Filtered faces at the beauty contest:

Spatial frequency analysis of facial attractiveness

Ilaria Schettino

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Author: Ilaria Schettino

Supervisor: Bruno Laeng

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Abstract

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Background. The main question of the present research was born from the intersection between two issues: the relevant feature behind our sense of facial beauty and two kinds of information carried within different spatial frequency channels. Given its strong ability in communicating important information, facial beauty has gradually gained researchers' attention. On the other side, given its importance in carrying significant information about the world we see, the spatial frequency of images –namely the different spatial bands– has been widely investigated in neuroscience. **Objectives.** Assumed that lower spatial frequencies carry information about the global feature of a picture, while higher spatial frequencies provide local characteristics, the present research aims at studying which band of the spatial frequency carries the most useful information when a judgement on beauty of two same-sex faces is required. Using eye tracking methods, the most relevant AOIs of faces are investigated in order to reveal which regions are the most attended when people evaluate someone else's beauty. **Methods.** Fifty participants performed a two-alternative forced choice task where they had to decide which between pairs of female and male same-sex faces they found more attractive in filtered and broadband conditions. Eye tracking data revealed which AOIs of the face are most attended during beauty judgements and pupil dilations were collected in order to measure real time effort. **Results.** Analyses of behavioral and eye tracking data revealed a difference between evaluations of attractiveness of female and male faces. Pupillometry data revealed a difference in pupil sizes in correspondence to each spatial frequency condition. **Conclusion.** Results revealed that neither very low nor very high spatial frequencies carry sufficiently useful information to perform judgements on faces' beauty, compared to medium-level ones. Furthermore, both behavioral and eye tracking data show that people tend to evaluate differently female and male faces: it seems that while global information, carried by the lower spatial frequencies, is sufficient for evaluating a male face's beauty, local information provided by higher spatial frequencies are needed in order to perform effective judgements of a female face's attractiveness.

Key Words: human face, facial beauty, face perception, spatial frequency, neuroscience

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Table of contents

1 Introduction ... 1
  1.1 The human face as a relevant visual stimulus ... 1
  1.2 Attractive faces capture and hold attention ... 2
  1.3 Different spatial frequencies carry specific information ... 5
  1.4 Investigating cognitive processes with eye tracking and pupillometry techniques ... 10
  1.5 The purpose of the research ... 11
2 Methods ... 14
  2.1 Recruitment and sample ... 14
  2.2 Materials ... 14
  2.3 Procedure and apparatus ... 16
3 Results ... 19
  3.1 Behavioral data ... 19
  3.2 Eye tracking data ... 20
  3.3 Pupillometry data ... 26
4 Discussion ... 28
  4.1 Limitations and recommendations for future research ... 34
5 Conclusion ... 35
Bibliography ... 36
Appendix ... 43

1 Introduction

1.1 The human face as a relevant visual stimulus

Given its important evolutionary and social significance, the human face has been the center of psychological research for several years. The branch of neuroscience became interested in faces perception during the last years of the 80s, when numerous studies about emotions and developmental psychology were published. Few years later, with the advent of the research on human attention, human faces became an interesting stimulus to test. According to Theeuwes (1994), who suggested the idea of a double attentional system in humans, the most salient stimuli attract human attention in a bottom-up fashion regardless of the current goals. This was the assumption at the base of many experiments that have been run during the past years and which led to the conclusion that faces are among those stimuli that easily attract attention to their location in a bottom-up way more than other objects (Langton, Law, Burton & Schweinberger, 2008). According to researchers, it is likely that a wide experience in detecting faces and the information they carry, which is relevant for adaptive behavior, led to the strengthening of the connections from high-level representations of faces to the lower-level features detectors so that an item which contains these particular features (i.e., faces) have the priority on other objects in the visual attentional system (Langton, Law, Burton & Schweinberger, 2008). Another explanation that could describe the priority that faces have over other objects in attracting attention is that some neural circuitries dedicated to faces analysis exist and are activated in a pre-attentive view of the world; the same process could exist for body parts (De Renzi et al., 1994; Farah, 1996; Downing, Jiang, Shuman & Kanwisher, 2001; Peelen & Downing, 2005). The reason why such circuitries could exist is not clear yet and, on the other hand, according to Bindemann, Burton, Hooge, Jenkins and De Haan (2005), an attentional bias towards faces and body parts does not necessarily imply the existence of a dedicated attentional module.

Other studies have reported that not only human attention is more attracted to faces than other objects, but also people are generally more able to detect changes in faces compared to other stimuli (Ro, Russel, & Lavie, 2001). Furthermore, researchers have demonstrated that not only faces stimuli are able to attract visual attention, but also they can hold it for a certain amount of time (Ro, Friggel & Lavie 2007). Although many studies have been conducted on this topic, it still remains unclear why this happens. In an evolutionary perspective, one possibility is that humans are biased in directing their attention towards other humans' faces in order to monitor the changes in their expressions and capture any dangerous signal (Bindemann, Buron, Hooge, Jenkins, & De Haan, 2005; Palermo & Rhodes, 2007); however, the degree to which a face receives attention depends also on its features.

1.2 Attractive faces capture and hold attention

Research has demonstrated that people spend more time looking at faces that they consider more attractive compared to less attractive faces (Aharon, Etcoff, Ariely, Chabris, O'Connor, & Breiter, 2001). In addition, it seems more difficult for people to disengage their attention from attractive faces compared to unattractive ones (Chen, Liu & Nakabayashi, 2012). Interestingly, the presence of several equally attractive faces may disturb effective distribution of attention on the different stimuli, thus resulting in longer processes of decision making on the attractiveness of beautiful faces than on that of unattractive ones (Kranz & Ishai, 2006; Chen, Liu, Nakabayashi, 2012). On this purpose, based on previous studies (Leopold, O'Toole, Vetter & Blanz, 2001), Shimojo, Simion, Shimojo and Scheier (2003) have proposed a fascinating model called 'gaze cascade effect' that can explain why some two-alternative forced-choice tasks are so difficult and how they are solved. At the beginning of the task, people's gaze is similarly distributed between the two stimuli, but then it is gradually shifted towards the preferred stimulus: "because such a pattern can only be achieved by gradually increasing the duration of gazing at one of the stimuli, and decreasing inspection time for the other, we called this 'gaze cascade effect'". The 'gaze cascade effect' contributes to the process of decision making when the task is difficult (e.g., when the choice is between two equally attractive faces) and the cognitive biases are weak.

In the same way as the prevailing tradition does, in the present paper I will refer to attractiveness and beauty as synonyms, although some theorists prefer to distinguish between the two concepts (Donovan, 2003). Furthermore, although different kinds of attractiveness may exist (e.g., sexual attractiveness, cuteness, etc.), most of the previous research has referred to a general concept of attractiveness, which refers to common aesthetic features of same-sex and opposite-sex faces (Rhodes, 2006).

There still remains uncertainty about the processes undergoing visual perception and preference of faces. Since the research about perception of faces as relevant stimuli for human attentional system is strengthened and has led to several interesting findings, the concept of beauty related to faces has turned out to be a topic of interest for biology and neuroscience. The reason why beauty is considered such an important feature of human faces can be searched in evolutionary studies: Darwinian research posits that characteristics of beautiful faces are relevant biological cues of mate values (Symons, 1995). In his study, Johnston (2006) explains why an element like facial beauty that could appear so ephemeral, carries instead relevant information about people's quality both in terms of "good genes" and in terms of "paternal care". Johnston argues that physical attraction develops through a process involving both the perceiver's brain and a perceived face, which, due to the actions of sexual hormones, undergo several alterations. Males and females' faces are indeed subjected to transformations under the effect of pubertal hormones, whose effects are most visible in those face's cues that are considered to characterize a prototypical masculine or feminine face (e.g., broad jaw, thin lips and sunken smaller eyes for males and full lips, smoother texture of skin and higher cheeks for females). These facial features tend to change again due to hormones alterations during old age in parallel with the decrease of fertility. For this reason, Johnston argues that people make decisions about mates based on their facial beauty, which is considered a visible cue of their fertility and the "good genes" they own. Of course, judgements upon attractiveness cannot be reduced to a sum of ratings of any single feature; instead, it is likely that facial cues are evaluated altogether by perceivers (Fink & Penton-Voak, 2002). However, people are not computers and their decisions are not only driven by the cognitive processes that take place in their brains. Johnston's research also supports Trafimow's hypothesis (Trafimow, Sheeran, Lombardo, Finlay, Brown & Armitage 2004) that choices have both a cognitive and an emotional components and both of them are equally important for the decision process. Indeed, a study conducted by Scarbrough and Johnston (2005) concluded that most heterosexual females seem to fall somewhere in between of a continuum, whose extremes are "good genes" and "good dad". These extremes seem to be represented respectively by a more masculine face and a more feminine face and a choice towards the "good genes" extreme is considered more cognitively driven, while a choice towards the "good dad" extreme is considered more emotionally driven. The emotional component usually depends on the perceiver's brain and the hormonal events to which it has been subjected.

Sexual dimorphism, which is considered a relevant element for facial attractiveness evaluations, is also described in a comprehensive review by Rhodes (2006) as one of the three elements that most affect facial attractiveness. Nevertheless, if femininity in females has been always found to be attractive both in real faces (Koehler, Simmons, Rhodes & Peters, 2004) and in manipulated faces (Johnston, Hagel, Franklin, Fink & Grammer, 2001) with exaggerated feminine traits, the same is not always true for masculinity in male faces. Indeed, while some studies revealed that very masculine male faces were preferred to feminized ones (Keating, 1985), more recent research found opposite results (Penton-Voak, Jacobson & Trivers, 2004). In other words, if a too much feminine female face is in any case attractive, a too much masculine male face is not necessarily perceived as beautiful, perhaps because extreme masculinity features render a face too “strong” looking (O’Toole, Defenbacher, Valentin, McKee, Huff & Abdi, 1998).

Results are instead much more consistent for what regards the other two important components that affect facial attractiveness: averageness and symmetry. It has been proven that average faces, which are therefore closer to the mean population, are considered more attractive than distinctive faces (Morris & Wickham, 2001). Equally, more symmetric faces are considered more attractive than slightly less symmetric ones (Perret, Burt, Penton-Voak, Lee, Rowland & Edwards, 1999; Evans, Wenderoth & Cheng, 2000). Furthermore, the same evolutionary importance that has been assessed to sexual dimorphism has been shown for averageness and bilateral symmetry, which, in the same way, advertise important aspects of mate quality, such as resistance to disease (Thornhill & Møller, 1997).

Interestingly, perception of facial beauty not only seems to be explicable by some evolutionary reasons, but recent research has demonstrated that it is also innate (Slater, Quinn, Hayes, Brown, 2000; Langlois, Ritter, Roggman & Vaughn, 1991) and universal for several races and cultures (Perret, May & Yoshikawa, 1994; Fink & Penton-Voak, 2002). Nonetheless, there are clearly differences in attractiveness judgements among people, but in general, “it seems likely that human beings evolved mechanisms for detecting and assessing cues of mate value […] resistant to cultural modification” (Fink & Penton-Voak, 2002).

