Vision Research 112 (2015) 45–54

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

A comparison of spatial frequency tuning for judgments of eye gaze and facial identity

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ARTICLE INFO

Article history:
Received 8 December 2014
Received in revised form 13 April 2015
Available online 14 May 2015

Keywords:
Face perception
Spatial frequency
Eye gaze
Facial identity
Noise masking
Ideal observer

ABSTRACT

Humans use the direction of eye gaze and facial identity to make important social judgments. We carried out the first measurements of spatial frequency (SF) tuning for judgments of eye gaze, and compared SF tuning for judgments of facial identity and eye gaze. In Experiment 1, participants discriminated between leftward and rightward shifts of gaze, or between two male faces or two female faces. Faces were masked with visual noise that blocked one of 10 SF bands. For each task and masking SF, we measured contrast thresholds for human observers, and used an ideal observer to measure the amount of visual information available to perform the task. As in previous research, low to mid SFs were most important for judgments of facial identity. Mid to high SFs were most important for judgments of eye gaze, and the highest SF important for these judgments was higher than that for identity. In Experiment 2, participants discriminated horizontal and vertical shifts of gaze. The highest SF important for judgments of gaze did not differ between the horizontal and vertical axes. However, SFs above and below this value were more important for judgments of vertical shifts of gaze than for horizontal shifts of gaze. These results suggest that the visual system relies on higher SFs for judgments of eye gaze than for judgments of facial identity, and that SF tuning is broader for judgments of vertical shifts of gaze than for horizontal shifts of gaze.

1. Introduction

Humans use facial identity to categorize (e.g., familiar versus unfamiliar) and individuate (e.g., Bob versus Jim) people, and use the direction of people's gaze to make inferences about their mental and emotional states (Argyle & Cook, 1976; Emery, 2000). Adult humans rely primarily on low (coarse details) to mid (finer details) spatial frequencies (SFs) when discriminating facial identity (e.g., Gao & Maurer, 2011; Goffaux & Rossion, 2006). Previous studies have not examined SF tuning for judgments of eye gaze. Here, we carried out the first investigation of SF tuning for judgments of eye gaze, and compared that tuning to the tuning for judgments of facial identity.

1.1. Spatial frequency tuning for judgments of facial identity

Previous studies have examined the role of SF in humans' ability to discriminate between facial identities. One method used to investigate this question involves blocking access to a target SF band by adding visual noise (Gao & Maurer, 2011; Näsänen, 1999; Ojanpää & Näsänen, 2003) or another pattern (e.g., a sinusoidal grating) (Tieger & Ganz, 1979) in the target band, an approach known as masking. The more important the target band is for performance on the task, the more masking is expected to disrupt performance. Spatial frequency tuning for at least some non-changeable (e.g., facial identity) and changeable (e.g., facial expression) facial signals varies only slightly with viewing distance (e.g., Gao & Maurer, 2011). Hence, throughout this article, we report measures of SF tuning for judgments of both types of facial signals in units of cycles per face width (c/fw), rather than in cycles per degree. We use "mid SFs" to refer to the range (around 8–17 c/fw) of SFs most consistently implicated in face perception (Gao & Maurer, 2011; Näsänen, 1999). We use "low SFs" and "high SFs" to refer to SFs above and below this range, respectively. Masking mid SFs leads to the greatest disruption in discrimination of facial identity (Gao & Maurer, 2011; Näsänen, 1999; Ojanpää & Näsänen, 2003; Tieger & Ganz, 1979), a result suggesting that SFs in this range are particularly important for judgments of facial identity.

Previous studies have also investigated SF tuning for judgments of facial identity by applying a SF filter directly to a face image (Costen, Parker, & Craw, 1996; Fiorentini, Maffei, & Sandini,

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http://dx.doi.org/10.1016/j.visres.2015.04.018
0042-6989/

1983; Hayes, Morrone, & Burr, 1986; Näsänen, 1999). In this approach, performance is expected to be best when information important for performance on the task is not removed by the filter. Studies using this approach have reported that discrimination of facial identity is best when SFs between 8 and 16 c/fw are included in the face image (Costen, Parker, & Craw, 1996; Näsänen, 1999), with some studies reporting a range including lower (5 c/fw) (Fiorentini, Maffei, & Sandini, 1983) or higher (20 c/fw) (Hayes, Morrone, & Burr, 1986) values. Hence, as with the masking approach (Gao & Maurer, 2011; Näsänen, 1999; Ojanpää & Näsänen, 2003; Tieger & Ganz, 1979), evidence from studies using the filtering approach indicates that mid SFs are particularly important for judgments of facial identity.

Human observers' ability to discriminate facial identity may depend critically on the amount of information available to perform the task. The amount of low-level visual information available to discriminate facial identity increases with SF (Gao & Maurer, 2011; Gold, Bennett, & Sekuler, 1999). After adjusting estimates of human sensitivity to take into account the amount of information available to perform the task in each SF band, humans appear to rely approximately equally on low to mid SFs, with a steep drop-off in importance for higher SFs (Gao & Maurer, 2011). Although there is more information available to discriminate facial identity at higher SFs, humans appear not to make efficient use of it, except when performing a task in which faces differ only in the shape of facial features (Goffaux et al., 2005).

