

Size-invariant but viewpoint-dependent representation of faces

Yunjo Lee ^{a,*}, Kazumichi Matsumiya ^b, Hugh R. Wilson ^a

^a Centre for Vision Research, York University, 4700 Keele Street, Toronto, Ont., Canada M3J 1P3

^b Research Institute of Electrical Communication, Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan

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Abstract

The present study investigated the role of size and view on face discrimination, using a novel set of synthetic face stimuli. Face discrimination thresholds were measured using a 2AFC match-to-sample paradigm, where faces were discriminated from a mean face. In Experiment 1, which assessed the effect of size alone, subjects had to match faces that differed in size up to four-fold. In Experiment 2 where only viewpoint was manipulated, a target face was presented at one of four different views (0° front, 6.7°, 13.3°, and 20° side) and subsequent matches appeared either at the same or different view. Experiment 3 investigated how face view interacts with size changes, and subjects matched faces differing both in size and view. The results were as follows: (1) size changes up to four-fold had no effect on face discrimination; (2) threshold for matching different face views increased with angular difference from frontal view; (3) size differences across different views had no effect on face discrimination. Additionally, the present study found a perceptual boundary between 6.7° and 13.3° side views, grouping 0° front and 6.7° side views together and 13.3° and 20° side views together. This suggests categorical perception of face view. The present study concludes that face view and size are processed by parallel mechanisms.

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1. Introduction

A face is a three-dimensional (3D) object that is encountered from many directions and various distances and thus, face recognition requires representation of invariant aspects of facial structure across these changes. Despite these challenges, recognizing faces is usually an easy and effortless task for us. However, how the brain accomplishes face recognition under variations and changes in size and viewpoint still remains unclear. The present study addressed this question psychophysically and investigated how robust face perception would be under changes in size and view. Use of a psychophysical paradigm allows us to quantify these effects and also provides insight into the neural mechanisms that underlie them.

Recent fMRI studies have provided evidence that the fusiform face area (FFA; Kanwisher, McDermott, & Chun, 1997) is involved in analyzing objects or faces independent of the visual cues defining their shape, such as size, but could respond selectively to different viewpoints (Andrews & Ewbank, 2004; Grill-Spector & Malach, 2001; Grill-Spector et al., 1999; Vuilleumier, Henson, Driver, & Dolan, 2002). Grill-Spector and her colleagues observed that the overall activation of the posterior fusiform gyrus (FG) is sensitive to different views of the same faces or cars but not to changes in size and position. The face-selective voxels remained strongly adapted to size and position changes even though a robust recovery from adaptation was observed when the stimulating face was rotated. Andrews and Ewbank (2004) found the same results in the FFA that corresponds to the posterior FG region from Grill-Spector et al. (1999). Adaptation to repeated presentations of the same face persisted in the FFA despite changes in size, but FFA responses were sensitive to the manipulation of viewpoint and emotional expressions. In contrast, they failed to

* Corresponding author.

E-mail address: yhlee@yorku.ca (Y. Lee).

find any adaptation to repetitions of the same face in face-selective regions in the superior temporal lobe (STS). Also, Vuilleumier et al. (2002) showed similar results with objects presented in a long-term repetition priming design. The right FG showed priming-induced decreases by repetition of the same viewpoint, irrespective of size, suggesting viewpoint-dependent and size-invariant representations in neuronal populations in that region.¹ These results are consistent with data from single-cell recording of the primate inferotemporal cortex (IT) or the superior temporal sulcus (STS) and fMRI studies with human and primate subjects, which independently studied the effects of size and viewpoint changes (Desimone, Albright, Gross, & Bruce, 1984; Ito, Tamura, Fujita, & Tanaka, 1995; Logothetis & Pauls, 1995; Logothetis, Pauls, & Poggio, 1995; Lueschow, Miller, & Desimone, 1994; Malach et al., 1995; Op De Beeck & Vogels, 2000; Perrett, Mistlin, & Chitty, 1987; Perrett et al., 1985, 1991; Pourtois et al., 2005; Rolls & Baylis, 1986; Sáry, Vogels, & Orban, 1993; Schwartz, Desimone, Albright, & Gross, 1983; Wang, Tanaka, & Tanifuji, 1996).