Another hypothesis that can be considered together with the evolutionary one, takes into consideration the reward circuitry. Indeed, beautiful faces can be considered as rewarding stimuli such as food, odors or tastes, pleasant music or monetary gain, which are able to activate the reward system. Furthermore, an even larger activation is present in the related brain areas when people look at faces of the sexually preferred gender (Hayden, Parikh, Deaner & Platt, 2007; Isahi, 2007). In particular, it has been shown that the medial OFC (orbitofrontal cortex) represents the main cerebral region involved in the reward value of several concrete and abstract stimuli, among which attractive faces. Moreover, this area seems to be engaged in an automatic way, even when people are not consciously rating facial beauty (O’Doherty, Winston, Critchley, Perrett, Burt & Dolan, 2003). In an interesting study, Isahi (2007) showed how people of both genders and both sexual orientations not only had a greater brain activation when seeing attractive rather than unattractive faces, but all of them responded more to their sexually preferred faces, and in particular to the more beautiful. Additionally, Isahi's study supports the idea that the "OFC represents the reward value of faces of potential sexual partners, including same-sex mates, irrespective of reproduction" (Isahi, 2007).

Moreover, research has demonstrated that the OFC together with the ACC (anterior cingulate cortex) are densely interconnected with the LC (locus coeruleus) (Aston-Jones, Rajkowski, Lu, Zhu, Cohen & Morecraft, 2002). The latter represents a small group of noradrenergic neurons located in the rostral pons and projecting to several areas of the brain. Researchers suggested that OFC projections to LC could affect LC activation. More specifically, LC presents two modes of functioning (tonic and phasic), which are strongly correlated to task-specific decision processes (Aston-Jones & Cohen, 2005). Interestingly, researchers have demonstrated that pupil size varies with LC activation in response to task-relevant events (Rajkowski, Kubiak, Aston-Jones, 1993). Namely, since pupil diameter instantaneously detects LC activity, its "baseline corresponds to LC tonic firing rate, and task-evoked dilations correspond to LC phasic activity" (Gilzenrat, Nieuwenhuis, Jepma & Cohen, 2010).

1.3 Different spatial frequencies carry specific information

What kind of information do people need in order to make decisions upon facial beauty? Are judgements on attractiveness of faces possible with every kind of visually degraded image? To answer these questions, we must consider an intrinsic property extracted by the brain from all visible objects: their spatial frequency structure. "The spatial frequency parameter reflects how rapidly a property changes in space […]" (Deplanque, N'diaye, Scherer & Grandjean, 2007).

A commonly used form consists of vertical bars where lightness varies according to a sinusoidal function (Figure 1).

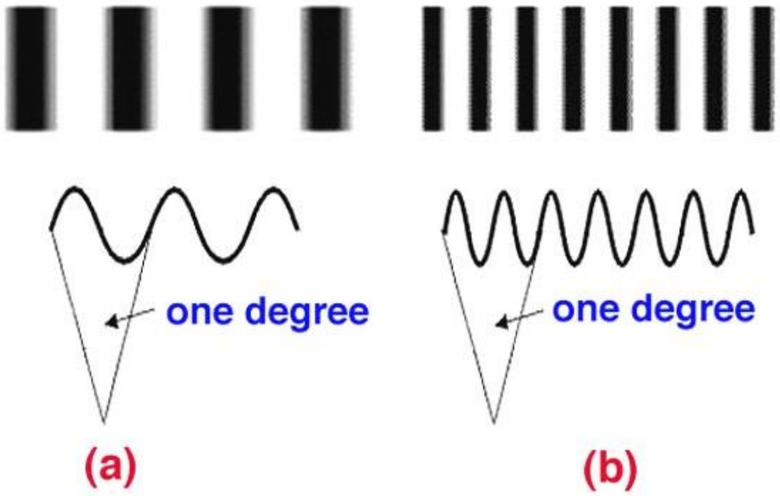

Figure 1. Visual Acuity (Kalloniatis & Luu, 2007). The picture is a representation of spatial frequency, which can be defined as the number of light-dark cycles that an image has in a cycle of degree. Figures 1a and 1b differ in the space between the bars. Since Figure 1b has twice as many bars in the same space, it is said to have a higher spatial frequency than that of Figure 1a.

In this case, “the spatial frequency of the stimulus is simply the frequency of the sinusoid used to generate the pattern” (Deplanque, N’diaye, Scherer & Grandjean, 2007). In general, stimuli with finer details have more energy on the high spatial frequencies (HSF), and stimuli with a more slowly change in their properties have more energy in the low special frequencies (LSF). The unit of spatial frequency (SF) is cycles per image ($c \cdot image^{-1}$) or cycles per degree of visual angle, and in a picture the number of pixels defines a cycle. In images of faces, the spatial frequency can also be measured in cycles per face and defines the number of sinusoidal repetitions in a given width of the face (Costen, Parker & Craw, 1996). Decades of research have explored the role of spatial frequency in visual processing. The spatial frequency theory is now well established and supports the idea that brain activity is influenced by the spatial frequency of the visual scene. Research based on electrophysiological responses have demonstrated that the electrical brain activity is strongly dependent on spatial frequency of the evoking stimulus and responses of various amplitudes have been observed as a function of the low and the high spatial frequency content of the stimuli (Kenemans, Baas, Mangun, Lijffijt, Verbaten, 2000; Baas, Kanemans & Mangun, 2002). Furthermore, using neuroimaging techniques, some authors discovered that different areas of the primary visual cortex are sensitive to different levels of the spatial frequency scale (Singh, Smith & Greenlee, 2000). According to some authors (De Valois & De Valois, 1988), the inspection of spatial frequency happens early in the visual process.

Two separate channels, the magnocellular and the parvocellular pathways, are known to be selectively set to different bands of spatial frequency. Magnocellular cells are mainly sensitive to fast temporal changes such as sparkle and sudden motion, and have bigger receptive fields making them sensitive to marginal and low-pass filtered stimuli. On the contrary, parvocellular cells respond to low temporal changes, and have smaller receptors that make them sensitive to foveal, high-pass filtered stimuli. The LSF channel, that is, the magnocellular pathway, is anatomically structured for a faster conversion of light contained in visual signals in electricity that is carried to the subcortical and cortical regions (in particular, amygdala, superior colliculus and pulvinar). Though this channel is fast, it is only able to carry large-scale luminance variations (i.e., coarse information), removing fine details. Contrarily, HSF information represents small-scale luminance variations (i.e., fine information) and has a slower transmission through the parvocellular pathway to the ventral visual regions (Bullier, 2001; Holmes, Winston & Eimer, 2005). In other words, the magnocellular pathway carries information about local features of the objects, removing the global one. Different spatial frequencies encode different aspects of faces and objects. Namely, research suggest that LSF information permits a global processing of the stimulus, whereas HSF information facilitates its finer features processing (Sergent, 1984). The processing of all visual stimuli relies both on local details and on configural relations between them. Research argues that LSF information supports the processing of the global information of faces (Goffaux, Hault, Michel, Vuong & Rossion, 2005).

Furthermore, both behavioral and neuroimaging studies (Yovel, Yovel & Levy, 2001; Lux et al., 2004) support the assumption that each of the hemispheres seems to play a different role in visual perception. While the right hemisphere might be involved in the processing of global information, the left one might be predominantly involved in local information analysis. In other words, we can say that right hemisphere relative dominance exists for LSF information processing and, in the same way, HSF information is processed predominantly by the left hemisphere (Peyrin, Chokron, Guyader, Gout, Moret & Marendaz, 2006). In their research, Peyrin et al. (2006), found that low-pass filtered scenes were recognized faster when presented in the left hemifield, projecting to the right hemisphere, whereas high-pass filtered stimuli were recognized faster when presented in the right hemifield, projecting to the left hemisphere. Interestingly, a gender difference was observed. Namely, men showed a greater right-sided hemispheric specialization in spatial frequency processing than women, in particular for LSF information. The authors propose that the gender differences in hemispheric specialization might be based on differences in the shape and surface of the corpus callosum. Specifically, women may have a larger splenium and, therefore, more connections between the two hemispheres may exist. This might permit a fast transfer of information to the specialized hemisphere when the stimulus is shown in the non-specialized one, thus removing the visual field differences. In addition, these gender differences in visual perception performance could be the result of differences in sex hormones levels, which, changing during the menstrual cycle, may affect the brain asymmetries. Based on this evidence a difference in processing low and high spatial frequency may be expected between women and men in the present research.

As discussed above, being considered special stimuli and processed in a qualitatively different way compared to other objects, numerous studies have been conducted involving human faces. Additionally, research has focused on different bands of spatial frequency in faces in order to understand whether a certain type of information (e.g., LSF and HSF information) is more necessary than others in order to process a human face. One of the most common methods for this purpose is the spatial frequency filtering. The author who first made use of these techniques was Harmon who, in 1973, thanks to the *pixelizing* method, was able to filter the images enlarging the value of the pixels. The result was an image of lower resolution (i.e., lower spatial frequency band). His study proposed that the minimum image quality that still allows recognition corresponds to a 16x16 pixels image. He also used a Fourier (smooth) low-pass filter technique, which implicates the advantage of not add supplementary spatial frequencies, as the *pixelization* method does. With this kind of technique, the minimum image quality allowing an effective identification was 2.5 cycles per face, measured at eye level. In particular, a slight difficulty in recognition is noticed below 8 cycles per face and the same problem is observed for higher spatial frequencies (Fiorentini, Maffei & Sandini, 2013). In other words, the recognition of faces seems to be preferentially supported by a band of intermediate spatial frequencies that is, between 8 and 16 cycles per face (Costen, Parker & Craw, 1996; Näsänen, 1999). Though difficult, it does not mean that face recognition below 8 and above 16 cycles per face is not possible. Translating numbers into words, face identification could be more difficult when only coarse or only local information is available compared to intermediate values of the spatial frequency scale. Talking about the extremes, the information carried by very low spatial frequencies may suggest that a face is present, without the possibility for the person to recognize whose face it is. Similarly, the information provided by very high spatial frequencies may also be of little use, since they do not allow the extraction of three-dimensional portions of the face (Fiorentini, Maffei & Sandini, 2013). Since low spatial frequency is processed faster, as discussed above, it is the first used to extract the information from the visual stimulus, resulting in a coarse description of the object. The following accumulation of finer features, represented by higher spatial frequency information, provides a more accurate processing (Sergent, 1984). In some studies, indeed, researchers demonstrated that people were faster in recognizing faces that have been modified with a low-pass filter compared to the high-pass filtered ones (Goffaux, Hault, Michel, Vuong & Rossion, 2005). Furthermore, there may also be a developmental reason for using the low spatial frequency information as the first to process facial configuration that can be found in the observation of newborns’ vision, which has a low spatial resolution, making difficult for the babies to see the world around them in a good visual quality (Le Grand, Mondloch, Maurer, & Brent 2001). Moreover, though high spatial frequency information is more detailed and richer than the one carried by lower spatial frequency in face processing, it is time-consuming.

