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Spatial frequency bands used by patients with glaucoma to recognize facial expressions

Running head: Face recognition in glaucoma

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SYNOPSIS

We investigated the contribution of spatial frequencies as mechanisms for impaired face perception in glaucoma. Patients exhibit a deficit in both low and high frequencies potentially leading to misinterpretation of some facial expressions.

ABSTRACT

The authors investigated the influence of spatial frequencies in foveal vision in glaucomatous patients in a recognition task of facial expressions. Nineteen patients, 16 age-matched and 14 young controls saw centrally presented photographs of faces. Participants categorized the facial expressions as happy, angry or neutral. Two versions were tested: filtered faces of either low (LSF) or high (HSF) spatial frequency content and hybrid faces constructed from a face with LSF content superimposed on a face with HSF content with differing facial expressions. Compared to age-matched controls a significant deficit was observed both on HSF and on LSF filtered faces for patients. Controls, but not patients, were biased towards the HSF component of the hybrid faces. Different spatial frequencies are normally used to recognize different facial expressions. Impaired processing of a spatial frequency bandwidth due to an ocular pathology can therefore lead to misinterpretation of emotions, and impact on social interactions.

Glaucoma is an ocular disease involving the progressive destruction of the optic nerve. Traditionally, glaucoma has been considered to affect peripheral vision first, with central vision relatively preserved until later stages of the disease. However, more recently it has been recognized that central vision including the macular area can be affected at all stages of the disease (Hood et al., 2014; Hood 2017). Central visual impairments in glaucoma involve low level processes such as form, contrast (McKendrick et al 2002), in addition to defects in motion perception (Shabana et al., 2003) and saccadic eye movements (Lamirel et al 2014). There is also evidence of abnormal foveal perception in several studies involving more complex stimuli. Lenoble et al (2016) found reduced accuracy, and longer response times, compared to age-matched controls in a categorization task of grey level photographs of objects (2.5°) presented foveally with a contrast of 50%. With random strings of three letters presented centrally for 200 ms with a contrast of 99%, Kwon et al. (2017) found lower accuracy in the identification of foveally displayed letters in glaucomatous patients than in normally sighted age-matched participants.

Though face perception has not been the subject of much interest in glaucoma, laboratory based studies (Glen et al., 2012; 2013; Mazzoli et al., 2019) converge to show an abnormal processing of centrally displayed faces in patients with glaucoma as compared to age-matched normally sighted controls. For instance, people with glaucoma need closer faces to recognize the facial expression, the identity and even the gender of the person approaching (Schafer et al., 2017). Yet, the mechanisms underlying the deficit in face perception and its impact on social cognition are not yet elucidated.

Psychophysical (Graham 1980; De Valois & de Valois 1990) and physiological (Campbell & Robson, 1968) studies have shown that the visual system analyzes the visual input with independent filters, each tuned to specific spatial frequency channels. It has been demonstrated in many studies on young normally sighted observers that some spatial scales are preferentially selected over others depending on task requirements (Brady & Oliva 2012; Schyns & Oliva 1994; 1997). For instance, with faces, categorization of gender can be performed based on LSF components (Goffaux et al., 2003). Low frequencies are sufficient to recognize some facial expressions (happiness, surprise, and disgust) whilst other expressions (anger, fear, sadness) require higher frequencies (Smith & Schyns 2009) or mid frequencies for pain (Charbonneau et al 2021). With faces as stimuli, impaired processing of a spatial frequency bandwidth can therefore lead to misinterpretation of emotions, and impact on social interactions.

The availability of the relevant spatial frequency information for a given task can also be modulated by the contrast sensitivity of the observer. In order to better understand the mechanisms underlying the deficit in face perception, and specifically in the recognition of some facial expressions in glaucoma, we investigated the hypothesis of a difficulty to perceive relevant spatial frequency bands as a possible account.

A technique that has been used to investigate the relevant spatial frequency bands for a given task is filtering images with low pass and high pass filters, in addition to using hybrid images (Schyns & Oliva, 1994; 1997; Prete et al., 2015; Tommasi et al., 2021). Hybrid stimuli mix two different pictures at two different spatial frequency bandwidths. For instance, they combine a low spatial frequency content face image of a man or a woman with a particular expression (e.g., happy) with a high spatial frequency content face image of the opposite gender with a different expression (e.g., angry). Hybrid images are not realistic stimuli but, because they are composed of two images, each at a different spatial frequency range, the image reported by the participant directly informs about the spatial scale perceived. In normally sighted observers the use of hybrid faces has shown that the visual system can preferentially select spatial frequency scales depending on the relevant information required to perform a task. For instance categorization on gender was LSF-biased whilst categorization as expressive/non expressive was HFS biased (Schyns & Oliva 1999).

In this exploratory study, we displayed high pass, low pass and hybrid faces in foveal vision to patients with glaucoma and age matched normally sighted controls, and also to young participants to assess the effect of normal aging. We used the same stimuli, the same filtering, and the same presentation conditions as Laprevote et al. (2010) who found that healthy young observers were biased towards the HSF component of the hybrid face in a categorization task on facial expression. We tested the hypothesis that recognition of facial expression, a function that is best accomplished in central vision, would be impaired in participants with glaucoma.

With young participants we expected a bias towards HSF in foveal vision both for filtered and for hybrid images as in Laprevote et al (2010) study. It has been shown that contrast sensitivity declines with normal aging (Owsley 2011) and that reduced contrast sensitivity is more detrimental to high than to low spatial frequencies (Ramanoel et al., 2015). We therefore expected that the bias towards HSF observed in young participants would be reduced in older normally sighted participants. It is now recognized that glaucoma impacts central visual function even at early stages of the disease (Hood et al 2014). As foveal vision is involved in the processing of featural information conveyed by HSF we expected that glaucoma would affect the perception of HSF filtered images more than LSF images and that patients would rely more on the LSF component of the hybrid faces compared to controls.

METHOD

Participants

The characteristics of the population are summarized in Table 1 for patients and in Table 2 for controls.

