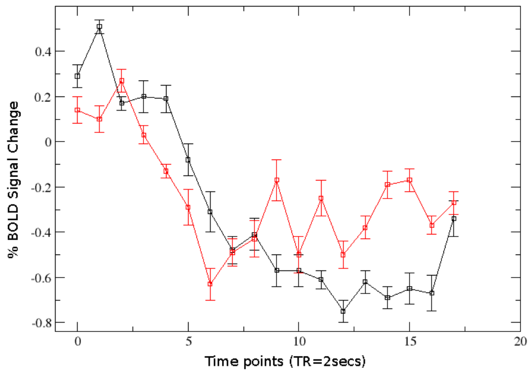
Subject 5 - LH



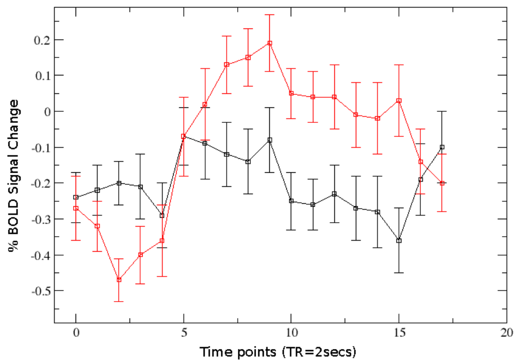
Subject 5 - RH



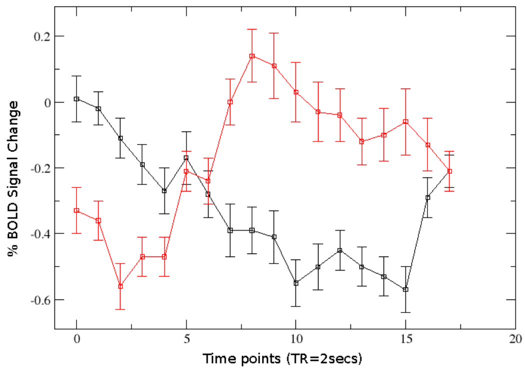
Subject 6 - LH



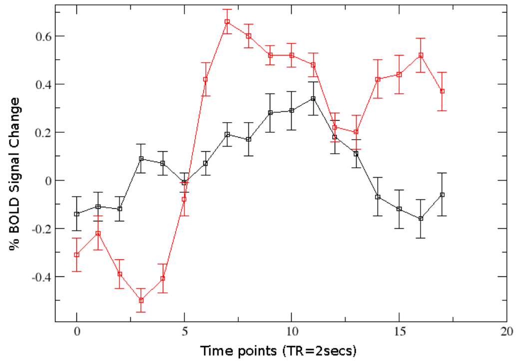
Subject 6 - RH



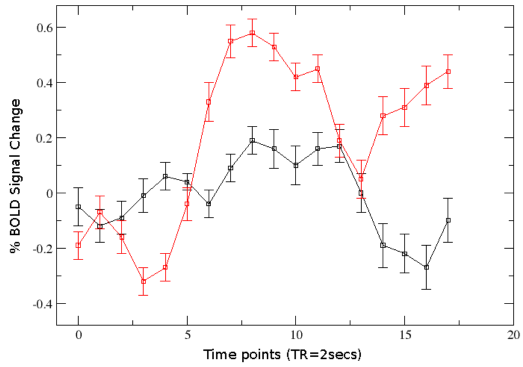
Subject 7 - LH



Subject 7 – RH



Subject 8 - LH



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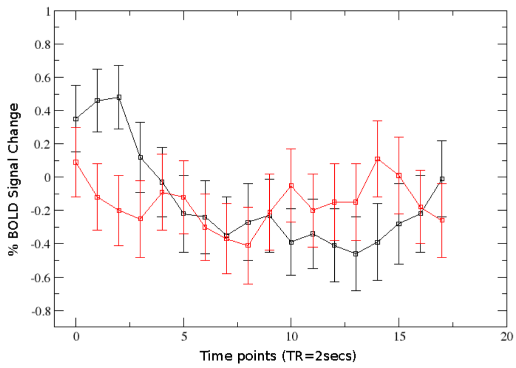
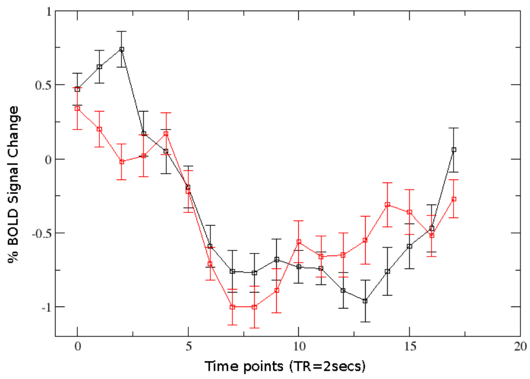
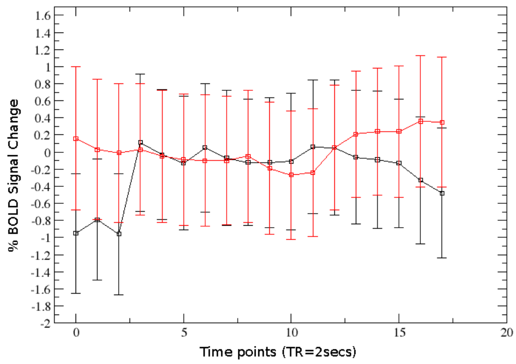


Subject 9 - LH



Subject 9 - RH



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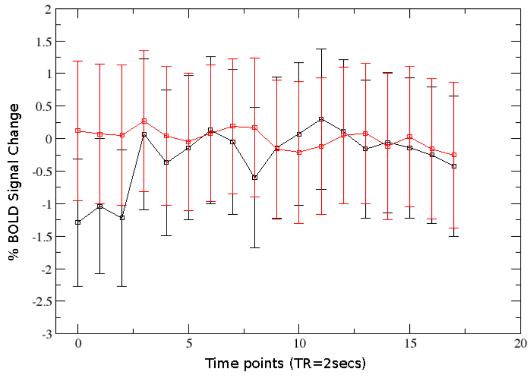
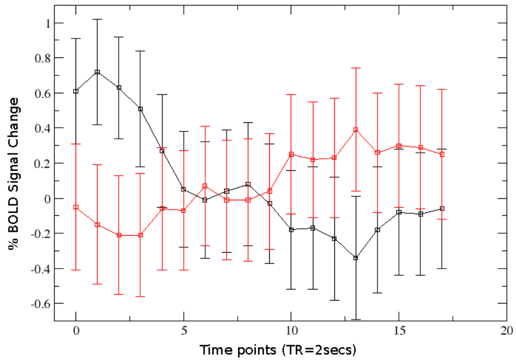
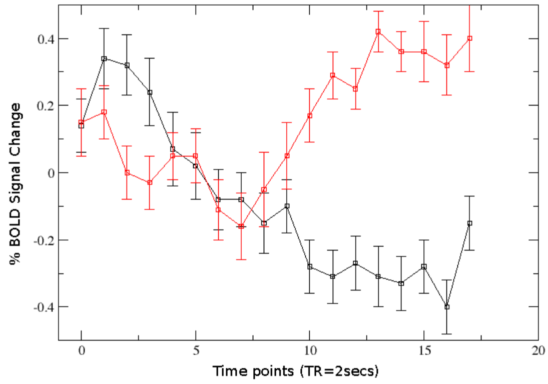