Although research on space frequency process of human faces has a relatively long history, the majority of the studies conducted until now were focused on face recognition. Less is known about perception of beauty in faces when the images have been modified with band-pass filters. Generally speaking, to say that a face is attractive requires that the information is rich enough. Nevertheless, it is still unclear whether attractiveness is carried by more coarse (LSF) or finer (HSF) information or instead, if beauty judgments are more accurate with medium frequencies. According to Bachmann (2007), the ability to make judgements upon facial beauty is strongly associated to the ability of establishing face identity. The author argues that if identity is hard to extract, beauty is impossible to determine. In his study, Bachmann found that, repetitively presenting the same image with systematically increased resolution, people made the first distinction between attractive and unattractive faces at a very low level of resolution (7 cycles per face), thus suggesting that the physical carriers of facial beauty are already present in the coarse information of faces. Furthermore, the author found that once perceived as attractive (or unattractive), a face remained in that category even after changes in the level of coarseness. Nevertheless, since there were exceptions in the data, it is not possible to talk about a universal precise value of spatial frequency for facial images where beauty suddenly appears or breaks down. Moreover, medium frequencies were excluded from the sample of images used in the study so that a complete range of spatial frequency was not investigated. However, it is possible to assume that, being attractiveness an important sociobiological cue, it would be useful to detect it rapidly. Therefore, lower spatial frequency information, which is processed faster, could actually be enough for the discrimination of beauty.

To ask which band of spatial frequency carries the most useful material in order to make effective decisions about facial beauty requires clarifying the distinction between the information that is carried by the lower and the higher spatial frequencies. As described above, low spatial frequency carries more global and coarse information, which, referring to faces, could be represented by the proportions and the general harmony of the face. Contrarily, high spatial frequency carries local information about details, the particular shape of every component of the face (e.g., the eyes, the mouth) and expression marks. From this idea, a consistent hypothesis can be shaped. If low spatial frequency information best correlates with broadband aesthetic choices, then it is likely that beauty is heavily based on global features (perhaps symmetry and the general proportions of the face). In contrast, if high spatial frequency best correlates with broadband aesthetic choices, it is likely that beauty is heavily based on local features (perhaps sexually dimorphic features that differ locally, e.g. nose and mouth shape, texture of the skin, etc.). Again, if medium spatial frequencies are the ones that best correlate with broadband aesthetic choices, then it is likely that both global and local features are in a certain proportion relevant to determine whether a face is attractive or not.

1.4 Investigating cognitive processes with eye tracking and pupillometry techniques

The majority of the studies conducted on perception of faces, their attractiveness and spatial frequency made use of some techniques for recording eye movements and pupil dilations. The history of research on eye movements started in the last decades of 1800 with Javial, who was the first in being interested in how eyes move while reading. Even though the tools and the techniques that we have at our disposition today are obviously more accurate and precise than the ones used by Javial and his colleagues, the goal is the same: discovering the cognitive processes that take place in the brain. Indeed, it is now established that eye movements, called *saccades*, and eye *fixations* reflect cognitive processing of the information registered. In the same way, pupil also gives us interesting information about the occurring cognitive processes. Indeed, researchers now agree that pupil dilation is an automatic and involuntary response not only to environmental variations (e.g., ambient light), but also to significant arousing stimuli, thoughts and emotions, independently of their valence (Goldwater, 1972; Janisse, 1973) and that it occurs following the onset of processing and decreases once the process is terminated (Beatty, 1982). Moreover, the magnitude of pupillary dilation is a function of the mental effort required to perform a task and therefore, pupillometry can be considered a valid tool for measuring task difficulty (Kahneman & Beatty, 1967). Furthermore, dilations of the pupil also occur in concomitance to fundamental cognitive mechanisms that may also take place before conscious perception is achieved, thus functioning, as Laeng, Sirois & Gredebäck (2012) proposed, as a window to the preconscious.

For what regards the processes taking place in people's brains when they are comparing faces of varying attractiveness, it is known that increased fixation time is reported for the most beautiful face (Leder, Tinio, Fuchs & Bohrn, 2010). Furthermore, eye tracking studies also support the difference in gender bias that women and men show when looking at same-sex and different-sex faces (Maner et al., 2003).

1.5 The purpose of the research

The goal of the present study is to comprehend which kind of information may be most relevant for the human brain to make judgements upon facial attractiveness. In particular, the first aim of this research is to understand which information - detailed versus global - is the most influential when it is the only information available for making attractiveness judgments. In other words, given five conditions, each of them representing one version of the same face, namely one low-pass filtered, one medium-low-pass filtered, one medium-high-pass filtered, one high-pass filtered and one broadband, in which filtered condition will the attractiveness judgments be best correlated with the answers given in the broadband condition? What one can hypothesize is that the lowest spatial frequencies conditions (i.e. low spatial frequency and medium-low spatial frequency information) may be sufficient for making effective judgments upon attractiveness of faces. Indeed, authors have suggested that global and configural information that is carried by the low spatial frequencies already contains the physical carriers of facial beauty (Bachmann, 2007). More specifically, we expect that in low and medium-low spatial frequencies conditions, choices will correlate best with those given in the broadband condition where all spatial frequency information is available in the image. Furthermore, not only low spatial frequency is considered to be the first used to extract a gist depiction of the face, but also finer details may provide only redundant information that may successively and progressively improve faces' representation (Goffaux, Hault, Michel, Vuong & Rossion, 2005). Bachmann's research demonstrates indeed that also when the resolution of pictures was gradually increased (i.e., from low to higher frequency pass filters), the faces that were judged as attractive or unattractive in the low spatial frequency condition were persistently perceived as attractive or unattractive in the higher spatial frequency conditions.

In addition, the study will avail of methods for the registering of eye movements and pupil dilations, which can give informative data regarding the cognitive processes taking place in parts of the brain controlling the allocation of attention (Just & Carpenter, 1993). In particular, the pattern of eye movements will permit to obtain information about which facial elements may be at the basis of the aesthetic preferences for faces. As widely discussed, several studies suggest that facial beauty captures and holds attention more than other objects. Additionally, authors suggest that beautiful faces are able to gain attention even when they are out of foveal vision (Chen, Liu & Nakanayashi, 2012). An analysis of the areas of interest (AOIs) will be carried out in order to examine which regions of the face are most considered, through gaze control, during decision making of attractiveness. It is not clear yet whether there is a predominant area of the face that is taken into consideration more than others when people make decisions upon facial beauty. What seems to be clear is that when people have to judge a close up of a face, they tend to look at specific regions (Judd, Ehinger, Durand & Torralba, 2009). In general, the areas that people usually find most interesting when they are looking at faces are eyes, nose and lips (Judd, Ehinger, Durand & Torralba, 2009; Hickman, Firestone, Beck & Speer, 2010). Remarkably, some studies showed that the location of the nose in the middle of the face captures much attention both when observers are asked to quickly decide on the gender of the face and during decisions on beauty (Sæther, Van Belle, Laeng, B., Brennen & Øvervoll, 2009). One reason why the nose region draws much attention may be found in evolutionary perspectives: being exposed and in a protruding position, the human nose is a particularly vulnerable region, which is often injured as a consequence of interpersonal violence. In this sense, an "intact" nose may be the physical signal of strength, similarly to the crest in roosters. A relevant research has investigated whether the position of the nose had an impact on beauty judgements and found that actually the "sense of attractiveness is affected more by the position of the nose than the mouth" (Mikalsen, Folstad, Yoccoz & Laeng, 2014). Being the nose positioned on an imaginary vertical axis for evaluating faces proportion, its location seems relevant for the perception of symmetry, a property that is known to affect attractiveness judgements (Perret, Burt, Penton-Voak, Lee, Rowland & Edwards, 1999; Evans, Wenderoth & Cheng, 2000). Furthermore, the human nose's shape and dimension as well as the mouth are dependent on sexual hormones levels and can therefore signal underlying reproductive qualities (Folstad & Karter, 1992). For these reasons, a predominant attention to the eyes, nose and mouth regions is expected from participants when they are asked to make a decision upon attractiveness between two faces of the same gender.

Finally, justified by research demonstrating the dense interconnection between the OFC, the LC and the pupil size, and in accordance with the studies showing the relevance of pupil dilation as a valid tool to "measure" task difficulty (Kahneman & Beatty, 1967; Beatty, 1982), the present experiment will avail of tools of pupil diameter recording. More specifically, since the mental effort required in order to perform a cognitive task can provoke a pupillary dilation (Beatty, 1982), it is expected that the pupil will be larger in difficult trials compared to the less difficult ones. In agreement with theorists arguing that two-alternative forced-choice tasks can actually be highly cognitively demanding (Leopold, O'Toole, Vetter & Blanz, 2001; Shimojo, Simion, Shimojo and Scheier, 2003; Kranz & Ishai, 2006; Chen, Liu, Nakabayashi, 2012), it is assumed that participants will find more difficult to express a preference between two similarly attractive faces compared to faces of very different beauty. Therefore, it is expected that pupil diameter will increase in trials where two faces of similar attractiveness are shown (difficult trials) and that it will progressively be less large with the increasing of the difference in beauty of the two faces (gradually less difficult trials).

2 Methods

2.1 Recruitment and sample

A total of fifty subjects were recruited for the research. Three additional people participated in the piloting study before the actual experiment took place. The size of the sample seems consistent with typical sample size in studies based on eye tracking techniques. Using a snowball sampling technique, participants were recruited among people living in Oslo. The sample was composed by 18 males and 32 females with age ranging from 19 to 37 (M = 25.44, SD = 4.16). Participants were requested to answer few personal and demographic questions on a paper questionnaire. In terms of education level, 4 participants declared to have earned a PhD, 25 a Master's degree, and 17 people indicated Bachelor's degree, whereas only 4 selected High School. In addition, the sample included two Arabic/Middle Eastern, 4 Asian/Middle Asian, 37 Caucasian, 6 Hispanic and 1 multiethnic participants. The majority of the subjects were right-handed (46) and 28 of them reported less-than-normal vision (myopia or astigmatism), which was corrected with eyeglasses or contact lenses. As a non-mandatory request, participants were also asked to indicate their sexual orientation (between males, females and both genders). All the participants answered the question; therefore, the sample was composed by 48 heterosexual and 2 homosexual people. All the participants were compensated with 100 NOK that they received through bank transfer.