Nineteen participants (8 males), with clinically significant visual field defects in both eyes due to Primary Open Angle Glaucoma, were recruited from the department of ophthalmology in Lille University Hospital. They ranged in age from 36 to 84 years (mean 67.4, SD: 10.1). Each patient underwent a complete ophthalmological examination including a visual field evaluation, a measure of acuity, of contrast sensitivity using the Pelli-Robson chart, and optical coherence tomography (OCT; Cirrus OCT HD-OCT 4000 Carl Zeiss Meditec, Inc. Dublin CA 94568 USA) just before the experiment. Their mean monocular visual acuity was at least equal to 0.1 LogMar. Visual field sensitivity was measured with a Humphrey Field Analyzer (HFA, Carl Zeiss Meditec, Dublin CA, USA). As we tested in central vision, the 10-2 stimulus pattern (SITA standard) was employed. The 10-2 field analyzer measures 68 spotlights in the central 10 degrees of the visual field. Table 1 provides the clinical data for each eye. The visual field of only one eye could be measured on 9/19 patients. The other eye was at an advanced stage and was not measurable due to loss of fixation and/or too many false negatives or false positives (see Table1). Sixteen age-matched controls (8 males) ranging in age from 37 to 81 years (mean: 64.5 SD: 9.4) were recruited within the relatives of patients and within the staff of the department of ophthalmology. None of them had a family history of glaucoma and none had signs of glaucoma, cataract or macular degeneration. An evaluation of their visual acuity was performed just before the testing. Patients and age-matched controls did not differ significantly in age (F(1, 33) = 0.81, p = 0.37).

All the patients and controls older than 60 years were assessed with the French version of the Mini Mental State Examination (MMSE) to check for age related cognitive impairment. A MMSE score lower than 27/30 was a criterion of exclusion. A group of 14 young participants (8 males) was included to dissociate the effect of aging from the effect of pathology. They were medical students ranging in age from 21 to 32 (mean 26 years SD: 4.2). An evaluation of their visual acuity was performed just before the testing. The minimum acuity required for selection was 0.1 LogMar.

During the test all participants, patients, young and older controls wore optical corrections adapted to a distance of 140 cm.

The study was approved by the ethics committee in behavioral sciences of the university of Lille (RVPG 2018 – 270-60). In accordance with the tenets of the Declaration of Helsinki written informed consent was obtained from all participants.

[tables 1 and 2 about here]

Stimuli

The stimuli were the set of high and low filtered faces and hybrid faces provided by Aude Oliva (MIT Boston) and used in Laprevote et al. (2010) In that set, faces from different individuals are aligned so that inner and outer face characteristics overlap (see Figure 1). Images were 256×256 pixels size, in grayscale. Faces from 12 different individuals were used (six males and six females), each showing three different expressions: angry, happy or neutral. There was a low-pass version (below 8 cycles/face) and a high-pass version (above 24 cycles/face) of each face (see examples in Figure 1), for a total of 36 LSF-only faces and 36 HSF-only faces. The description of the filters used can be found in Oliva and Schyns (1997). The 36 LSF and the 36 HSF filtered faces were used to create 96 hybrid faces. These hybrid faces were built by overlapping the low-pass filtered face from one individual with the high-pass filtered face of another individual. Each hybrid was composed of one male face and one female face. One face of the hybrid displayed a neutral expression and the other face displayed either a happy or an angry expression. Peyrin et al (2017) found that contrast enhancement of HSF filtered scenes improved performance in the residual parafoveal vision of patients with macular degeneration. We chose not to enhance the contrast of the HSF filtered faces as keeping contrast the same for both spatial scales is presumably more relevant to daily tasks.

Procedure

Participants were seated 140 cm from a large screen (84 inches Company Speechi, Lille, France). At that viewing distance the stimuli subtended 2.5° X 2.5° of visual angle. Within the black square of 2.5° X 2.5° the angular size of the face was 2.32° X 1.92°. There was no chin rest and viewing was binocular. Stimuli were presented in a dimly illuminated room with the light off and a weak light coming from the edges of venetian blind of the window. A central white fixation cross was shown for 1 sec on a black background. It was followed, 100 ms later, by a face stimulus displayed centrally for 150 ms. Participants were tested on two blocks of trials in the experimental session. The Filtered block contained 72 trials including 36 HSF filtered images and 36 LSF filtered images, each filtered version was composed of 12 (6 males) neutral, 12 (6 males) angry and 12 (6 males) happy faces. The Hybrid block contained 96 images composed of an expressive face (happy, angry) and a neutral face. The neutral face appeared 48 times in LSF (superimposed to 24 HSF happy and to 24 HSF angry faces) and 48 times in HSF (superimposed to 24 LSF happy and to 24 LSF angry faces). The faces were the same in the filtered and in the hybrid versions as hybrids were built from the filtered faces. The order of the filtered and hybrid blocks was counterbalanced between participants in each group. Within each block (filtered/hybrid) the different faces, spatial frequencies and expressions were randomly presented. The task was a 3 alternative forced choice on facial expression (happy, angry, neutral) for both versions of images (filtered and hybrid). The three facial expressions, and the 3 versions (low pass, high pass and hybrid), were presented on paper before the experiment in order to ensure that observers understood the task. Participants responded orally: Happy, Angry or Neutral. The verbal answer was coded (H, A, N) by the experimenter on the keyboard of the computer.

A training session, including 3 blocks of 20 trials with randomly presented LSF and HSF filtered faces was performed for patients and age-matched controls. This training session was performed to familiarize the older participants with a short exposure time. We started with a block of 20 trials presented for 300 ms, followed by 20 new trials presented for 250 ms and 20 new trials presented for 200 ms. Performance was not recorded in the training session but the experimenter provided a feed back on each response. No feed back was given in the experimental session.

Statistical analysis

A Post hoc power analysis was conducted with the software G_Power (Faul et al 2007). It showed that the power of our design was: Power (1-β err prob) = .98 (α = .05; effect size = 1.9). Statistical analyzes were conducted with the software Systat 8 (Systat Software, Inc San Jose, California). Two repeated measure ANOVAs were conducted, one for filtered images and one for hybrid images. For filtered faces the dependent variable was the percentage of correct responses for each spatial frequency. For hybrid faces the dependent variable was the percentage of spatial frequency bandwidth used by the participant to recognize the facial expression within the two expressions that composed the hybrid face. The within factors were the spatial frequency (HSF vs LSF) and the facial expression (angry, happy, neutral). The group (young, older controls, patients with glaucoma) was the between factor**.** We used Cohen's d to determine the effect sizes when standard deviations were similar between groups with identical sample sizes. When the groups have different sample sizes, Hedges' g makes it possible to weight the effect size according to the relative size of each sample. A bonferoni correction was applied when a T test was used. The results are presented in Figure 2 for filtered and hybrid faces. Figure 3 illustrates performance for each facial expression. Individual data are presented in Figure 4 for patients in relation with clinical data.. The Spearman R was used to check any relationship between a bias towards a spatial frequency bandwidth and the visual field defect, age, contrast sensitivity and acuity.