Subject 10 - RH



Subject 11 - LH



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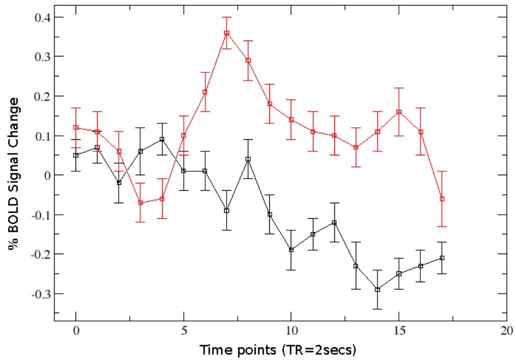

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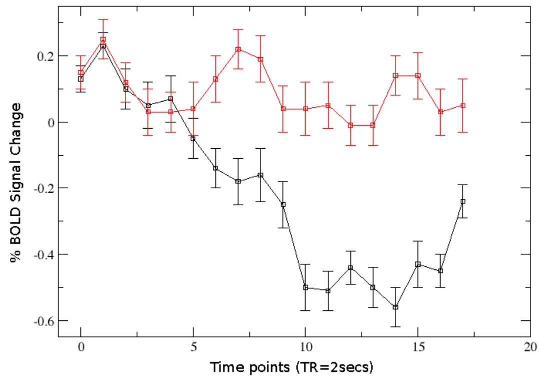

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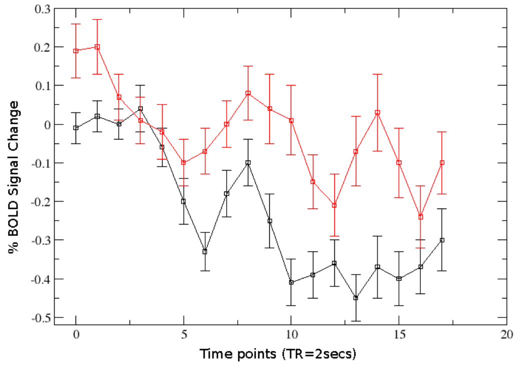
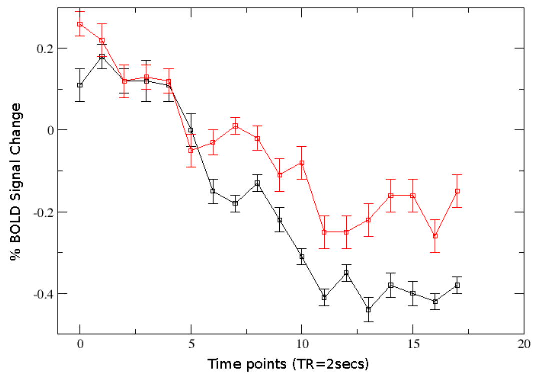


Subject 13 - LH



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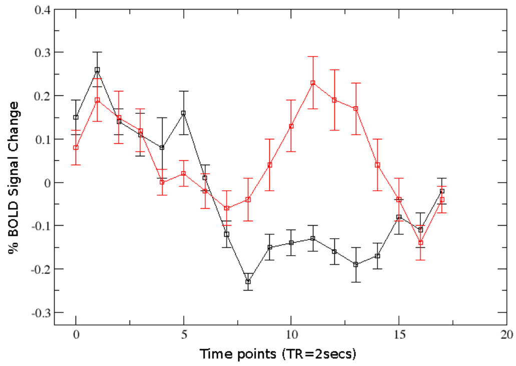
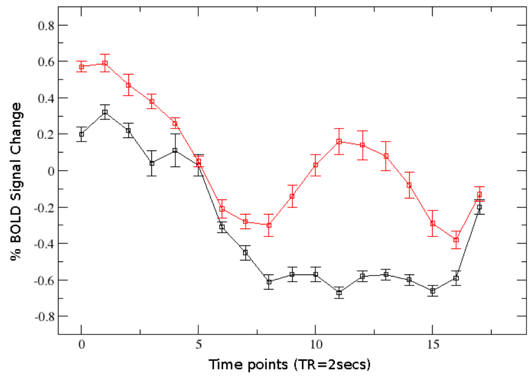