2.2 Materials

Forty images of female faces and forty images of male faces were chosen among the ~200 present in the *Oslo Face Database* (Leknes, n. d.). All the faces included in the database have neutral expression and three positions of gaze, but only the ones with center gaze were chosen for the present study. The images were modified using MatLab and Photoshop softwares in the Cognitive Laboratories at the University of Oslo. Each face was placed on a 1680x1050 background and set to RGB 128 (middle gray). Using different band-pass filters and pairing the faces randomly, forty pairs of broadband faces (the original images), twenty pairs of low-pass filtered faces, twenty pairs of medium-low-pass filtered faces, twenty pairs of medium-high pass filtered faces and twenty pairs of high-pass filtered faces were obtained. Namely, the four frequency bands have been defined as following; low frequency: 0-05 cycles per degree;

middle-low frequency: 1.5-2.5 cycles per degree; middle-high frequency: 3.5-5.5 cycles per degree; high frequency: 6.5-10.5 cycles per degree (Figure 2). Each pair was always constituted by two faces of the same gender.

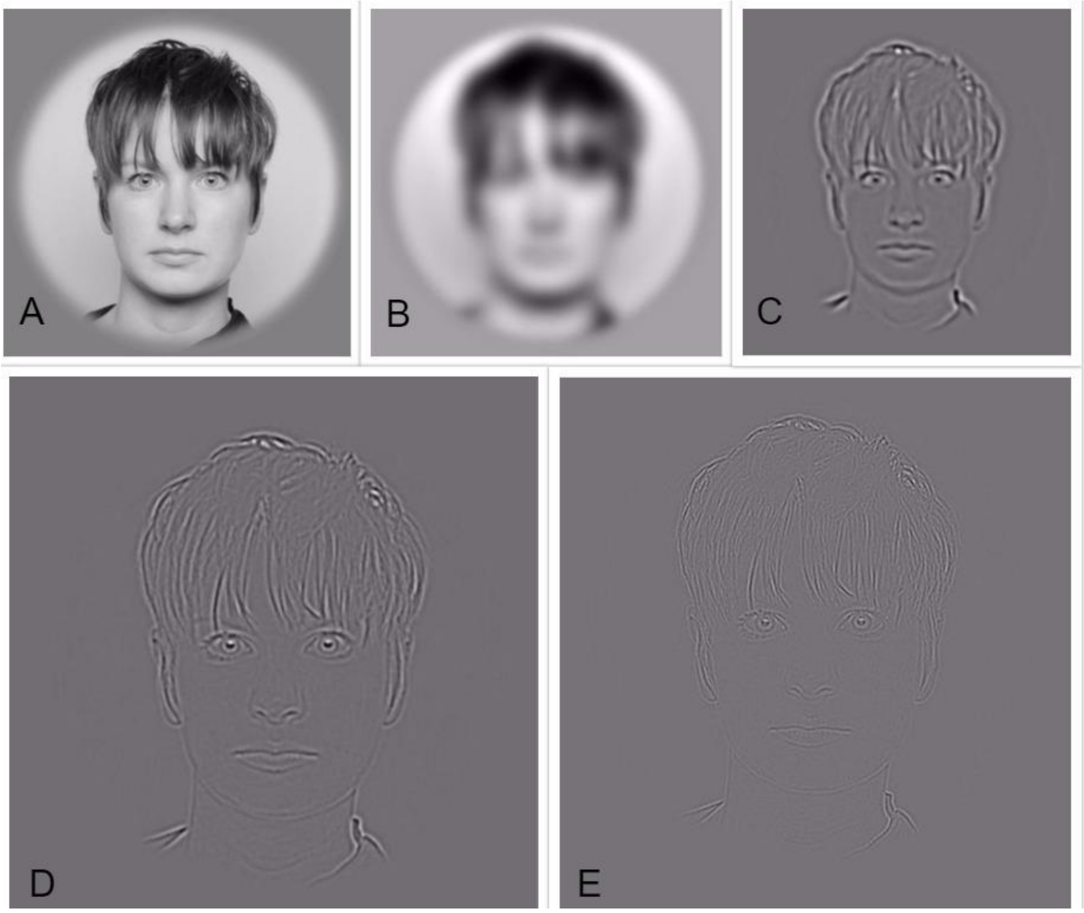

Figure 2. The first image (A) is an example of one of the broadband female faces, followed by the other versions of the same face photo obtained using four filters of different frequencies. Namely, low-pass filtered face (B), medium-low-pass filtered face (C), medium-high-pass filtered face (D) and high-pass filtered face (E).

Moreover, a group of 41 participants (21 females and 20 males with a mean age of 24.7, SD = 9.2) previously rated the beauty of all the faces used in the present research. The difference between the attractiveness ratings of the two faces included in each pair was indicated in the name of every stimulus.

Baselines for each pair of both filtered and broadband faces were created using Photoshop Software. In particular, a blank screen with the same average brightness of the stimulus' pixels (in HSL-RGB values) was used as baseline. Then, a fixation target was showed in the center of the baseline blank screen before each pair.

A paper questionnaire containing a brief survey of seven questions was submitted to participants prior to the experiment (see Appendix for the complete survey).

2.3 Procedure and apparatus

The experiment took place in the Cognitive Laboratory at the Department of Psychology at the University of Oslo and lasted approximately sixty minutes. Participants were received and guided to the Cognitive Laboratory where they were first requested to read and sign the consent form, answer a few demographic and personal questions on a paper and fill in a form for the honorary. The room was windowless and was artificially illuminated at a constant level.

Participants sat in front of a Dell P2213 VGA LCD monitor of 18.5" with a resolution of 1680x1050 pixels, which was positioned 60 cm far from the head support where they were asked to lean their chin and forehead. They were instructed to sit comfortably on the chair in front of the eye-tracker's desk and to adjust its height so that they could easily reach the chin-rest. They were asked not to move their head and their body too much during the experiment and remain as stable as possible. Thereafter, they were briefly explained the structure of the experiment and the different tasks they were going to complete, in addition to the keys they had to press on the keyboard in order to submit their answers.

The experiment included three distinct blocks. In the first block, 160 pairs of filtered images of males and females' faces (40 pairs of low-pass filtered faces, 40 pairs of medium-low-pass filtered faces, 40 pairs of medium-high-pass filtered faces and 40 pairs of high-pass filtered faces) were shown according to one randomized sequence one after the other (the randomized order was kept the same for each subject). Each image was preceded by a luminance-matched baseline image that stayed on screen for 1000 ms and then a fixation target that remained on the screen until the person looked at it for at least 1000 ms. Participants were asked to choose which one of the two faces they found more attractive and to press the correspondent keys that were marked with two stickers on the keyboard (B if the favorite face was the one on the left, N if they preferred the face on their right). Since the images stayed on the screen for five seconds, the participants were asked to make a decision within this span of time. The time chosen of five seconds was justified to be sufficient for participants to make a decision.

The second block of the experiment was a brief eye-tracking task used as a distractor between the first and third experimental blocks. Specifically, the subjects participating in the present experiment also constituted a control group of non-Chinese-speakers (the experimental group was made of Chinese-speakers) for a separate psycholinguistic study conducted by some researchers of the Department of Psychology at the University of Oslo. The task consisted in looking at 96 pictures presented on the screen for 6000 ms while a sentence in Chinese was played using speakers connected to the computer. This brief task was placed in between the two blocks of the experiment and served as a break that might have prevented participants from remembering their responses given in the first block while completing the third one.

In the third block, the broadband version of the same 160 pairs of males and females' faces shown in the first block were presented in the same randomized sequence one after the other (also in this case, the order of presentation was the same for each subject). Each image was preceded by a baseline image that stayed on the screen for 1000 ms and a fixation target that remained on the screen until the person looked at it for at least 1000 ms. The task was exactly the same as the first one.

Figures 3a and 3b show respectively a trial of the first section (filtered faces) and a trial of the third section (broadband faces) of the experiment.

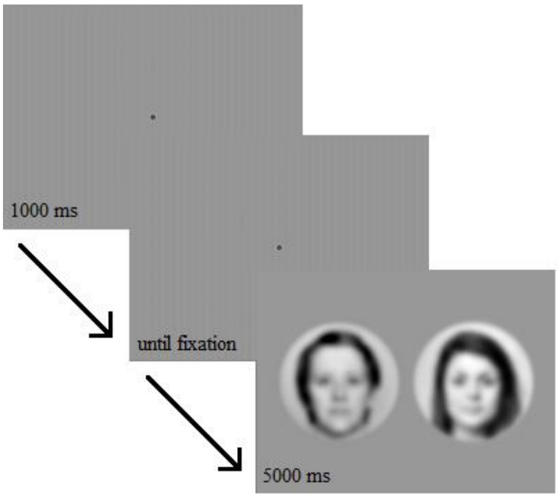

Figure 3a. One trial of the first block of the experiment (filtered faces).

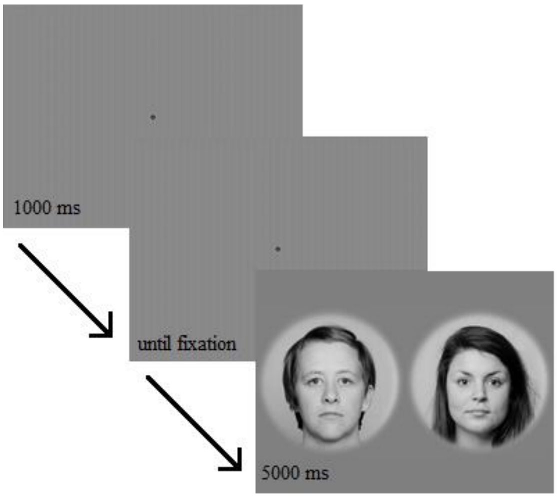

Figure 3b. One trial of the third block of the experiment (broadband faces).

The experiment was run on a Dell Latitude E6530 powered by an Intel i7-3520M CPU, running Windows 7 at 32 bit, using the SMI Experiment Center 3.2.17 Software. During the whole experiment, pupillary movements were recorded with iView X Hi-Speed Software, using a Remote Eyetracking Device (SensoMotoric Instruments GmbH) at a sampling rate of 60 Hz.

Every block in the experiment was preceded by a calibration procedure for the eye tracker. Participants were asked to follow with their eyes a moving white dot that stopped in four different fixed positions of the screen. After the calibration, a validation procedure was performed in order to estimate the precision of the gaze. Furthermore, after each block, participants could have a few minutes break to relax their eyes.

During the experiment, answers, reaction times, eye movements and pupil dilations were recorded.

3 Results

Results were organized and analyzed using SMI BeGaze, Microsoft Excel, SPSS and StatView softwares.

3.1 Behavioral data

Participants' key presses for the two blocks of the experiment were extracted using SMI BeGaze analysis software and the acquired data were organized in Microsoft Excel. Each response was converted in right or left preference (N corresponded to right preference and B corresponded to left preference). For each face shown, the number of times it was chosen was reported. Since the number of times each face appeared in the five conditions was not always the same, the relative frequencies of choices were calculated.