Single-cell recording studies on monkeys have shown that IT cells are invariant to size changes and other shape properties. Schwartz et al. (1983) demonstrated that many IT cells are selective for shapes systematically varying in boundary curvature and maintain this selectivity over a two-fold increase in size, 3–5° of position changes, and contrast change. Sáry et al. (1993) also reported preserved shape selectivity over a four-fold size change and 4–5° of position changes. Ito et al. (1995) tested wide ranges of size with simply shaped images and found two types of cells: cells that are sharply tuned to particular ranges of size and those responsive to wide ranges of size. 43% of the anterior IT cells studied responded to ranges of linear size variation less than 2 octaves, but 21% responded to size ranges of more than 4 octaves. The selectivity for shape was mostly preserved throughout the entire range of size changes. On the other hand, Op De Beeck and Vogels (2000) found position-dependent size effects in the anterior part of the inferior temporal cortex (TE). They presented the four stimulus sizes over a four-fold range either in the foveal or peripheral position. When the general response pattern was separately plotted for each position, the average response increased with size at the periphery but the effect of size disappeared at the foveal position.

Using fMRI, Sawamura, Georgieva, Vogels, Vanduffel, and Orban (2005) found object adaptation and size invariance in macaque IT complex and human LOC though they failed to find complete size invariance unlike Grill-Spector

et al. (1999). Their overall human data agree with Grill-Spector et al. (1999), but the extent of size invariance in Sawamura et al. was somewhat smaller. This discrepancy might result from the different ranges of sizes used in these two studies. Sawamura et al. used five discrete sizes of the same object over a four-fold range (2.3–9.2°), while Grill-Spector et al. presented 30 different sizes over a range of 10–30°.

Invariance to size changes has also been observed with face stimuli. Rolls and Baylis (1986) found that the majority of neurons in the macaque middle and anterior STS showed invariant responses with respect to size as well as contrast alternation of the stimulus. The median size change that can produce greater than half of the maximal response was a factor of 12.0. Desimone et al. (1984) also demonstrated that IT and STS neurons maintained their selectivity to both monkey and human faces or hands over a wide range of size changes. In their previous studies, they found that macaque IT neurons have large receptive fields of median size 26° × 26° that invariably included the fovea (Desimone & Gross, 1979; Gross, Rocha-Miranda, & Bender, 1972). With these receptive fields larger than the stimulus, IT neurons responded to stimuli regardless of sizes changed within the receptive field (Desimone et al., 1984). In the human brain, activation of the LOC posteriorly including the lateral aspect of the posterior FG was not influenced by a four-fold change in visual size of both faces and objects (Malach et al., 1995).

While neuroimaging data have reported complete size invariance in the FFA and LOC (Andrews & Ewbank, 2004; Grill-Spector & Malach, 2001; Grill-Spector et al., 1999; Malach et al., 1995; Vuilleumier et al., 2002), most neurophysiological studies found size-invariant responses in a fraction of the neurons in the macaque IT that is homologous to the human LOC (Ito et al., 1995; Lueschow et al., 1994; Op De Beeck & Vogels, 2000; Schwartz et al., 1983). This surprising discrepancy would be attributed to the different approaches taken by these two techniques. Most single-cell studies report size-invariance in terms of stimulus selectivity, whereas fMRI assesses size-invariance on neuronal response levels (Sawamura et al., 2005). In single-cell studies, changes in size or position usually alter the absolute firing rate of the neuron, but the relative preference for a stimulus is maintained over changes within the receptive field. To this extent, IT neurons may exhibit size and position constancy (Desimone et al., 1984; Logothetis & Pauls, 1995).

Despite the size-invariant representation of faces and objects in the human and primate ventral stream, the majority of these cells appear to be viewpoint-dependent. In a study by Logothetis et al. (1995), a population of IT cells responded selectively to learned views of previously unfamiliar objects, while some of these view-selective cells exhibited response-invariance for changes in size or position. Six out of the nine view-selective cells tested showed size-invariant responses. Logothetis et al. (1995) found only a very small number of cells that showed viewpoint-invariance.

¹ Additionally, Vuilleumier et al. (2002) found a hemispheric asymmetry: the left FG showed a generalization across views and sizes. The discrepancy between the results of Vuilleumier et al. and Grill-Spector and her colleagues (1999, 2001) seem to arise from different presentation paradigms adopted. The immediate fMR adaptation paradigm used by Grill-Spector may favor perceptual stages of processing, whereas the long-term repetition priming used in Vuilleumier et al. is likely to assess more abstract, memory-based stages of processing (Pourtois, Schwartz, Seghier, Lazeyras, & Vuilleumier, 2005).

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