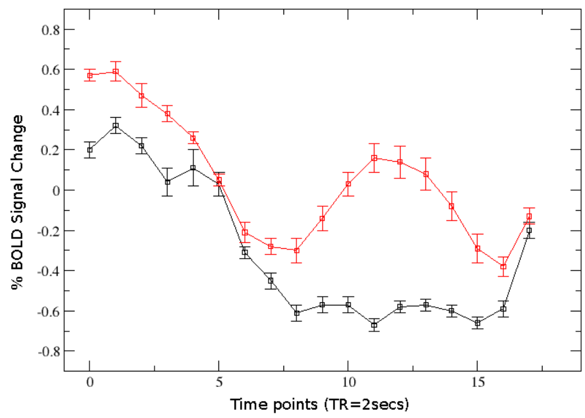
Subject 14 - LH



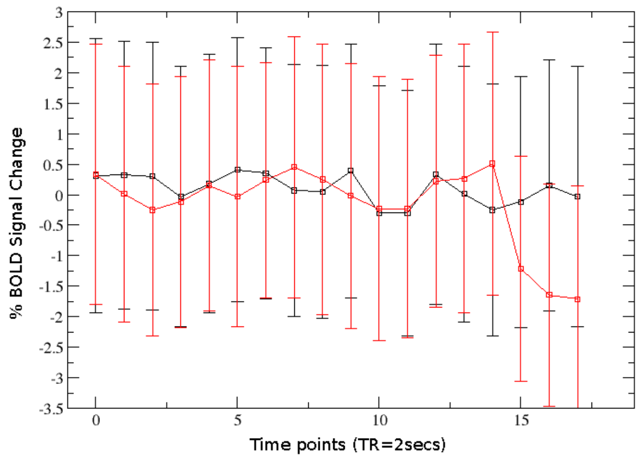
Subject 14 - RH

Symmetric face versus identical asymmetric face

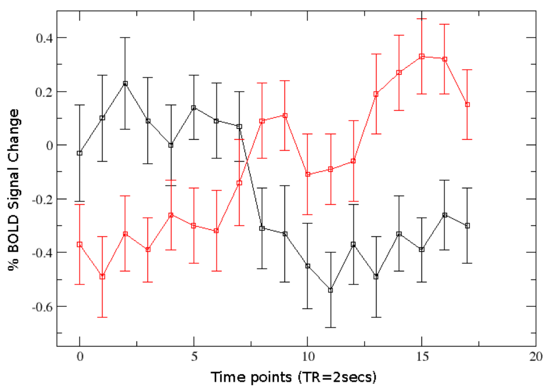
LO1



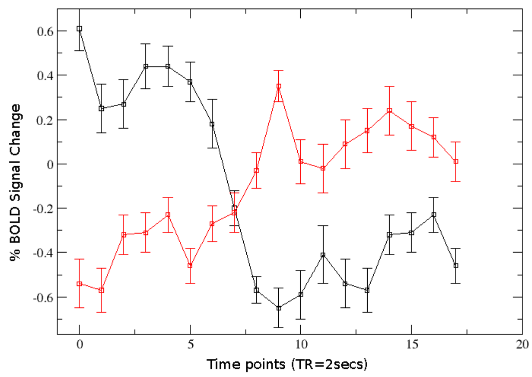
Subject 1 - LH



Subject 1 - RH



Subject 2 - LH



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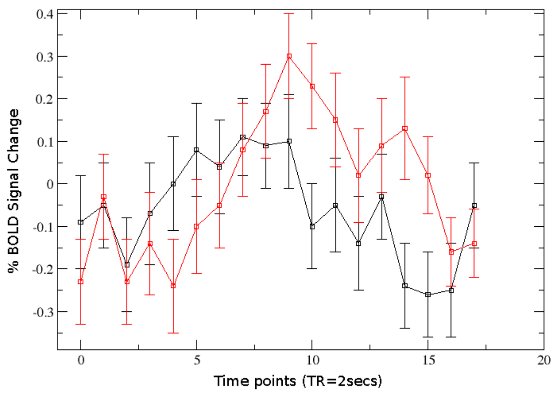
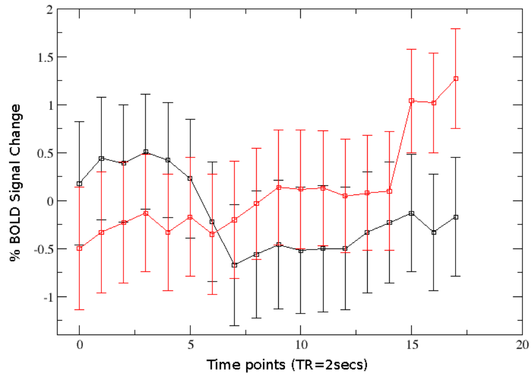


Subject 3 - LH



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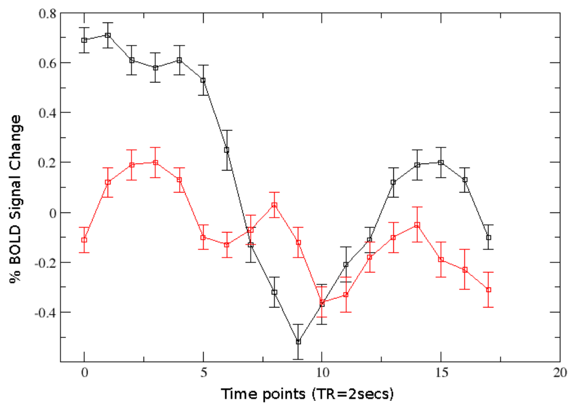
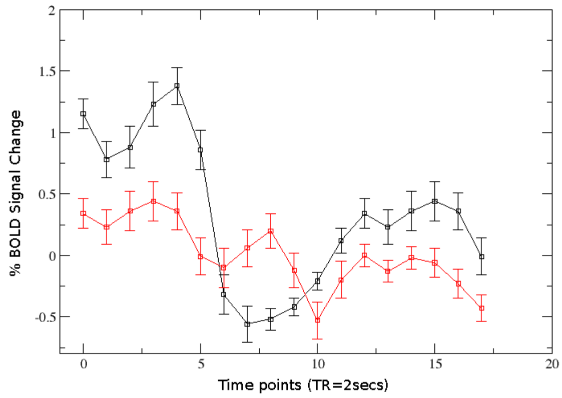
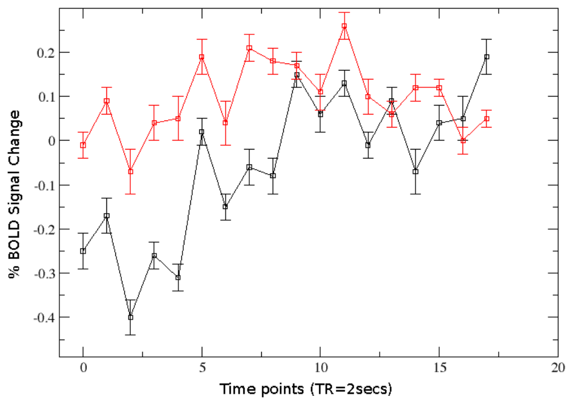


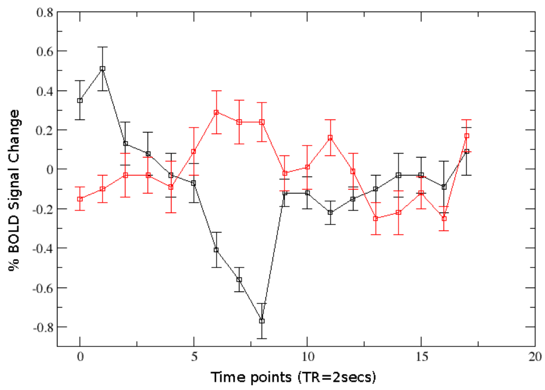
Subject 4 - LH



Subject 4 - RH



Subject 5 - LH



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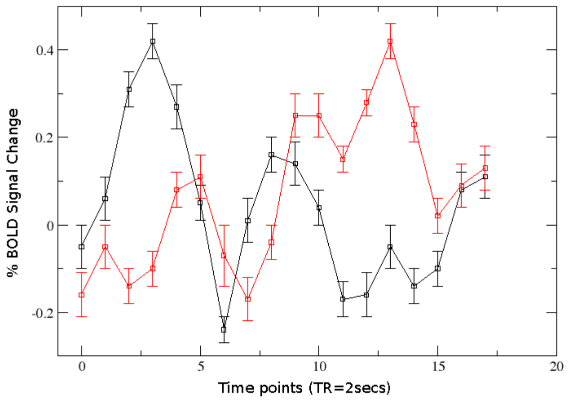
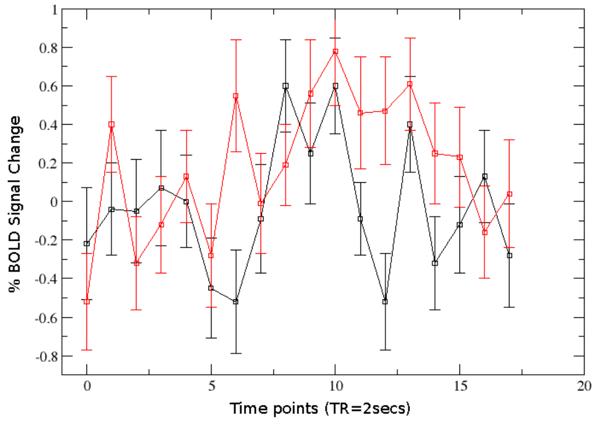