Following an innovative way of proceeding, a statistical analysis by item was performed in order to reveal a possible correlation between the preferences calculated for each face in the four filtered conditions (low-pass filtered, medium-low-pass filtered, medium-high-pass filtered and high-pass filtered) and the broadband condition. In particular, four simple linear regressions were calculated to predict the preference for each face in the broadband condition based on the choices registered in each of the four filtered conditions. The preferences measured in all the filtered conditions positively correlated with the answers given in the broadband condition. Namely, a significant regression equation was found for low frequency condition (F (1,54) = 35.986, p < .0001), with an R of .632; for medium-low frequency condition (F (1,57) = 146.502, p < .0001), with an R of .848; for medium-high frequency condition (F (1,50) = 131.126, p < .0001), with an R of .851; for high frequency condition (F (1,55) = 78.699, p < .0001), with an R of .767. It can be noticed that the highest R-value is .851, which indicates a very high degree of correlation between the relative frequency of choices between medium-high frequency and broadband conditions. The R-value correspondent to the correlation between medium-low frequency and broadband conditions follows with an almost equally strong relationship.

Successively, in order to discover any possible difference of data registered for female and male faces, simple regression analyses were performed again separately. Then, independent sample t-tests have been conducted in order to find any significant difference between the regression coefficients. Thus, four independent sample t-tests have been performed. Interestingly, there was one significant difference in the slopes found for medium-high frequency filtered condition predicting broadband preferences differently for female (b = .874, SD = .086) and male (b = .623, SD = .094) faces; t(48) = 1.97, p = .05. Furthermore, another almost significant difference was revealed for the slopes found for high frequency condition, which revealed a difference between female (b = .850, SD = .099) and male (b = .566, SD = .122) faces; t(49) = 1.8, p = .07. In general, the strongest correlations found for female faces were between preferences registered in the broadband and medium-high and high filtered conditions, whereas the strongest correlation found for male faces was between preferences given in the broadband and medium-low filtered conditions.

3.2 Eye tracking data

In order to study participants' pattern of fixations on faces while completing the task, four different areas of interest (AOIs) have been created for each face of every pair, using the AOI Editor Tool on SMI BeGaze Software. The areas of interest, which were all made equal in terms of covered area, were the following: forehead, eyes, nose and mouth (Fig. 4).

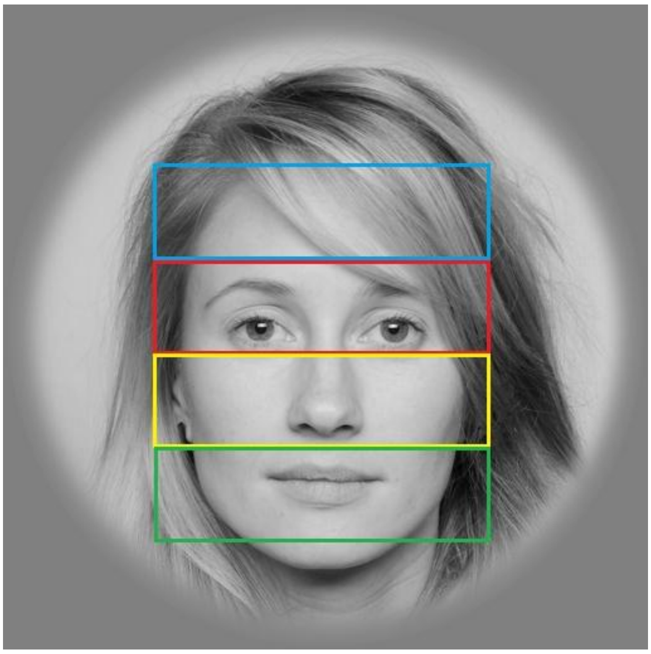

Figure 4. The image shows how the four AOIs were built for each face. From the top, the AOIs are forehead, eyes, nose and mouth.

The AOIs were chosen following the “bar codes” approach suggested by Dakin and Watt (2009). Indeed, the authors proposed that face decoding benefits most from the information included in horizontal bands. The bands, constituting the “bar code”, are due to light-reflectance properties of faces and are consistently correspondent to the different parts of the face. Moreover, the “bar code” is present both in coarse-scale and in finer-scale face images and are highly resistant to variability of face features.

An AOI detailed statistic was run on SMI BeGaze Software in order to gain data about the percent average fixation time for each subject, which corresponds to the percent time participants spent in looking inside the AOIs. The “white space”, which refers to the screen area that was not covered by the AOIs that were manually created, was automatically calculated as an additional AOI, but not considered in the analyses, since it is unspecific to location. The obtained data were successively completed on Microsoft Excel with further information about participants and faces’ gender and the filter condition to which each stimulus belonged.

A four-way ANOVA was performed in order to analyze the effect of the four independent variables (Sex of Participants, Sex of Faces, Spatial Frequency and AOI) on the Mean Percentage Fixation Time as the dependent variable.

The Sex of Participants and Faces variables had two levels each: we will refer to the terms “woman” and “man” for participants’ gender and to “female” and “male” for the stimuli faces’ gender; the Spatial Frequency variable had five levels (Broadband, Low Spatial Frequency, Medium-Low Spatial Frequency, Medium-High Spatial Frequency and High Spatial Frequency); the AOI variable had four levels (Forehead, Eyes, Nose and Mouth).

The ANOVA revealed that all four main effects of the independent variables on the dependent variable were significant.

Sex of Participants effect, $F(1,48) = 15.024$, $p = .0003$, revealed that women looked more inside the AOIs compared to men, while Sex of Faces effect, $F(1,48) = 22.241$, $p < .0001$, showed that female faces were more attended (within all areas of interest) than male faces. The main effect of Spatial Frequency on Fixation Time, $F(4,48) = 13.546$, $p < .0001$, revealed that the time participants spent in looking inside the AOIs progressively grew with increasing spatial resolution with a maximum value for the Broadband condition. Nonetheless, a Tukey post-hoc analysis did not reveal any significant difference between the effects that each frequency condition had on the dependent variable. The effect of AOI, $F(3,48) = 60.925$, $p < .0001$, showed that the Eyes constituted the most attended area of the face, ordinarily followed by Nose, Mouth and Forehead.

The ANOVA also revealed several interesting interaction effects. A significant interaction effect of Sex of Faces*Sex of Participants, F (1,48) = 16.359, p = .0002, revealed that men spent more time in looking at female faces compared to male faces, while there was no difference in looking at opposite-sex and same-sex faces for women. These results are consistent with previous research (Maner et al., 2003; Nummenmaa, Hietanen, Santtila & Hyönä, 2012), demonstrating that while men generally spend more time in looking at opposite-sex faces compared to same-sex faces both in beauty-judgements and sex-recognition tasks, women do not show a difference in time spent in looking at female and male stimuli.

A relevant interaction effect of Sex of Face*Spatial Frequency, F (4,192) = 4.267, p = .0025, revealed that the previously shown main effect of Spatial Frequency on Fixation Time was only slightly present for male faces, while female faces were almost equally looked in all the five conditions.

A further significant interaction effect was found for Sex of Face*AOI, F (3,144) = 9.203, p < .0001. The effect revealed that the most attended AOIs in female faces were Eyes and Nose, while the most attended one in male faces was the Mouth. The results seem logical and in line with the literature, which argues that eyes and cheeks shape (contained in Nose AOI in the present study) are important areas of femininity in female faces, which is strongly correlated to attractiveness rates (Koehler, Simmons, Rhodes & Peters, 2004; Johnston, Hagel, Franklin, Fink & Grammer, 2001), while Mouth AOI also contained chin and jaw, which are known to be relevant in masculinity and attractiveness judgements in male faces.

The interaction effect for Spatial Frequency*AOI was also found to be statistically significant, F (12,576) = 6.288, p < .0001, and revealed that Eyes and Nose were the most attended AOIs in every Spatial Frequency condition. A Tukey post-hoc analysis revealed a significant difference in Fixation Times on Eyes between the Low Spatial Frequency and the Broadband conditions (p = .008) and on Mouth between the Low Spatial Frequency and the Medium-High Spatial Frequency conditions. In general, an augmenting of Fixation Times on Mouth has been registered with increasing Spatial Frequencies.

Although Peyrin et al. (2006) found differences between women and men in processing low and high spatial frequencies, no significant interaction effect of Spatial Frequency*Sex of Participants was registered on Fixation Time dependent variable.

A three-way interaction effect for Sex of Participants*Sex of Face*AOI was also found to be statistically significant, F (3,144) =2.583, p = 0.05 (Fig. 5).

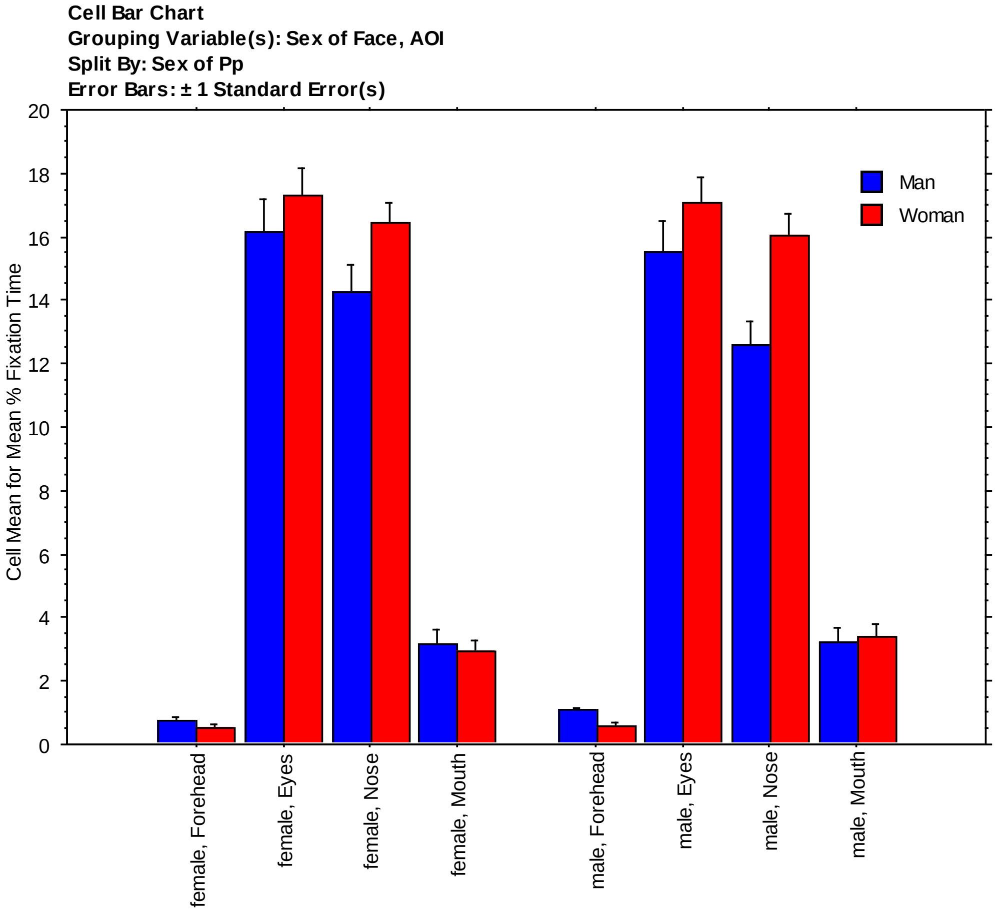

Figure 5. The graph shows the three-way interaction effect for Sex of Participants*Sex of Faces*AOI on the dependent variable Mean Percentage Fixation Time.