[Figure 1 about here]

RESULTS

Patients and age-matched controls: effect of pathology

Filtered faces

Accuracy was better for controls than for patients (83.5% vs 52.7% F(1, 33) = 32.7, p<.001 Hedge’s g = 1.84). On average accuracy was better for LSF than for HSF filtered images (71.3% vs 64.8% F(1, 33) = 12.8, p<.01 Cohen’s d = 0.27) in the two groups (see Figure 2). The interaction between group and spatial frequency was not significant (F(1, 33) = 3.3, p = 0.79). A separate analysis for the two spatial scales showed that performance was significantly lower for patients than for controls both on HSF (by 34.1% F(1, 34) = 21.7, p<.001 Hedge's g = 1.80) and on LSF (by 27.5% F(1, 34) = 34.9, p<.001 Hedge's g = 1.99). The patients' performance was significantly above chance (33%) both for HFS (t(18) = 2.76, p<.01) and for LSF (t(18) = 5.9, p<.001). There was a significant effect of facial expression (F(2, 66) = 3.36, p<.05). Figure 3 shows that age-matched controls were more accurate to categorize expressive than neutral faces: happy: 89.3%, angry: 85.8%, neutral: 75.3%, (angry/neutral F(1, 15) = 11.4, p<.004; happy/neutral F(1, 15) = 19.7, p<.001, happy/angry F(1, 15) = 0.19, p = 0.67). Patients were more impaired at recognizing an angry (42.3%) than a happy (55.6%) or a neutral expression (60.1%) (angry/neutral F(1, 18) = 8.8, p<.01; happy/angry F(1, 18) = 7.6, p< .01, happy/neutral F(1, 18) = 1.4, p = 0.24). The interaction between group and facial expression was significant (F(2, 66) = 9.7, p<.001). For patients the decrease in accuracy for HSF was greater for expressive than for neutral faces.

Within the patient's group 15/19 patients (Figure 4) exhibited a better accuracy for LSF than for HSF (by 13.7%). For these patients the mean MD of their best eye was -10.9 and the mean contrast sensitivity of the best eye was 1.52. The remaining 4/19 patients (P2, P3, P4 and P12 see Figure 4) exhibited a better performance for HSF than for LSF filtered images. The mean MD of their best eye was -10.7 and their mean contrast sensitivity was 1.72. The loss in ganglion cells (measured as the GCIPL thickness) was larger in the subgroup of patients who exhibited a better accuracy for LSF than for those who exhibited a better accuracy for HSF (57 vs 65 ηm). The differences between the subgroups of patients were not statistically significant for MD (t(17) = 0.07, p = 0.942), contrast sensitivity (t(17) = 1.87, p<.08) and GCIPL (t(14) = 1.23, p = 0.23).

A significant correlation was found between contrast sensitivity and age (r = - .507, p<.027) and between contrast sensitivity and acuity (r = - .737, p<.001). No significant correlation was found between the MD of the best eye and the other variables. Contrast sensitivity was related with both LSF (r = - .710, p<.001) and HSF (r = - .733, p<.001).

Figure 2 about here]

Hybrid faces

As hybrid stimuli are composed of faces in two SF bandwidths the facial expression reported indicated which spatial scale was preferentially perceived. The spatial frequency bandwidth selected for response is presented in Figure 2.

The percentage of errors (ex: responding angry for a neutral/happy hybrid) was significantly higher for patients than for controls (8.22% vs 20.6% F(1, 33) = 9.7, p<.01 Hedge's g = 1.07). The Anova was conducted on correct responses. There was no significant main effect of spatial frequency (F(1, 33) = 1.95, p = 0.17) but spatial frequency interacted significantly with group (F(1, 33) = 4.95, p<.05). Controls selected more the HSF component of the hybrid face than patients (55.6% vs 38.2% F(1,33) = 9, p<.01 Hedge's g = 1.09). There was no difference between groups for the LSF component of the hybrid face (controls: 38% vs patients: 42.2% F(1,33) = 0.56, p = 0.45). The analysis also showed a significant main effect of facial expression (F(2, 66) = 10.8, p<.001) with a better performance for happy (53.9%) than for angry (36.5%) and for neutral faces (40.1%). This result was observed for both groups. The interaction between group and facial expression was not significant (F(2, 66) = 0.8, p = 0.44). Fig. 3 shows a bias towards HSF for the three facial expressions in the control group. Patients exhibited a slight bias towards LSF for happy faces and equivalent performance in the two SF bands for angry and neutral faces.

Within the patient's group 12/19 patients selected more (by 13%) the LSF than the HSF component of the hybrid image. For these patients the mean MD of their best eye was -9.7 and the mean contrast sensitivity was 1.51. The remaining 7/19 patients responded on the basis of the HSF (by 11.4%) than on the LSF component of the hybrid image. The mean MD of their best eye was -12.9 and their mean contrast sensitivity was 1.63. The loss in ganglion cells (measured as the GCIPL thickness) was larger in the subgroup of patients who exhibited a bias towards the LSF component of the hybrid face than for those who exhibited a bias towards the HSF component (55 vs 65 ηm). The differences between the subgroups were not statistically significant in terms of MD (t(17) = 1.25, p = 0.30), contrast sensitivity (t(17) = 1.05, p = 0.227) and GCIPL (t(14) = 1.98, p<.067).

No significant correlations were found between a bias toward the LSF component of the hybrid image and age (r = - .387, p = .101), the MD of the best eye (r = -.250, p = .300), acuity (r = .019, p = .937) and contrast sensitivity (r = .239, p = .324).

[Figure 3 about here]

To summarize: Compared to age-matched controls, glaucoma affected the perception of both high and low spatial frequencies when a single face was displayed, in the filtered version. When two faces were superimposed, in the hybrid version, normally sighted participants saw more easily the HSF component of the face. The perception of HSF was more impaired in patients than in controls in the hybrid version. In both versions of images, filtered and hybrid, the patients who exhibited a deficit in the perception of HSF were those with lower contrast sensitivity in central vision and the greater loss in ganglion cells. However, due to the small samples the differences were not statistically significant.