Subject 6 - LH



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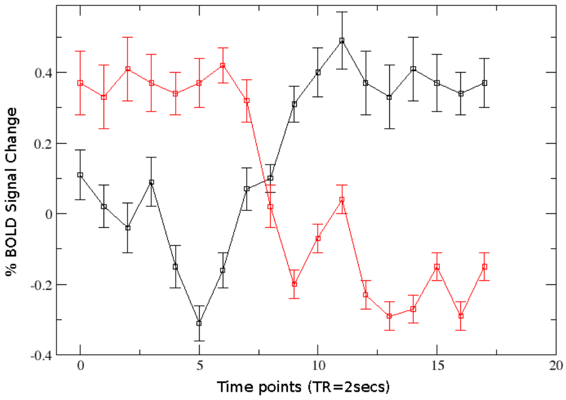
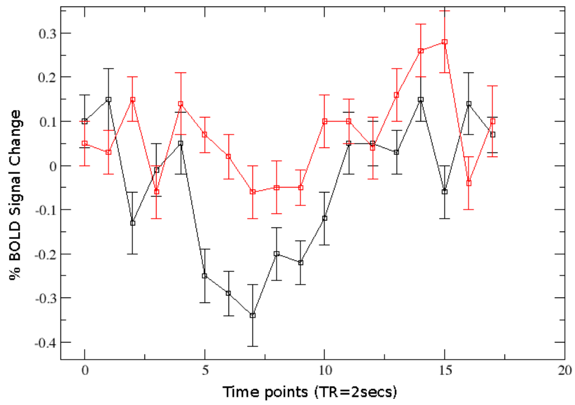
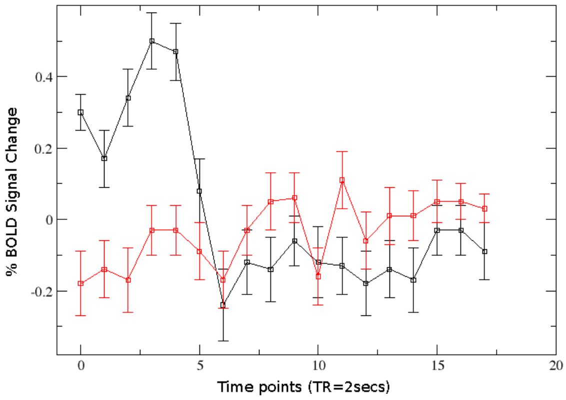


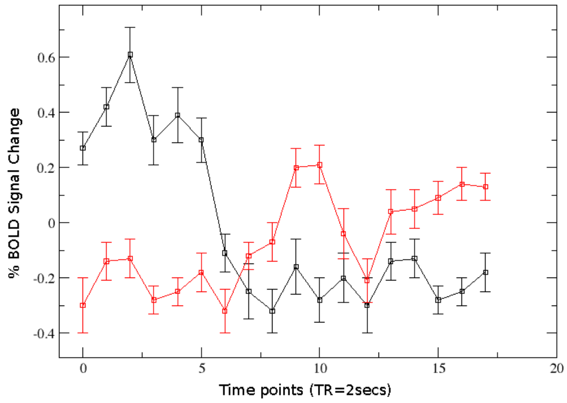
Subject 7 - LH



Subject 7 – RH



Subject 8 - LH



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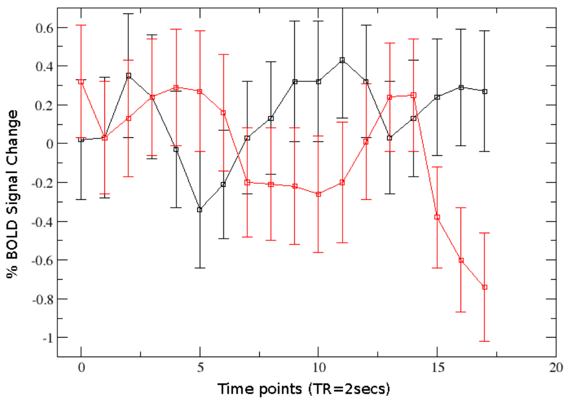
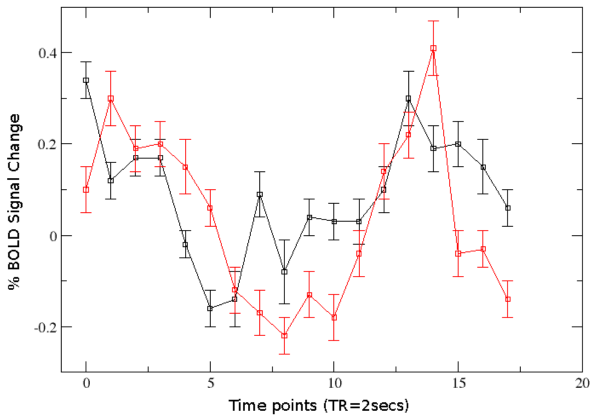


Subject 9 - LH



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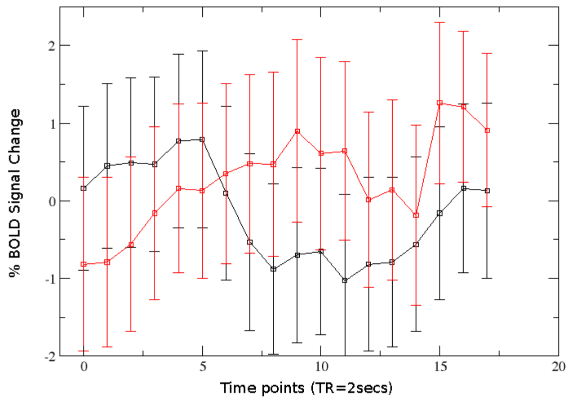
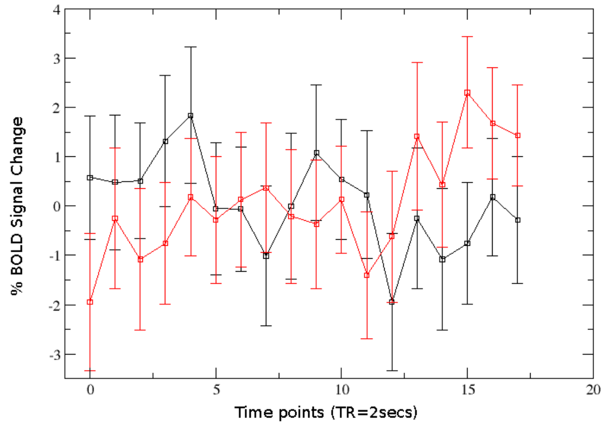


Subject 10 - LH



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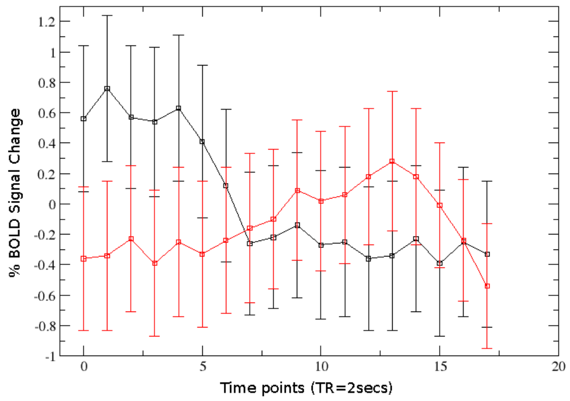
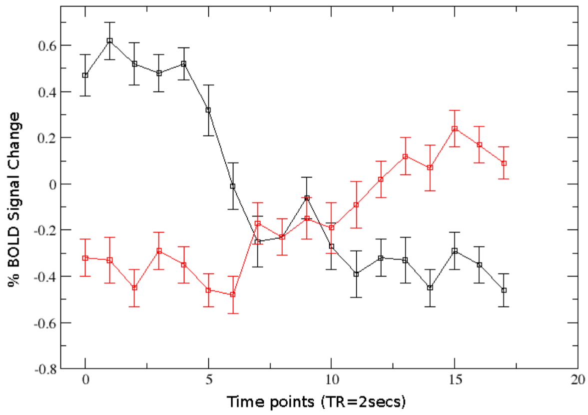