The analysis explained the previously presented main effects of the three independent variables on the Fixation Time. A Tukey post-hoc analysis revealed several further significant differences between the time that women and men spent in looking at specific AOIs in female and male faces. Namely, a statistically significant difference was found in time that women and men spent in looking at the Nose of female faces (p = .049) and in male faces (p = .002). More specifically, Nose AOI was more attended by women both in female and in male faces. In general, the data are in line with the main effect of Sex of Participants on the dependent variable, showing that women overall looked more inside the AOIs compared to men.

Lastly, another three-way significant interaction effect was found for Spatial Frequency*Sex of Face*AOI, F (12,576) = 4.925, p < .0001 (Fig. 6).

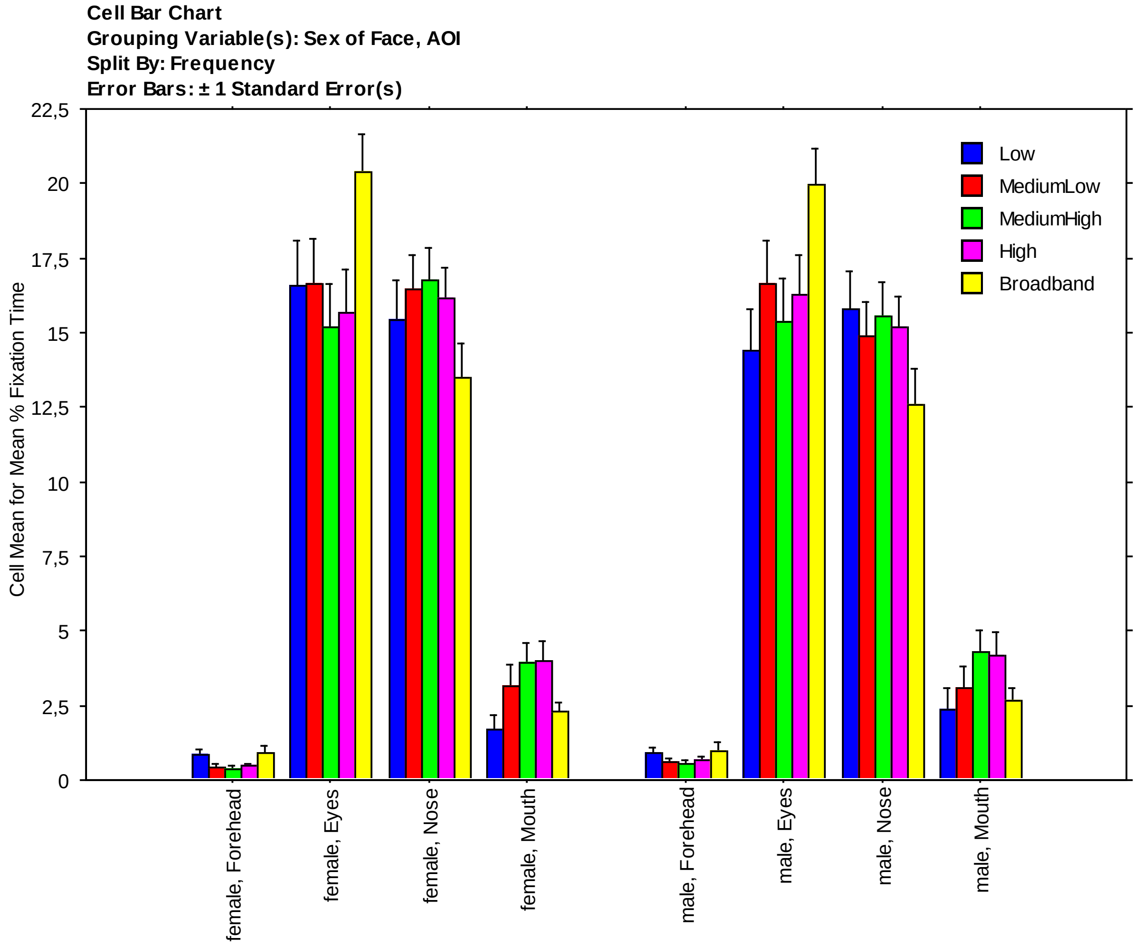

Figure 6. The graph shows the three-way interaction effect for Spatial Frequency*Sex of Face*AOI on the dependent variable Mean Percentage Fixation Time.

The analysis confirmed the effect of AOI independent variable on Fixation Time dependent variable. By looking at the graph, it is possible to observe that male faces' Eyes are progressively more attended with increasing spatial resolution of the images, while an opposite effect is visible for males' Nose. Interestingly, for female faces, we can observe a reverse tendency: it seems, indeed, that females' Eyes are more attended in the lower Spatial Frequencies and less looked in the higher, while an augmenting of Fixation Times is registered for females' Nose with increasing Spatial Frequency of pictures. An equal tendency in looking progressively more at the Mouth with increasing Spatial Frequency is registered both for female and male faces.

Successively, by summing up the Fixation Times registered for all the AOIs per each face, simple regression analyses were performed in order to discover whether the preference of a face could be predicted by the time spent in looking at it. As one could expect, in each pair of both female and male faces and in every condition, the preferred face was the one that was most attended by participants (Fig. 7).

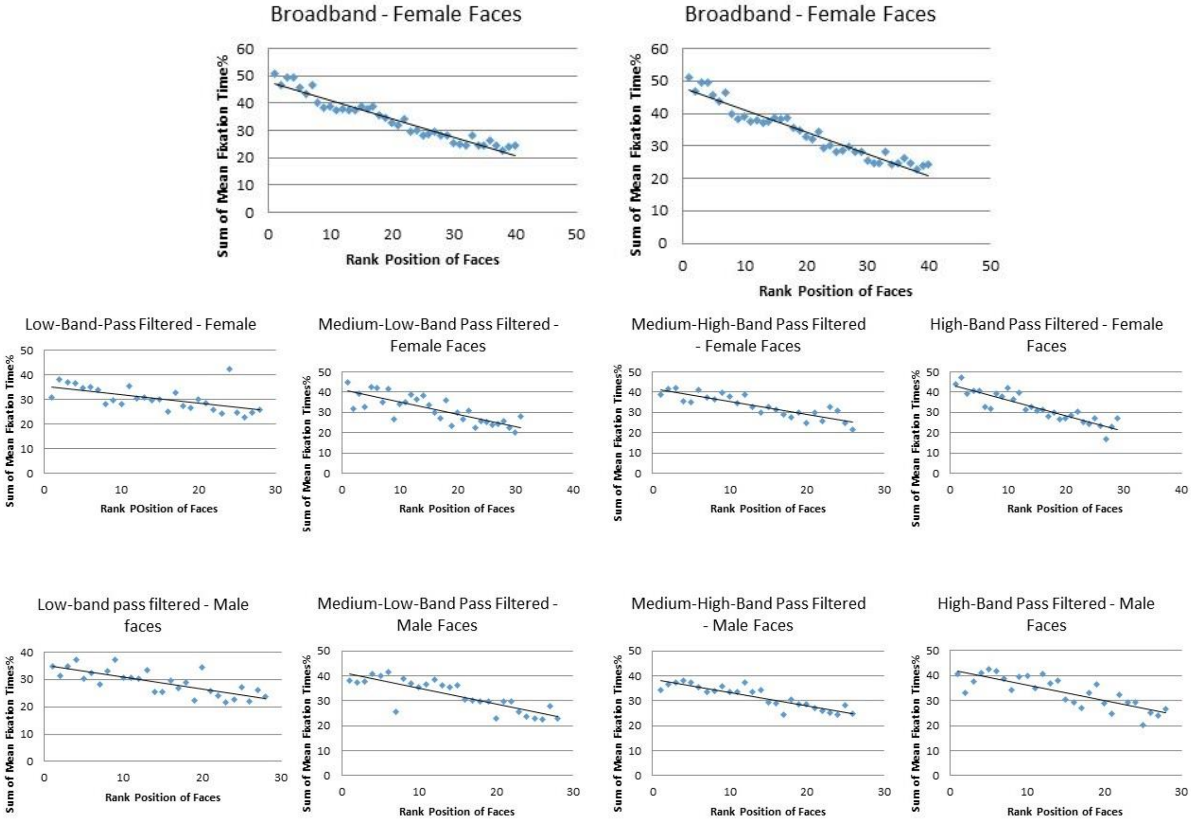

Figure 7. The graphs show the linear correlations observed for female and male faces in each condition between the position in the classification of each face and the relative mean fixation times calculated for all the AOIs of the face.

3.3 Pupillometry data

In order to investigate a possible relation between the mental effort required by the different trials of the task and pupil size, pupil dilations were recorded both for broadband and filtered conditions. Using SMI BeGaze Software, pupil diameters correspondent to each fixation on every stimulus were extracted. Pupil baselines for each stimulus were calculated by averaging the pupil dilations measured for each fixation on the baseline images. Equally, pupil dilations registered for all the fixations on each pair of faces were averaged in order to obtain a correspondent mean pupil dilation value for each stimulus. By performing a baseline-correction, it was possible to measure how the pupil diameter changed from the baseline in correspondence of each pair.

It must be noticed that environmental luminosity was kept at a constant level for the whole duration of the experiment in order to prevent pupillary dilations caused by sudden luminance variations.

Therefore, two simple linear regression analyses were performed on SPSS in order to determine whether the difficulty of the trial, given by the difference of beauty ratings of the two faces of each pair, could affect the pupil diameter in broadband and in filtered conditions. Unfortunately, the quality of the prediction of the dependent variable (baseline-corrected pupil diameter) on the independent variable (difference of facial beauty between the faces) was very low both in broadband (R^2 = .001) and in filtered (R^2 = .001) conditions.

Furthermore, a repeated-measures ANOVA was performed in order to analyze how the pupil size changed in correspondence to each of the five spatial frequency conditions. The analysis reveal an interesting result (Fig. 8).