[Figure 4 about here]

Young and older controls: effect of aging

Non hybrid filtered faces

Young and older participants differed significantly on accuracy (young: 88.7% vs older: 83.5% F(1, 28) = 4.1, p<.05 Hedge's g = 0.61). There was no main effect of spatial frequency (F(1, 28) = 0.3, p = 0.56). Spatial frequency did not interact significantly with group (F(1, 29) = 1.7, p = 0.20). The difference between groups just failed to reach statistical significance for HSF (F(1, 28) = 3.7, p<.06) and performance was equivalent for LSF (F(1, 28) = 2, p = 0.16). The effect of facial expression was significant (F(2, 56) = 21.3, p<.001) with a better performance for expressive faces (happy: 91.6%, angry: 89.3%) than for neutral faces (77.2%) in both groups. The only correlation observed for age-matched controls was between age and acuity (r = .614, p<.01). The oldest participants exhibited a lower acuity.

Hybrid faces

The percentage of errors on the facial expression was significantly higher for older than for young participants (8.22% vs 4.5% F(1, 28) = 6.4, p<.01 Hedge's g = 0.86). The Anova was carried out on correct responses. There was a significant main effect of spatial frequency (F(1, 28) = 30.6, p<.001 Cohen's d = 1.79) and a significant interaction between group and spatial frequency (F(1, 28) = 7.7, p<.01) resulting from a strong bias towards HSF for young participants (HSF: 73.9% vs LSF: 20.8% (F(1, 13) = 44.5, p<.001 Cohen's d = 3.65) and a smaller bias towards HSF in older participants (55.6% vs 38% (F(1, 15) = 3.3, p <.08 Cohen's d = 0.94). There was also a significant main effect of facial expression (F(2, 56) = 18.1, p<.001) with a better performance for happy faces (56.9%) than for angry (40%) and for neutral faces (44.3%) in both groups.

To summarize: Aging affected more the perception of HSF than LSF and this was amplified by the superimposition of a low pass face in the hybrid version.

DISCUSSION

In natural environments our visual system is exposed to a large range of spatial frequencies. To reliably categorize stimuli participants must attend to the information that is more appropriate (i.e., diagnostic) for the task. The diagnostic band of spatial frequencies for a given task depends on category specific diagnostic information in object frequencies (e.g., global versus featural information). For instance, reliably identifying a person requires both medium (5–8 cycles per face), and high (8–12 cycles per face) spatial frequency information (Fiorentini et al., 1983).

Consistent with Laprevote et al. (2010) we observed an equivalent performance for LSF and HSF filtered faces and a bias towards the HSF component of the hybrid faces in normally sighted young participants. Compared to young participants, older controls were impaired with HSF images, particularly in the hybrid version. Behavioral experiments investigating the use of spatial frequencies in normal elderly people have produced conflicting results. For instance, using sine-wave gratings, Govenlock et al. (2010) found that spatial frequency selectivity was not affected by normal aging. Ramanoel et al. (2015) used more complex stimuli. Young and older normally sighted participants had to categorize grey level photographs of scenes filtered in LSF (SF cutoff 0.5, 1, and 2 cpd) and in HSF (SF cutoff 3, 6, and 12 cpd) as indoor/outdoor. They reported a deficit in performance for older participants only when categorizing HSF filtered scenes. The same tendency was observed in the present study with filtered faces. In the hybrid version, the smaller bias towards the HSF component in older participants, as compared to younger ones, suggests that older participants were more sensitive to interference from the LSF component on the HSF component of the hybrid face. With hybrid faces as stimuli Prete et al (2015) found that the emotional LSF component of the hybrid face can be subliminally processed, with a 28 ms presentation time, and affect the perception of the HSF component.

Compared to age-matched controls the deficit in HSF was not confined to hybrid faces for patients. The perception of both low and high frequencies was affected in filtered faces. However, in both filtered and hybrid versions a majority of patients exhibited a better performance for LSF images. Though the differences were not statistically significant due to the small samples, the subgroup of patients who exhibited a better accuracy for LSF in the filtered version had a lower contrast sensitivity and a greater loss in retinal ganglion cells than the subgroup who exhibited a better accuracy for HSF. These results suggest that the impairment does not result from a mere sensitivity to masking or to overlapping hybrid faces appearing scrambled. The deficit can be attributed to reduced contrast sensitivity and ganglion cell loss in central vision in glaucoma. A deficit in contrast sensitivity has been reported in foveal vision in patients with glaucoma despite good visual acuity (Lahav et al., 2011; Wilensky et al., 2001) and also in patients diagnosed with glaucoma in the absence of visual field defects on standard perimetry (Ichhpujani et al., 2020). Glen et al. (2012) found that patients with significant central 10-2 defects in the best eye performed worse in the Cambridge face memory test than patients without significant central vision loss and age-matched controls. Contrast sensitivity was an important factor for explaining face-recognition performance in their study. In the present experiment the performance of young and older controls indicates that categorization of facial expression relies more on HSFs. If HSFs are not, or are less, visible to patients they have to base their decision on LSFs which were less efficient than HSFs to recognize the facial expressions at the angular size used in our experiment.

In the present study both young and older controls were more likely to select the HSF than the LSF component of the hybrid face for response. This result contrasts with Schyns and Oliva (1999) who found, with the same stimuli and the same low and high-pass cut-offs, that normally sighted young participants exhibited a bias towards the LSF component of the hybrid face to categorize facial expressions as happy, angry or neutral. Conflicting results have been reported in the literature regarding categorization of facial expressions in normally sighted young observers. Studies have reported different use of spatial frequencies depending on the facial expression (Kumar & Srinivasan 2011), on the number of facial expressions to discriminate (Jennings et al., 2017), on the spatial frequency cut-offs (Charbonneau et al., 2021), and on whether high and low frequency filtered faces are equated in contrast and luminance (Vlamings et al., 2009). The bias towards HSFs in our study is likely due to the longer exposure time (150 ms) than in Schyns and Oliva (1999) who used a presentation time of 50 ms with the same task and the same stimuli. Indeed, Wang et al. (2017) reported a LSF preference for the expressions of pain, happiness and fear with hybrid faces but this low frequency preference decreased with the increase in presentation duration (33, 67, 150, and 300 ms).