Subject 11 - LH



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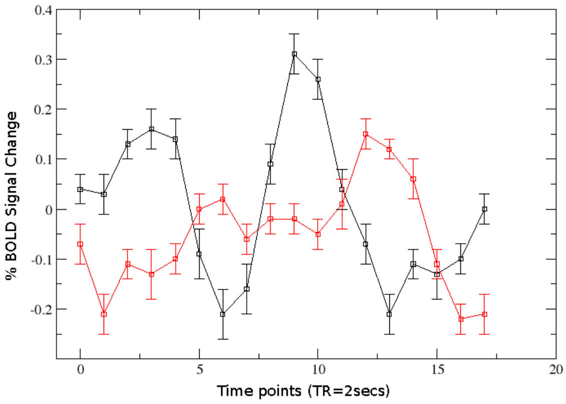

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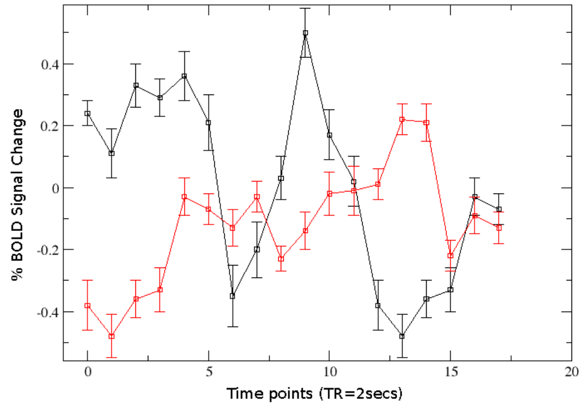

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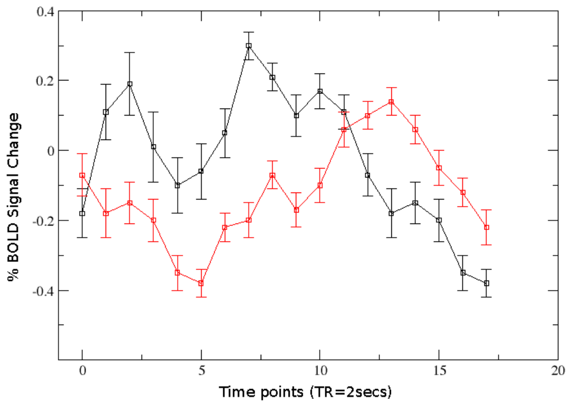

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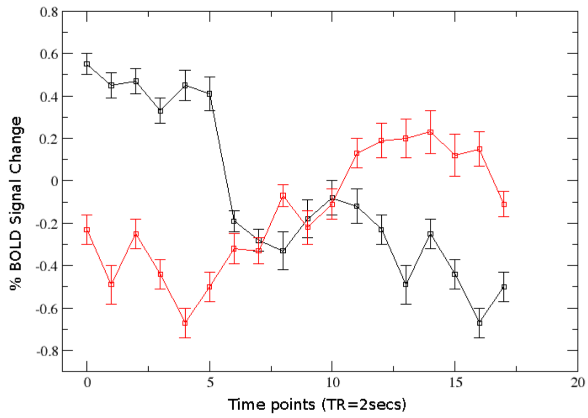

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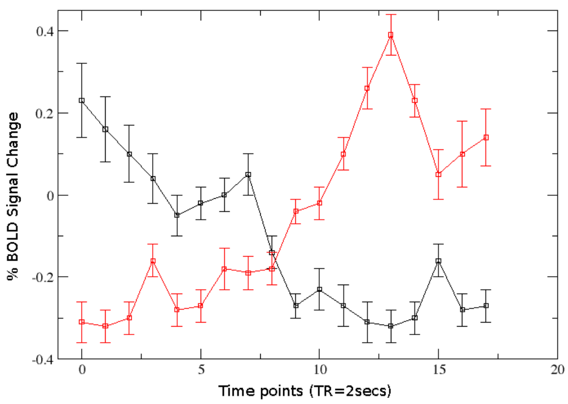
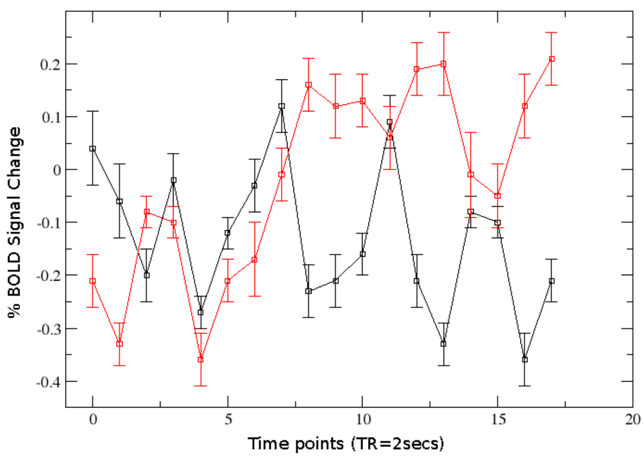
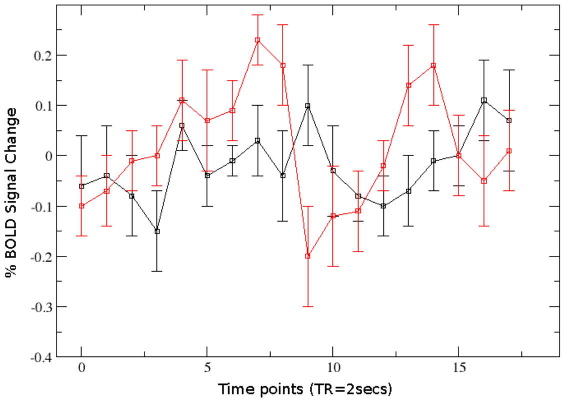