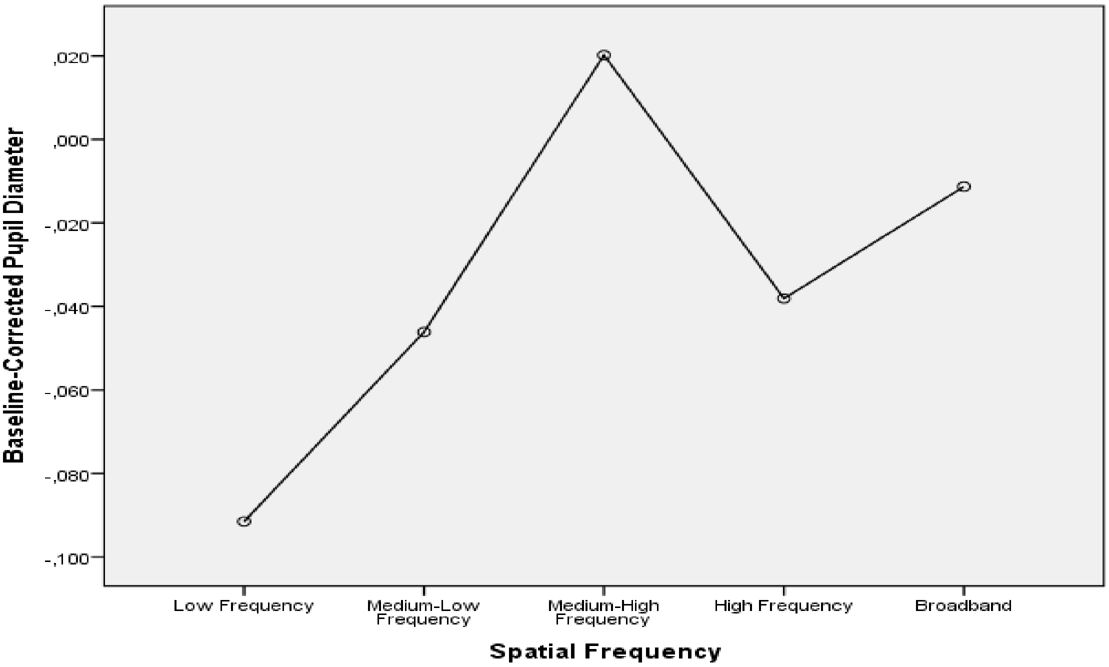

Figure 8. The graph shows how pupil size changed in correspondence of each of the five spatial frequency conditions.

Namely, it is noteaceble that a gradual enlargement of pupil diameter was registered with increasing spatial frequencies from Low to Medium-High Frequency conditions and in correspondance to the latter a significant peak was registered. Pupil diameter tended to decrease again in relation to the High Frequency condition. The value of pupil diameter observed in correspondence to the Broadband condition was more similar to the ones registered for the medium and the high spatial frequencies compared to the pupil size registered in the Low Spatial Frequency condition, where the minimum value of pupil diameter was registered.

4 Discussion

As Rhodes (2006) wrote in his review, “there are few more pleasurable sights than a beautiful face”. The reason why facial beauty has progressively gained more and more importance in research is that not only it has a relevant role in activating the reward centers of the brain in the same way as other stimuli do, but it also has the ability to communicate significant information about one person’s health and personality, it motivates sexual behaviors and reproduction strategies. That is why beyond the meticulous attention that people often have towards their faces’ appearance, it is hidden something more than just an ephemeral and useless vanity.

The present study moves towards the direction of understanding what people usually look for in other same-sex and other-sex faces with a specific attention to what is considered global and local information. If global information includes more general and coarse features, like symmetry, the proportions, and in general the harmony of a face, the local information refers to details and the specific characteristic elements.

Namely, the goal of the present research was to determine which kind of information, between global and local, could be the most relevant when judging a face’s attractiveness. In other words, the main question that drove the study regarded the possibility that one kind of information between coarse and detailed could have a heavier “weight” than the other one while making decisions upon facial beauty of two faces of the same gender. In order to answer this question, broadband and band-pass filtered pairs of same-sex faces (both female and male) were shown to participants, whose task was to decide which face they found more attractive. Four levels of spatial frequency were used in the “filtered faces” condition, namely: low spatial frequency, medium-low spatial frequency, medium-high spatial frequency and high spatial frequency. Given that lower spatial frequencies carry more global and coarse information, whereas the higher ones convey more detailed or local information, the preferences registered for each of the four spatial frequency conditions were compared with the answers given in the broadband condition in order to find which filtering level correlated best to the condition where all the information is available. Furthermore, eye tracking method was employed in order to obtain much more information about which regions of the face people usually scrutinize while judging someone else’s facial beauty and, more specifically, which areas may be the most relevant and useful when part of the information is missing (i.e., in the filtered conditions).

Based on previous research, it was hypothesized that information carried by lower spatial frequencies (in this study, low spatial frequency and medium-low spatial frequency) would have been sufficient for making judgements upon facial beauty and also that the answers given in these conditions would have best correlated with the ones registered in the broadband condition. Indeed, Bachmann (2007) suggested that global and configural information, which is carried by the lower spatial frequencies, already contains the main physical cues of facial beauty. Furthermore, researchers argue that not only information carried by low spatial frequency is the first used to extract a gist depiction of the face, but also that more detailed information may only convey redundant material (Goffaux, Hault, Michel, Vuong & Rossion, 2005). This assumption was indeed confirmed by Bachmann's study (2007), which found that when the resolution of pictures was gradually increased (i.e., from low to higher spatial frequencies), the faces that were judged as attractive or unattractive in the lower spatial frequencies conditions were persistently perceived as attractive or unattractive also in the higher spatial frequencies conditions.

Moreover, based on literature, it was expected that the central areas of the face, namely eyes, nose and mouth would have been the most attended, constituting some of the most important cues of sexual dimorphism in the face.

Results revealed several interesting and statistically reliable effects that to some extent confirmed the previously described expectations. Indeed, the regression analyses that were separately performed for female and male faces and eye tracking data revealed that substantial differences exist in processing female and male faces' attractiveness, consistent with previous research (Maner et al., 2003). Namely, by performing separate analyses on the preferences, the responses given in the medium-low spatial frequency condition were the ones that best correlated with those given in the broadband condition for male faces. Contrarily, the best correlation for female faces was found between broadband and medium-high spatial frequency conditions. From the first observations it is therefore deducible neither that one extreme nor the other gives the most useful material for making effective judgements. In according to Parker and Costen (1999), it might be the "golden mean" (i.e., between 7.85 and 15.69 cycles per face) that carries the most useful information.

Furthermore, analyses on the data that were obtained with eye tracking methods revealed interesting effects, which were consistent with the behavioral information. In particular, the effect of the different spatial frequency bands affected in different ways the fixation times registered for each AOI, either in female or male faces. Differences of tendencies were indeed revealed for female and male faces concerning the most attended AOI with increasing spatial frequency. More specifically, as spatial frequency was increased, males’ eyes were looked progressively more and males’ nose was gradually less attended. This means that participants’ gaze gradually shifted from the nose to the eyes with increasing spatial frequency. This phenomenon can be accounted for by considering that each face’s AOI (at least, the ones that were chosen for the present study) provides both local and global information, which are more or less available under band-pass conditions. The fact that participants spent more time on males’ nose compared to eyes in the low spatial frequency condition and that this tendency is progressively overturned with the gradual increasing of spatial frequency, could mean that for low-pass filtered images the nose delivers more important information than the eyes and in particular when people have to decide upon beauty of two male faces. Being the nose at the center of both the vertical and horizontal axes of the face, it is presumable that it constitutes the most important element in evaluating the proportions, the configural relations and the global harmony of a male face, consistent with the study by Thornhill and Møller (1997). When the spatial frequency is gradually increased, the nose becomes less and less visible so that it is probably gradually more difficult to make an effective evaluation on a male face’s global symmetry and proportions based on it. For this reason, participants may have moved their gaze towards another AOI that carries useful global and configural information of the face. Eyes, being two and being horizontally centered, may indeed convey relevant information on faces’ proportions, or at least more relevant than the one carried by the nose region in higher spatial frequencies conditions. It is therefore assumable that male faces’ beauty is judged based more on the information carried by the lower spatial frequencies compared to the higher spatial frequencies and, in other words, global information seems to be more relevant than the local one. Importantly, these results are consistent with the previously presented behavioral data that revealed that preferences in the broadband condition best correlates with the ones registered in the medium-low spatial frequency condition.

Interestingly, the opposite tendency is instead registered for female faces. Indeed, if the females’ noses were looked progressively more with increasing spatial frequency, then the females’ eyes gradually attracted less attention. In other words, participants’ gaze gradually moved from eyes to nose. In this case, it may be possible that participants directed gaze differently in the higher spatial frequencies when the local information became available (i.e., towards the nose region). However, we should note that the AOI of the nose used in the present study also included the cheeks, which are known to be relevant elements when judging female faces' femininity, which is strongly correlated to attractiveness (Koehler, Simmons, Rhodes, & Peters, 2004). It can be assumed that not only the shape of the nose, which previous studies revealed to be important in judging facial beauty (Sæther, Van Belle, Laeng, B., Brennen & Øvervoll, 2009), but also the profile of the face at the level of the cheeks attracted participants' attention more than eyes once local information became available. Thus, female faces' beauty may be judged more on the information carried by higher spatial frequencies compared to lower spatial frequencies because local information is more relevant for this sex than the global one. Notably, these results are consistent with the previously showed behavioral data that revealed that preferences in the broadband condition best correlates with the ones registered in the medium-high spatial frequency condition.

In contrast to the above sex-related findings, fixation times registered for the forehead and the mouth AOIs showed the same tendencies both for female and male faces. Namely, an augmenting in time spent in looking at the mouth region was registered with increasing spatial frequency. This effect may mean that the mouth region includes both local and global relevant information and that both are progressively more available in the higher band-pass filtered conditions. Indeed, with increasing spatial frequency not only the shape but also the detailed position of the mouth became more and more visible and perhaps provided additional information about the symmetry of the face, although less saliently than the nose (Mikalsen, Folstad, Yoccoz, & Laeng, 2014).

The fact that in the broadband condition the eyes constituted the most looked AOI and that the nose comes in second position both for female and male faces may be both a normal consequence of social interactions that usually bring people to look others in the eyes and a strategy of anchoring gaze. A recent study found indeed that people tend to preferentially attend to a precise area located between the eye and the nose while judging frontal faces' sex in order to quickly gain all the information needed for completing the task (Sæther, Van Belle, Laeng, Brennen & Øvervoll, 2009) and this region was included in eyes AOI in the present research.