The patients were more impaired at categorizing angry than happy faces. This is consistent with the literature supporting a dominant role of LSFs in the processing of the facial expression of happiness. Compared to other expressions like anger, sadness and fear for instance, happiness has been found to be recognizable from a far distance (Smith & Schyns 2009) or in peripheral vision (for Calvo et al 2014; Goren & Wilson 2006, Smith and Rossit 2018) where the visual system must rely on the lower spatial frequency content of the stimulus due to the decrease in receptors. As patients performed better with the LSFs the expression of happiness was less affected than angry and neutral expressions.

Limitations: There are several limitations for this study. The presentation duration (150 ms) does not reflect natural conditions of face perception which is usually unlimited in time. However, if patients require more time than normally sighted people to identify faces and facial expressions then they might be impaired when watching movies or when scanning several faces in a room. The angular size used (2.5°) was designed to assess foveal perception in glaucoma but it is smaller than the angular size of a face at conversational distance. To reduce the duration of the test for older participants, patients and controls, we used only three facial expressions and arbitrary spatial frequency cutoffs. Yet, several studies have shown that the relevant band of spatial frequency varies as a function of the facial expression. For instance, Charbonneau et al (2021) demonstrated that the visibility of features relevant to categorize the expression of pain (brow furrowing, the wrinkling of the nose with the raising of the upper lip, and the narrowing of the eyes) can be altered by filtering. In manipulating distance they showed that categorizing pain among other facial expressions is more accurate when stimuli are displayed in a distance range of 1.2–4.8 m from the observer rendering available a broad range of object based SFs from low to high with a crucial role of mid frequencies (between 16 and 32 cycles per face).In a future study we plan to use more basic facial expressions and an angular size corresponding to a human face at more natural viewing distances.

Conclusion: Previous studies have demonstrated that people with glaucoma exhibit difficulties in key central visual functions, such as reading (Burton et al., 2014; Smith et al.; 2014; Kwon et al., 2017) and face recognition (Glen et al., 2012; 2013; Schafer et al., 2017; Stievenard et al., 2021). Our study supports these previous findings, but further demonstrates that people with glaucoma are impaired in the categorization of facial expression in foveal vision and that this impairment results in part from a deficit in the perception of both high and low spatial frequencies. Notably, despite all our patients having manifest visual field loss on clinical perimetry, most had a relatively normal visual field in the very central test area and normal visual acuity, yet still demonstrated difficulty with the facial expression task.

Implications: Facial expressions reflect a person's emotion and intentions. Rapidly decoding accurate information from the expressions is thus an important skill for successful social behavior. Poor face perception resulting from visual deficits is known to have a profound impact on a person's ability to participate efficiently in social interactions and to the quality of life (Jin et al., 2019).

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FIGURE AND TABLE LEGEND

Table 1: clinical and demographic data about patients. MD = Mean Deviation (10-2) in decibel. VA= visual acuity (LogMar), L = left eye, R = right eye, VF = visual field, CS = contrast sensitivity, RNFL = retinal nerve fiber layer (µm). GCIPL = ganglion cell-inner plexiform layer (µm), - = not measured.

Table 2: Age and acuity (VA) of young and older controls.

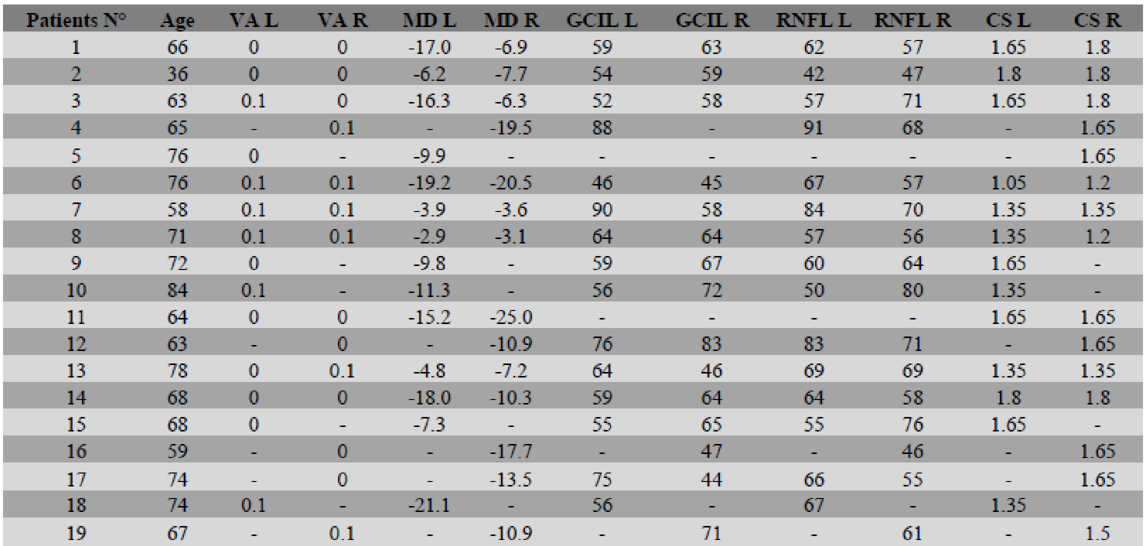
Figure 1: Examples of HSF and LSF filtered faces exhibiting the three facial expressions selected in the study and a hybrid face that combines a low-pass filtered man with a happy expression and a high-pass filtered woman face with a neutral expression. View the images from a distance, or defocus, to reveal the low-pass component of the hybrid image. (Stimuli provided by Aude Oliva).

Figure 2: Top: percentage of spatial frequency bandwidth selected by each participant in each group for hybrid faces. The vertical bars represent the means and confidence intervals . Bottom: percentage of correct responses, means and confidence intervals, for low frequency and high frequency filtered faces as a function of the group of participants.

Figure 3. Mean accuracy (and standard errors) for each group as a function of the facial expression and the version of faces (filtered/hybrid).