Subject 14 - LH

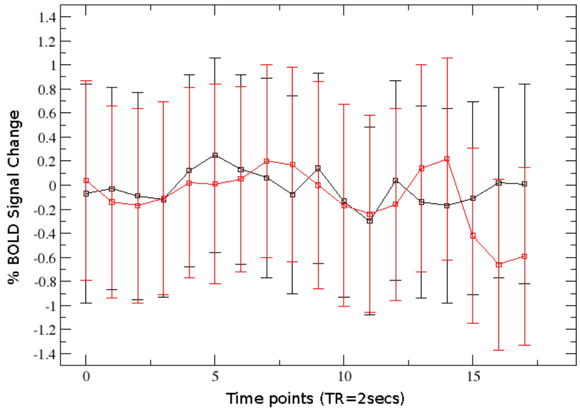


Subject 14 - LH

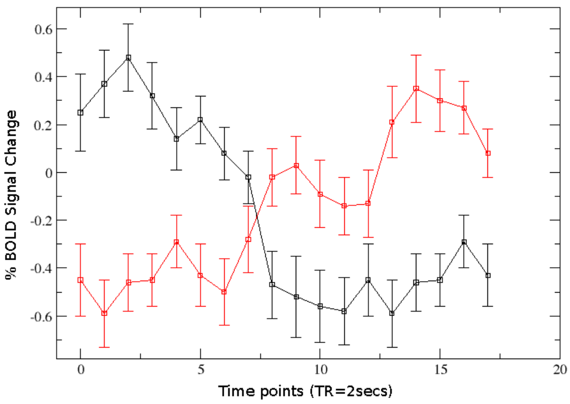
LO2 Results



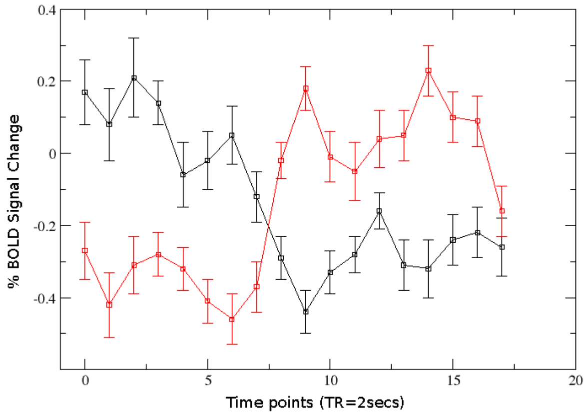
Subject 1 - LH



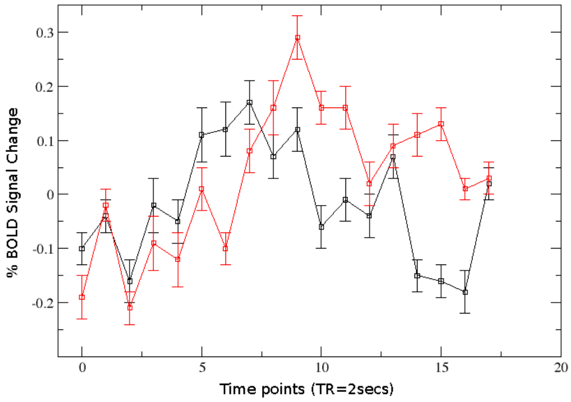
Subject 2 - RH



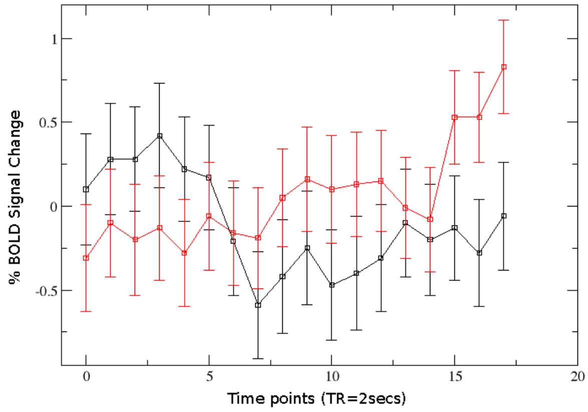
Subject 2 - LH



Subject 2 - RH



Subject 3 - LH



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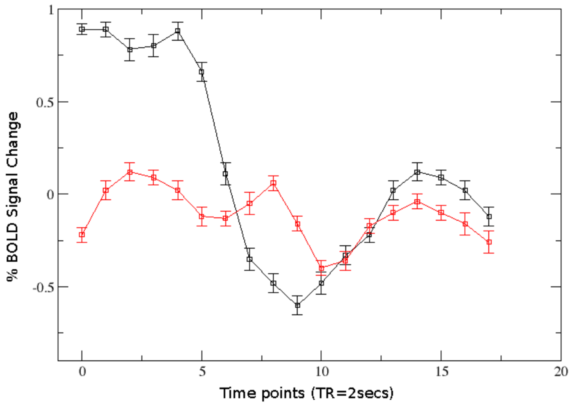
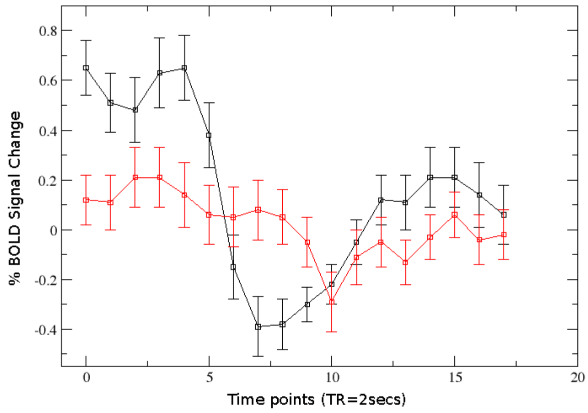


Subject 4 - LH



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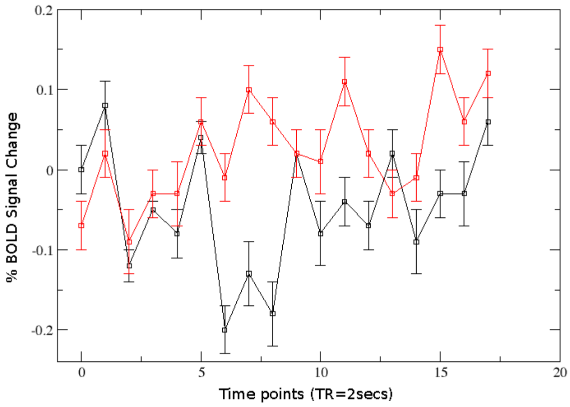
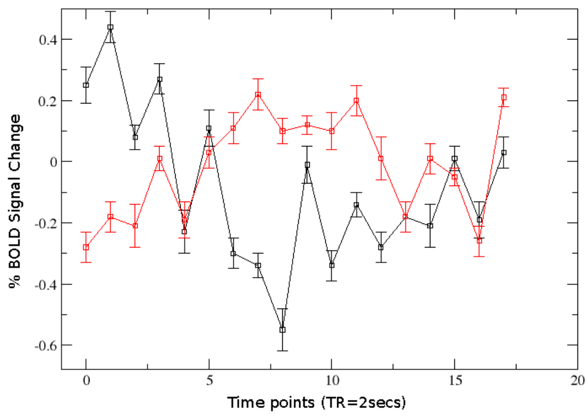