1.2. Sensitivity to the direction of eye gaze

Adult humans are highly sensitive to shifts of eye gaze: they can detect horizontal (e.g., Symons et al., 2004; Vida & Maurer, 2012b) and vertical/oblique (Bock, Dicke, & Thier, 2008) shifts of 1–2° in gaze relative to objects in the environment. This high sensitivity allows precise judgments of the focus of others' visual attention (Argyle & Cook, 1976).

Previous studies have not examined SF tuning for judgments of eye gaze. However, existing data and models allow tentative predictions about the role of SF in gaze perception. One relevant line of research has investigated the extent to which changeable (e.g., facial expression, eye gaze) and non-changeable (e.g., facial identity) facial signals are processed by separate mechanisms. Given that these two types of facial signals can carry independent social information about people, allocating each signal to a separate pathway could allow enhanced processing of each signal. However, it is also important to integrate information across changeable and non-changeable facial signals in at least some situations (e.g., when monitoring the emotional state of a specific individual). Integration between pathways for processing these two types of signals may support social perception in these situations (Baseler et al., 2014).

Evidence that the visual system has separate mechanisms for processing changeable and non-changeable facial signals comes from findings that anatomically distinct regions of human cortex are sensitive to these two types of signals (Hoffman & Haxby, 2000). The extent of functional overlap in processing of these two types of facial signals is not well-established. Behavioral studies indicate that variation in changeable facial signals can affect the speed of judgments of non-changeable facial signals, and vice versa. However, these effects can be abolished by manipulating the discriminability of the stimuli (Ganel, 2011; Wang et al., 2013). There is also evidence that variation in facial identity affects responses to changeable facial signals in posterior superior temporal sulcus, a cortical region consistently implicated in processing of changeable facial signals (Baseler et al., 2014). This interaction could reflect the integration of information from changeable and non-changeable facial signals.

Functionally separate components of the pathways for processing changeable and non-changeable facial signals could differ in SF tuning. Consistent with this hypothesis, a masking study found that judgments of facial expression are tuned to higher SFs than judgments of identity (Gao & Maurer, 2011). Functionally overlapping components of these two pathways may have similar SF tuning. Hence, comparing SF tuning between different types of changeable and non-changeable facial signals may provide information about the extent to which the visual system uses a common set of resources to process these different types of signals.

Subcortical neural mechanisms could also influence SF tuning for judgments of eye gaze. In one model, humans possess a subcortical neural mechanism that is sensitive to face identity and the direction of gaze, and responds selectively to low SFs (Johnson, 2005; Senju & Johnson, 2009). Such a mechanism could account for findings that newborns, who lack sensitivity to high SFs (Banks & Salapatek, 1978; Norcia & Tyler, 1985; Norcia, Tyler, & Hamer, 1990), nevertheless look longer at faces with direct gaze than at those with gaze averted far to one side (Farroni et al., 2002). The continued functioning of this mechanism in adults could lead to greater reliance on low SFs when discriminating the direction of eye gaze and facial identity. Furthermore, differences in reliance on low SFs for eye gaze and facial identity could reflect differences in the involvement of this subcortical mechanism.

In summary, previous research suggests that mechanisms underlying adults' judgments of facial identity are tuned to low to mid SFs (e.g., Gao & Maurer, 2011). Previous research also suggests at least partially separate mechanism to process these two facial signals (Baseler et al., 2014; Hoffman & Haxby, 2000). Previous studies have not measured SF tuning for judgments of eye gaze, and have not compared this tuning for judgments of facial identity and gaze. The purpose of the current study was to investigate these questions. In Experiment 1, participants viewed faces masked with noise filtered to contain a narrow range of SFs, with the centre SF of the noise varying between blocks. The task was to discriminate between leftward and rightward gaze, or to discriminate between two facial identities. We used an adaptive staircase procedure to measure participants' contrast thresholds, and used an ideal observer analysis to take into account the amount of information available to perform the task. In Experiment 2, we used a method similar to that of Experiment 1 to compare SF tuning for judgments of horizontal and vertical shifts of gaze.

2. General method

2.1. Apparatus

For Experiment 1, stimuli were displayed on a Dell P1130 21 inch CRT display set to a resolution of 1152 × 870 and a refresh rate of 75 Hz. The display had 256 grayscale levels. The mean luminance of each stimulus and the background against which all stimuli were presented were set to the mean luminance of the display. The experiment was run in MATLAB R2008a (MathWorks) using the Psychophysics Toolbox extensions (Brainard, 1997) on an Apple Mac Pro computer. Participants used a chinrest to maintain a constant head position.

2.2. Face images

All face images came from a stimulus set used in previous studies of gaze perception (Vida & Maurer, 2012a, 2013). We used images of two adult females and two adult males photographed fixating targets 4.8° and 8° to the left/right and above/below the