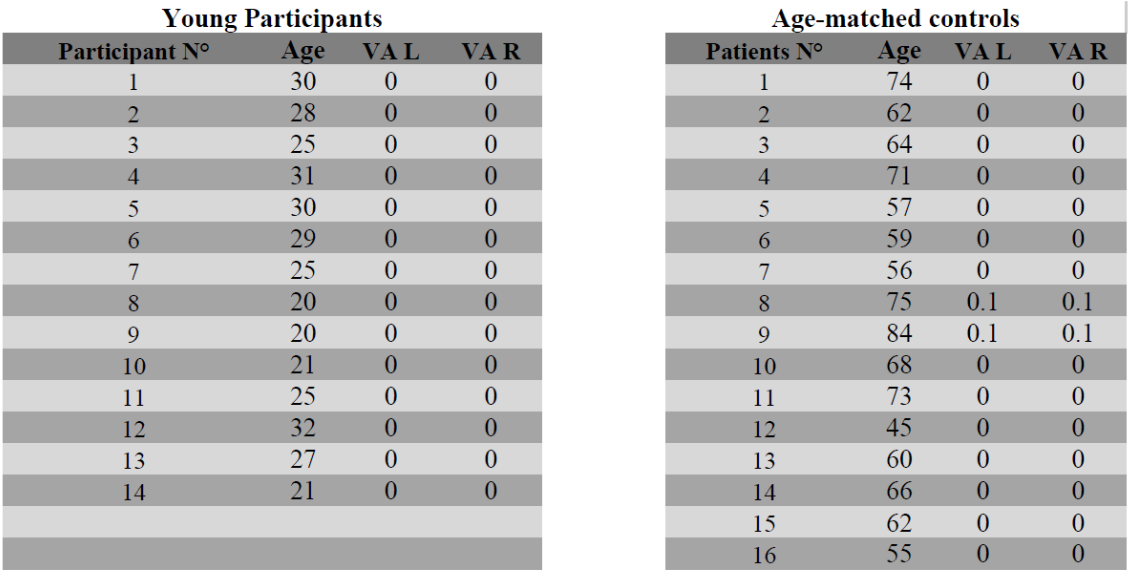
Figure 4: Bias towards a SF bandwidth (computed as HSF – LSF) for hybrid and filtered images and for each patients as a function of the MD and contrast sensitivity (CS) of the best eye.

Table1



Patients N°	Age	VA L	VA R	MD L	MD R	GCIL L	GCIL R	RNFL L	RNFL R	CS L	CS R
1	66	0	0	-17.0	-6.9	59	63	62	57	1.65	1.8
2	36	0	0	-6.2	-7.7	54	59	42	47	1.8	1.8
3	63	0.1	0	-16.3	-6.3	52	58	57	71	1.65	1.8
4	65	-	0.1	-	-19.5	88	-	91	68	-	1.65
5	76	0	-	-9.9	-	-	-	-	-	-	1.65
6	76	0.1	0.1	-19.2	-20.5	46	45	67	57	1.05	1.2
7	58	0.1	0.1	-3.9	-3.6	90	58	84	70	1.35	1.35
8	71	0.1	0.1	-2.9	-3.1	64	64	57	56	1.35	1.2
9	72	0	-	-9.8	-	59	67	60	64	1.65	-
10	84	0.1	-	-11.3	-	56	72	50	80	1.35	-
11	64	0	0	-15.2	-25.0	-	-	-	-	1.65	1.65
12	63	-	0	-	-10.9	76	83	83	71	-	1.65
13	78	0	0.1	-4.8	-7.2	64	46	69	69	1.35	1.35
14	68	0	0	-18.0	-10.3	59	64	64	58	1.8	1.8
15	68	0	-	-7.3	-	55	65	55	76	1.65	-
16	59	-	0	-	-17.7	-	47	-	46	-	1.65
17	74	-	0	-	-13.5	75	44	66	55	-	1.65
18	74	0.1	-	-21.1	-	56	-	67	-	1.35	-
19	67	-	0.1	-	-10.9	-	71	-	61	-	1.5

Table 2



Young Participants

Participant N°	Age	VA L	VA R
1	30	0	0
2	28	0	0
3	25	0	0
4	31	0	0
5	30	0	0
6	29	0	0
7	25	0	0
8	20	0	0
9	20	0	0
10	21	0	0
11	25	0	0
12	32	0	0
13	27	0	0
14	21	0	0

Age-matched controls

Patients N°	Age	VA L	VA R
1	74	0	0
2	62	0	0
3	64	0	0
4	71	0	0
5	57	0	0
6	59	0	0
7	56	0	0
8	75	0.1	0.1
9	84	0.1	0.1
10	68	0	0
11	73	0	0
12	45	0	0
13	60	0	0
14	66	0	0
15	62	0	0
16	55	0	0

Fig.1.