Subject 5 - LH



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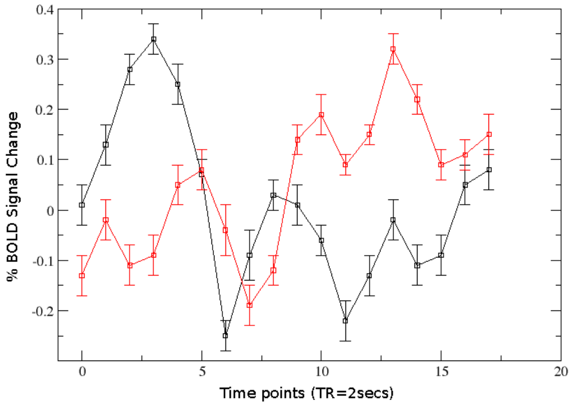
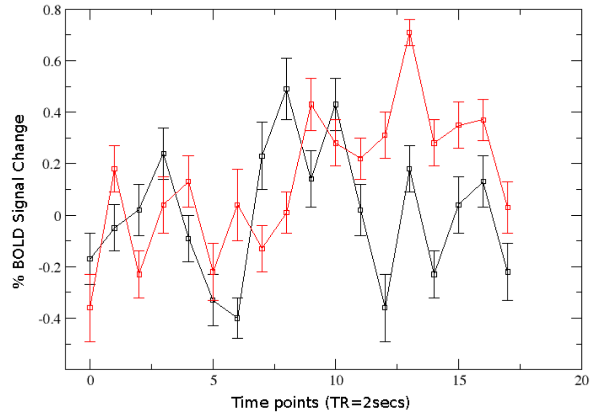


Subject 6 - LH



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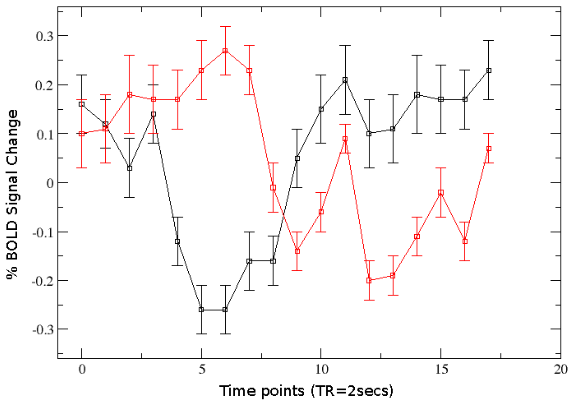
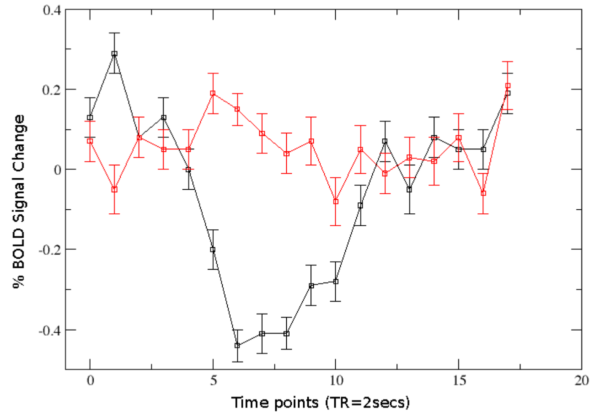


Subject 7 - LH



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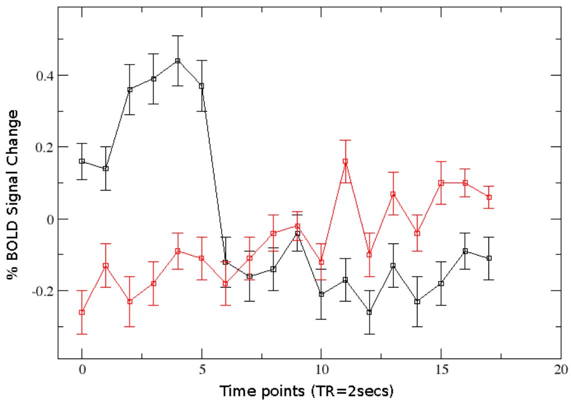
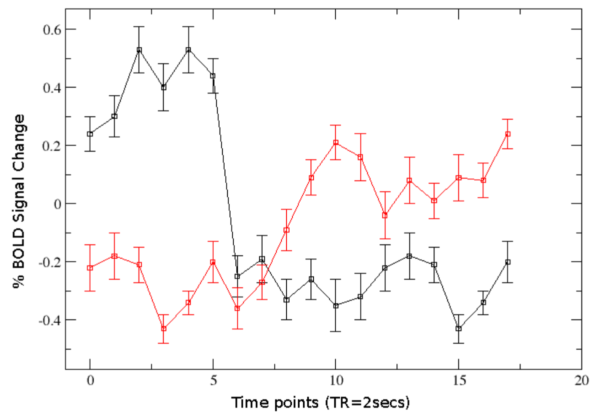


Subject 8 - LH



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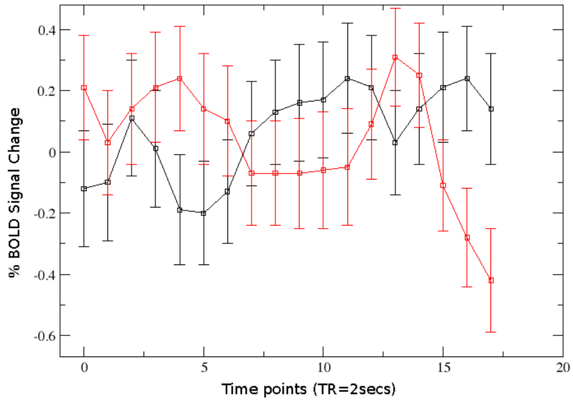
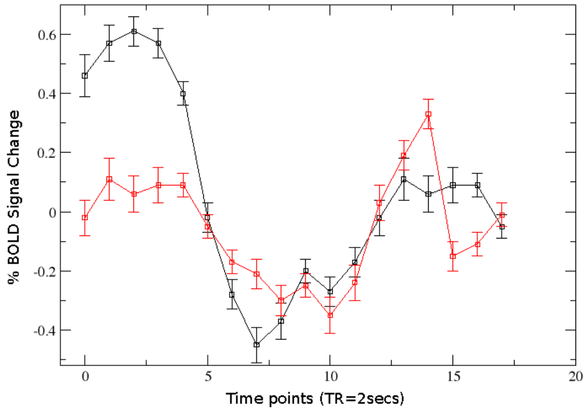
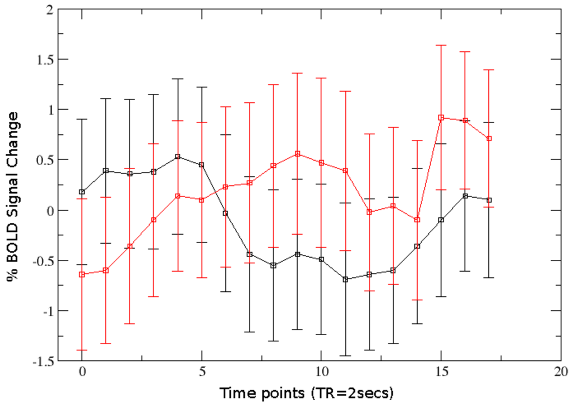