These explanations are also consistent with the effects that the different spatial frequency bands had on the time that participants spent in looking at female and male faces. Indeed, a progression in fixation times inside the AOIs is noticeable with increasing spatial frequency. When data are analyzed separately for female and male faces, they show that this phenomenon is slightly present for male faces, while female faces are equally looked in each condition. This means that while participants looked more to female faces, they tend to look slightly more away (outside of the AOIs) when they were judging male faces, especially in the lower spatial frequencies conditions. It may be possible that the global information carried by the lower spatial frequency conditions (i.e., symmetry and proportions) of two male faces was evaluated by looking at a central region between the two faces in order to quickly and simultaneously compare the information. Since this presumed area in the middle of the two faces was outside the created AOIs, it was automatically included in what was considered "white space" and discarded from the analysis, resulting in a decreasing of the registered fixation times. The ability of people to judge facial attractiveness when the stimulus is presented in the parafovea is consistent with previous research that found that the visual system is able to use the lower spatial frequencies to perform rapid evaluations on facial beauty (Guo, Liu & Roebuck, 2011). The fact that a similar phenomenon was not measured for female faces may once again confirm that the relevant information that is most useful in order to make effective decisions upon female faces' beauty is contained in details that can be best appreciated by fixating within the face itself. Furthermore, a study by Cellerino, Borghetti and Sartucci on gender recognition using band-pass filtered faces (2004), revealed that less information is needed to effectively identify a male face compared to the one needed to recognize a female face and that the information carried by the low spatial frequency is sufficient in order to recognize a male face, but not a female face, whose identification is only possible when information carried by higher spatial frequencies are available. If, as Bachmann (2007) argues, judgements upon facial beauty are only possible once the identity of the face is established, it is deducible that decisions on males' facial beauty are feasible with low spatial frequencies, whereas judgements on females' facial beauty may only be possible with information provided by higher spatial frequencies.

As expected, eye tracking data confirmed that participants spent more time in looking at their preferred face compared to the non-preferred one and that this was true both for the broadband and the filtered conditions.

The only relevant difference that was found between women and men regarded the time spent in looking inside the AOIs of same-sex and opposite-sex faces. While women spent equal time in looking at female and male faces, men spent more time in looking at opposite-sex than the same-sex faces. This result was consistent with previous research (Maner et al., 2003; Nummenmaa, Hietanen, Santtila & Hyönä, 2012) showing that while men generally spend more time in looking at female than male stimuli both in beauty-judgements and sex-recognition tasks, women tend to look equally long at female and male stimuli. Since no significant difference was found for fixation times registered for women and men in the different filtered conditions, it is not deducible that a gender difference exists in processing lower and higher spatial frequencies.

In accordance with previous studies assessing pupillometry as a valid tool for determining mental effort (Kahneman & Beatty, 1967; Beatty, 1982), pupillary dilations were recorded in order to "measure" the difficulty of the task. In particular, it was expected that participants would have found more difficult to express a preference between two faces of similar attractiveness (i.e., with a small difference between their beauty ratings) and that it would have been progressively easier to choose the most attractive face of a pair with increasing difference between their beauty ratings.

Unfortunately, analyses revealed a too weak model to be considered significant, presumably because of the large variations of data.

Finally, analyses revealed a significant difference in pupil size correspondent to each of the five spatial frequency conditions investigated in the present research. Namely, a gradual enlargement of pupil diameter was observed with increasing spatial frequencies from the low to the medium-high frequency filtered conditions (where the maximum peak of pupil dilation was registered) and it tended to decrease again in correspondence to the high spatial frequency filtered condition. The value of pupil size reigistered in relation to the broadband condition tended to be more similar to the ones observed for the medium and high spatial frequencies conditions (medium-low, medium-high and high spatial frequencies) compared to the pupil diameter reigistered for the low spatial frequency condition, where the minimum value of pupillary dilation was observed. These data may reveal that participants found more cognitively demanding to make decisions on facial beauty of two faces of the same gender in broadband, medium and high-pass filtered pictures compared to the low-pass filtered images. Since, it is established that pupillary dilations reflect the cognitive processes undergoing in the brain Goldwater, 1972; Janisse, 1973; Beatty, 1982), it is possible that the pupil variations registered during the present experiment reflect the cognitive operations taking place in the brain while processing the information carried by the different spatial frequencies. Being the information conveyed by the low spatial frequency processed faster than the one provided by the higher spatial frequencies (Bullier, 2001; Holmes, Winston & Eimer, 2005), it is possible that less cognitive effort is needed in order to detect global information compared to local information that is provided by higher spatial frequencies.

4.1 Limitations and recommendations for future research

One specific limitation must be considered in the research.

The way AOIs were created conveyed sufficiently relevant information, being the present study the first in asking which features of female and male faces might be the most relevant when deciding upon facial attractiveness. Nevertheless, a more detailed subdivision of the different regions of the face would have probably provided further interesting data. Namely, a partition that takes into consideration the global and the local features that each AOI carries could provide more precise information (e.g. separating the nose from the cheeks). That is, by adding a supplementary AOI in the middle of the two faces, it would be possible to understand whether the fact that male faces were looked less in the lower spatial frequencies conditions and gradually looked more in the higher could be linked to a particular strategy of simultaneous evaluation of global features of both faces.

Future research should therefore evaluate taking these modifications into consideration in order to confirm and complete the results of the present study.

5 Conclusion

In conclusion, it seems possible to answer the question about which kind of information, between local and global, is the most useful to judge facial attractiveness. However, the answer is not a clear-cut one, since both of them are relevant but in different proportions.

First, the present research highlighted that neither very low nor very high spatial frequencies carry sufficiently useful information to perform judgements on faces' beauty, compared to medium-level ones. Instead, confirming previous studies, medium spatial frequencies seem to be the ones that provide the optimal information.

Furthermore, the present findings revealed a slight difference between female and male faces that may lead to the deduction that people tend to have different strategies and look at different features of the face while judging each sex's attractiveness. Namely, it appears that while local features are more important than the global ones in evaluating female faces' beauty, the opposite effect may be true for male faces. For this reason, lower spatial frequencies seem to carry sufficient information in order to judge a male face's attractiveness, while female faces require higher spatial frequencies information.

Moreover, it seems that judging the facial attractiveness of two same-sex faces is less cognitively demanding when the global information is the only one available (i.e., in the low-pass filtered condition) compared to the other band-pass filtered and broadband conditions.

Future research is needed in order to furtherly confirm the present discoveries and should consider a more varied and detailed set of AOIs in order to increase the precision of the analyses.

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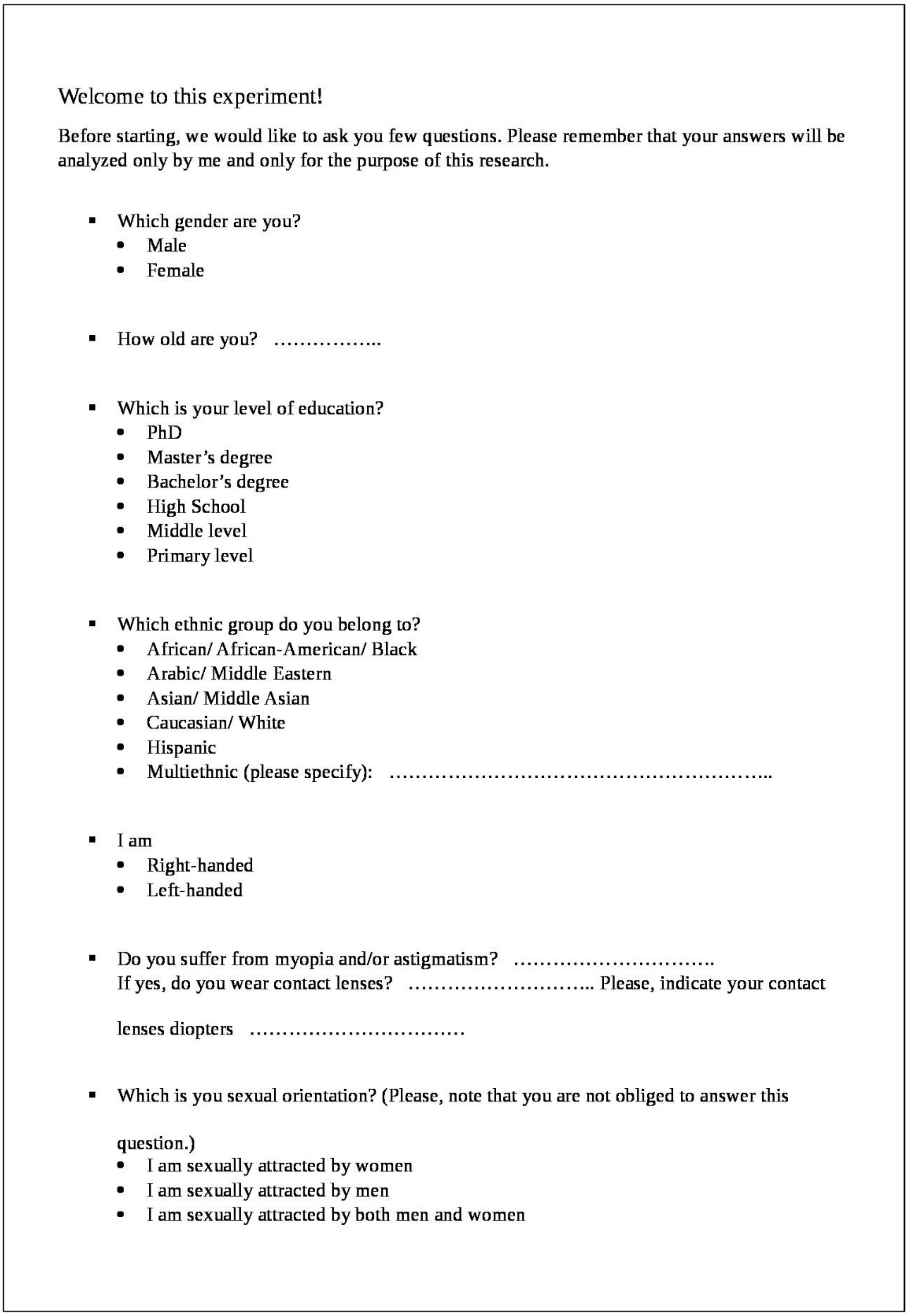
Appendix



Welcome to this experiment!

Before starting, we would like to ask you few questions. Please remember that your answers will be analyzed only by me and only for the purpose of this research.

- Which gender are you?
  - Male
  - Female

- How old are you? ……………..

- Which is your level of education?
  - PhD
  - Master's degree
  - Bachelor's degree
  - High School
  - Middle level
  - Primary level

- Which ethnic group do you belong to?
  - African/ African-American/ Black
  - Arabic/ Middle Eastern
  - Asian/ Middle Asian
  - Caucasian/ White
  - Hispanic
  - Multiethnic (please specify): …………………………………………………..

- I am
  - Right-handed
  - Left-handed

- Do you suffer from myopia and/or astigmatism? ………………………….
  If yes, do you wear contact lenses? ……………………….. Please, indicate your contact lenses diopters ……………………………

- Which is you sexual orientation? (Please, note that you are not obliged to answer this question.)
  - I am sexually attracted by women
  - I am sexually attracted by men
  - I am sexually attracted by both men and women