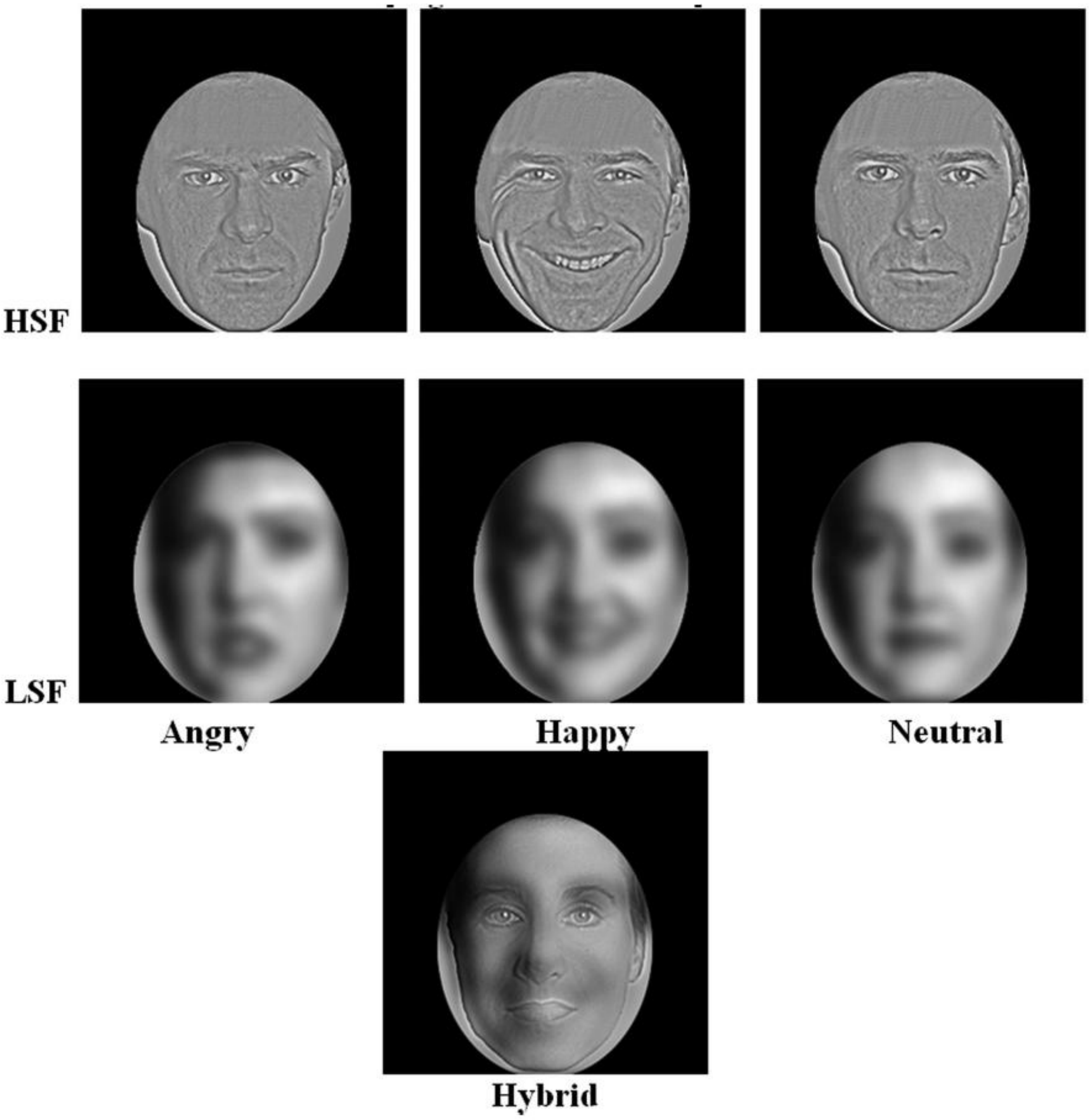


Fig.2

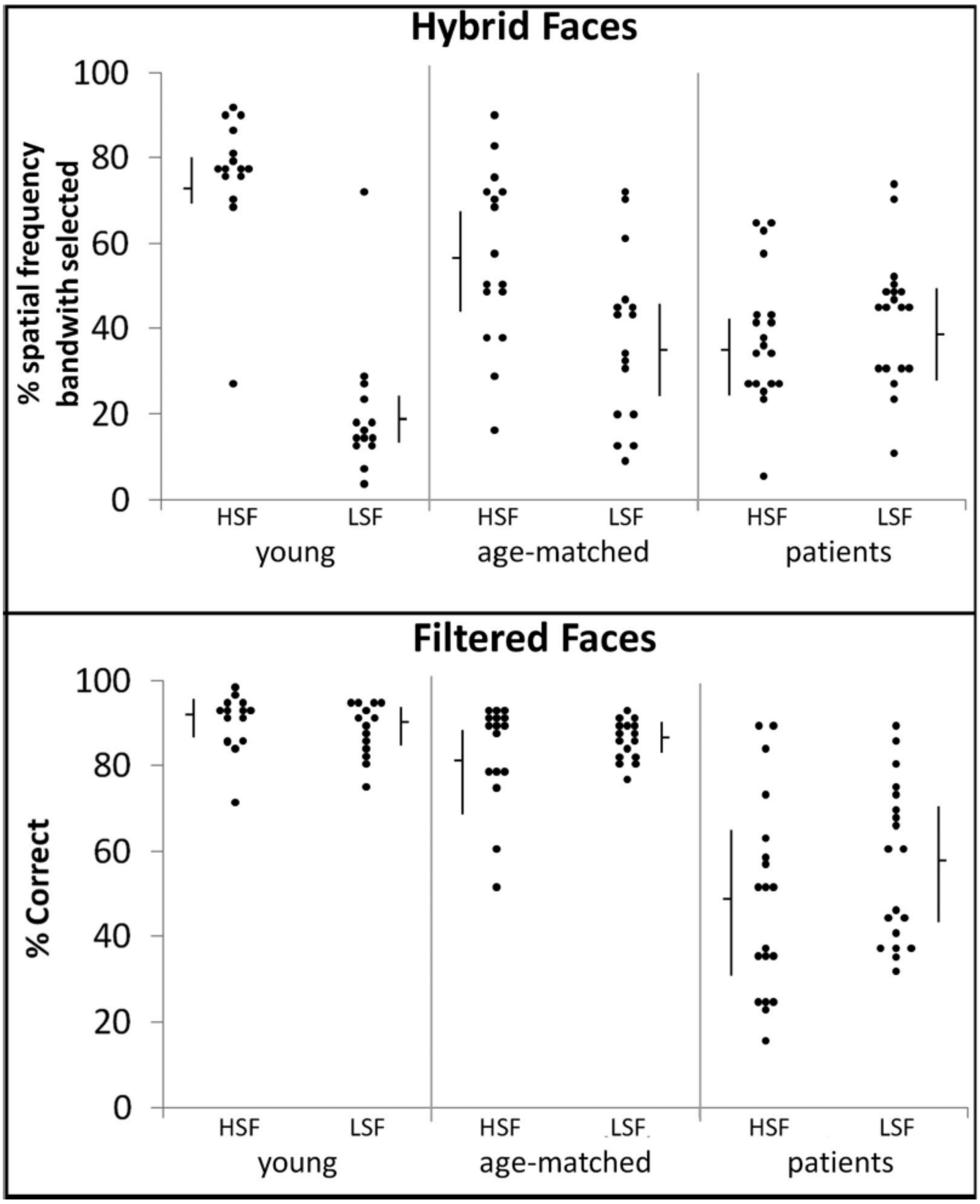

Hybrid Faces
% spatial frequency bandwith selected
100
80
60
40
20
0
HSF
LSF
young
HSF
LSF
age-matched
HSF
LSF
patients
Filtered Faces
% Correct
100
80
60
40
20
0
HSF
LSF
young
HSF
LSF
age-matched
HSF
LSF
patients

Fig.3.