Subject 9 - LH



Subject 9 - RH



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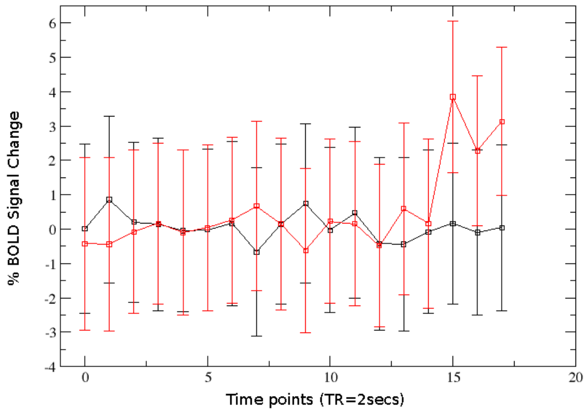
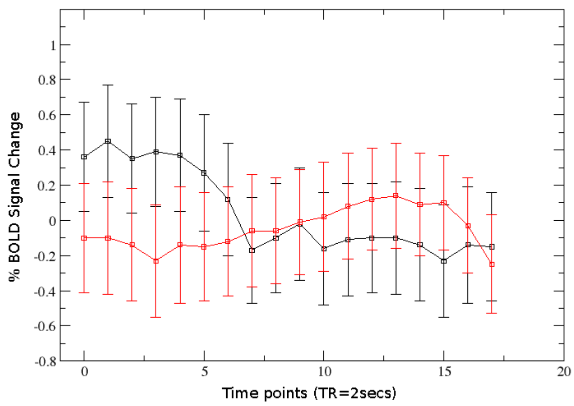
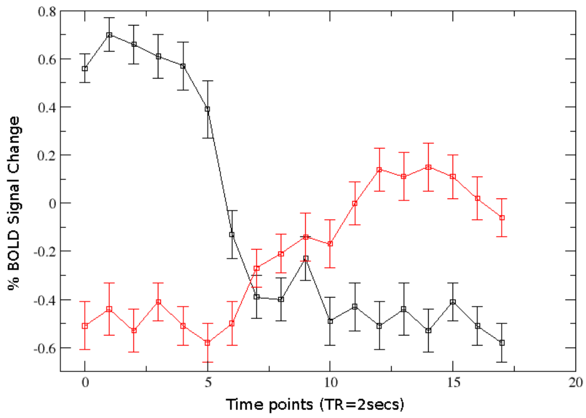


Subject 10 - RH



Subject 11 - LH



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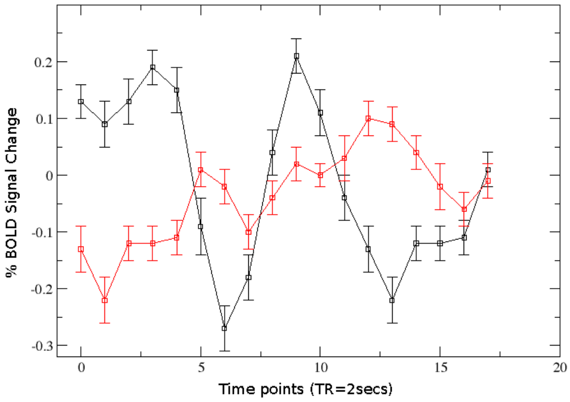
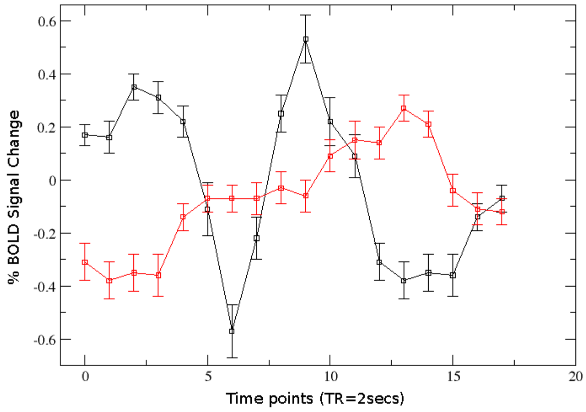


Subject 12 - LH



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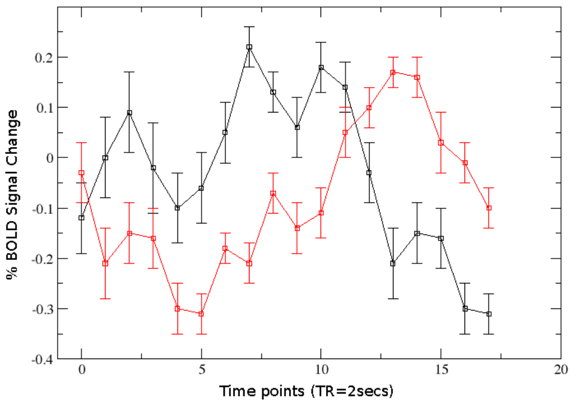
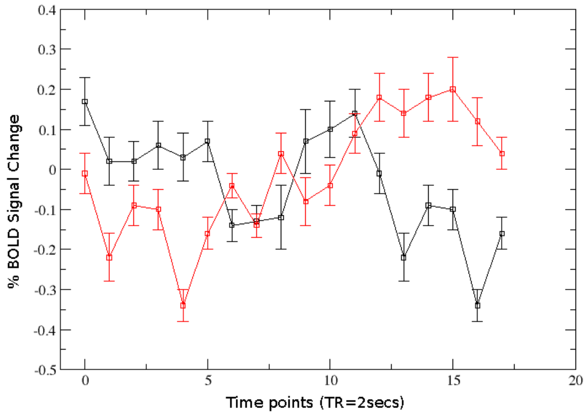
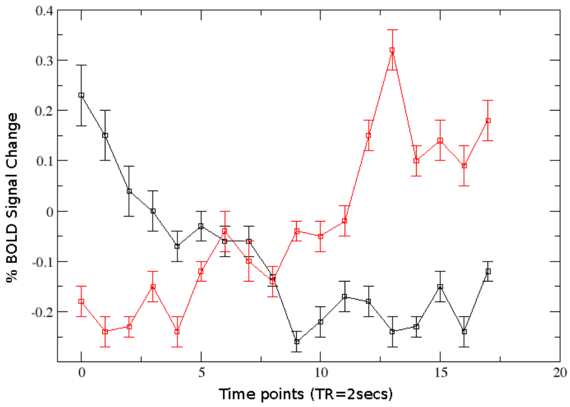


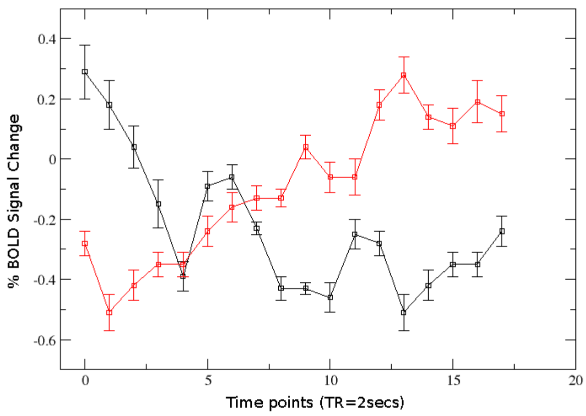
Subject 13 - LH



Subject 13 - RH



Subject 14 - LH



Subject 14 - RH