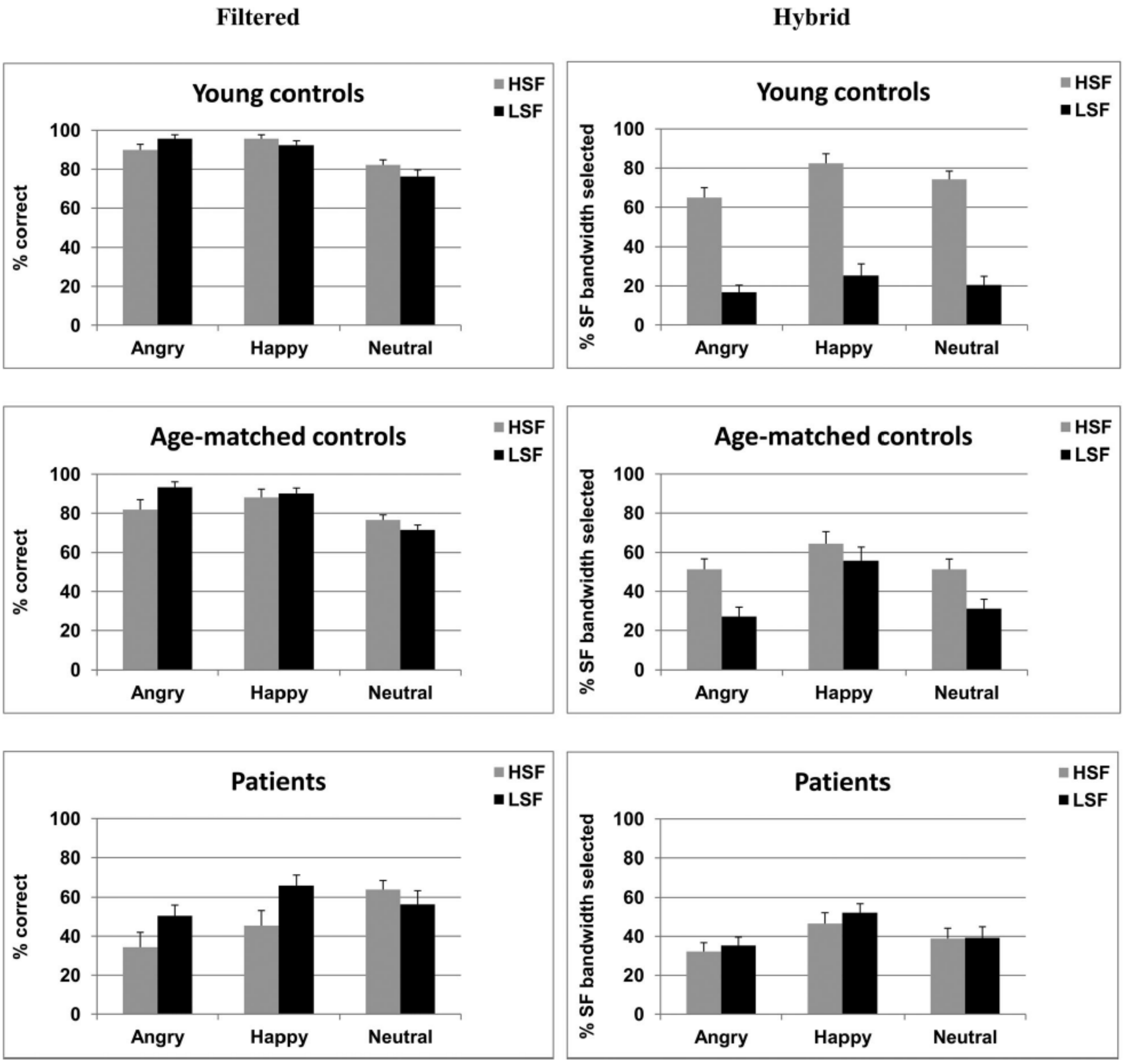
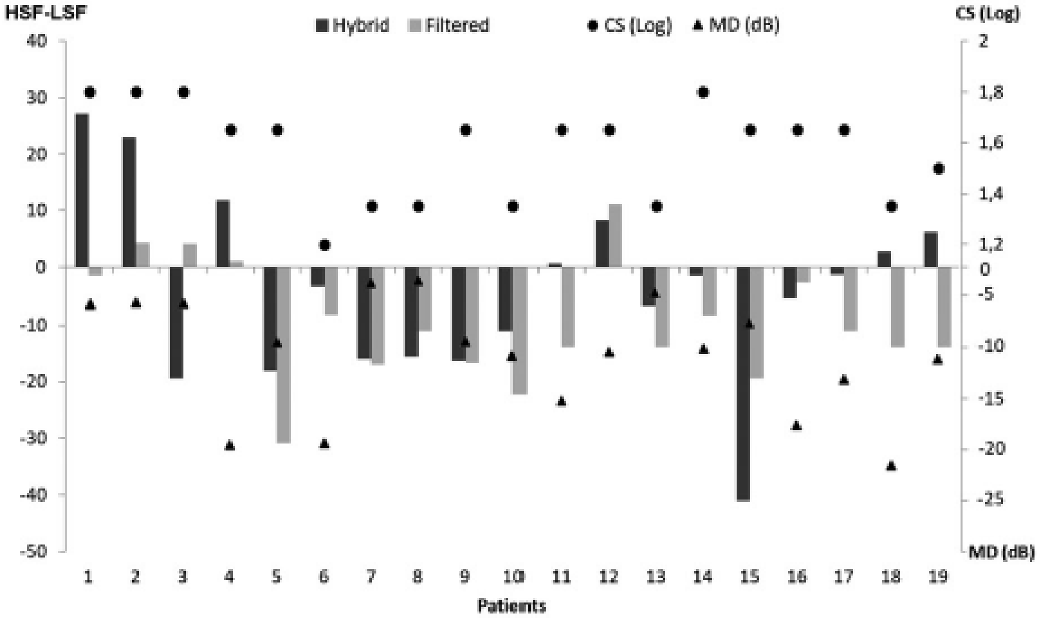

Filtered
Hybrid
Young controls
Age-matched controls
Patients
■ HSF
■ LSF
% correct
% SF bandwidth selected
0
20
40
60
80
100
Angry
Happy
Neutral

Fig.4.


HSF-LSF
■ Hybrid
■ Filtered
● CS (Log)
▲ MD (dB)
CS (Log)
40
30
20
10
0
-10
-20
-30
-40
-50
2
1,8
1,6
1,4
1,2
0
-5
-10
-15
-20
-25
MD (dB)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
Patients