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From theory to implementation: Building a multidimensional space for face recognition ☆

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ABSTRACT

The purpose of the present study was to empirically construct a multidimensional model of face space based upon Valentine's [Valentine, T. (1991). A unified account of the effects of distinctiveness, inversion, and race in face recognition. *Quarterly Journal of Experimental Psychology, 43A*, 161–204; Valentine, T. (2001). Face-space models of face recognition. In M. J. Wenger, & J. T. Townsend, (Eds.). *Computational, geometric, and process perspectives on facial cognition: Contexts and challenges. Scientific psychology series* (pp. 83–113). Mahwah, NJ: Erlbaum] metaphoric model. Two-hundred and ten participants ranked 200 faces on a 21-dimensional space composed of internal facial features. On the basis of these dimensions an index of distance from the center of the dimensional space was calculated. A factor analysis revealed six factors which highlighted the importance of both featural and holistic processes in face recognition. Testing the model in relation to facial distinctiveness and face recognition strengthened its validity by emphasizing the relevance of the constructed multidimensional space for face recognition. The data are discussed within the framework of theoretical models of face recognition.

1. Introduction

It is generally assumed that faces are encoded on the basis of mental schemes representing facial features and their holistic configuration (Brennan, 1985; Cabeza, Bruce, Kato, & Oda, 1999; Diamond & Carey, 1986; Goldstein & Chance, 1980; Valentine & Bruce, 1986a). The facial scheme develops by exposure to faces that share common features (Goldstein & Chance, 1980) until it is permanently fixated (Furl, Phillips, & O'Toole, 2002; Valentine & Bruce, 1986a).

A number of information processing models have been suggested in order to account for the process of face recognition. These models postulate a sequence of stages which begins with face encoding, continues with matching the encoded face to face representations and pertinent semantic information stored in memory, and ends with name retrieval (Bruce & Young, 1986; Burton, Bruce, & Hancock, 1999; Kampf, Nachson, & Babkoff, 2002). However, these models are descriptive and not functional.

1.1. The multidimensional space

A functional model for face recognition that focuses on the perceptual and memory processes was proposed by Valentine in 1991. The model, known as the multidimensional space (MDS) model, is unique in its approach to face recognition since it assumes that faces are encoded as points in the MDS that serves as a metaphor for the mental representation of faces (the term MDS refers to the Multidimensional Space model suggested by Valentine (1991), and not to the term Multidimensional Scaling).

According to Valentine (1991), any feature that discriminates among faces may be considered a continuous dimension; thus the number and nature of the dimensions are not predetermined (Bruce, Burton, & Dench, 1994; Valentine, 1991; Valentine & Endo, 1992). The center of the MDS is defined as the central tendency of all dimensions around which the faces are normally distributed (Bruce et al., 1994; Johnston, Milne, Williams, & Hosie, 1997; Lewis & Johnston, 1999; Valentine, 1991).

According to the MDS model, most faces that one encounters are typical, and therefore encoded close to the center of the MDS. Atypical faces are encoded farther from the center. Consequently, typical faces are located more densely than atypical ones, and they

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are relatively similar to each other (Busey, 1998). As a result, their recognition is more difficult than that of atypical faces. The recognition of highly atypical, distinctive faces is faster and more accurate than that of typical faces which are frequently erroneously recognized as having been seen before (false positive). Atypical faces are more easily recognized following prior exposure and more easily rejected if previously unexposed (Lewis & Johnston, 1997; Light, Kayra-Stuart, & Hollander, 1979; Valentine, 1991, 2001; Valentine & Bruce, 1986a, 1986b; Wickham, Morris, & Fritz, 2000).

Ever since the MDS model was proposed (Valentine, 1991), it has been extensively employed in accounts of a variety of phenomena associated with face recognition, such as distinctiveness (Bruce et al., 1994; Burton & Vokey, 1998; Tanaka, Giles, Kremen, & Simon, 1998; Wickham et al., 2000), the race bias (Byatt & Rhodes, 1998; Caldara & Abdi, 2006; Valentine & Endo, 1992), caricatures (Byatt & Rhodes, 1998; Chang, Levine, & Benson, 2002; Lee, Byatt, & Rhodes, 2000; Lewis & Johnston, 1999) and familiarity (Jiang, Blanz, & O'Toole, 2007; Lewis & Johnston, 1997). However, since the original MDS model was an abstract depiction of the face recognition process it lacked a priori operationally defined dimensions.

1.2. Approaches for multidimensional construction

So far, four approaches have been employed for constructing the MDS. The first approach (e.g., Burton, Miller, Bruce, Hancock, & Henderson, 2001; Burton et al., 1999) that was based on principal component analysis (PCA) and connectionist modeling, simulated face recognition by an artificial neural network. In the second approach (e.g., Johnston, Milne, et al., 1997; Lee et al., 2000) facial dimensions were derived mathematically (ALSCAL analysis) on the basis of participants' judgments of interface similarity. The third approach (e.g., Brennan, 1985; Byatt & Rhodes, 1998; Chang et al., 2002; Lewis & Johnston, 1999; Tanaka et al., 1998) was based on Brennan's (1985) computer-generated caricature production technique which compares faces on the basis of specified points dispersed throughout the face. Finally, a fourth approach (Rhodes, 1988) used direct measurements of facial features along with similarity judgments as a basis for a computerized depiction of the face space.

These approaches have greatly contributed to the understanding of face recognition by developing models in a way that enabled the comparison of human and computerized face recognition processes. As well, they enabled the computation of correlations between the location of faces in the MDS and other face-related characteristics, such as facial distinctiveness and attractiveness. The differences among the four approaches notwithstanding, all shared a common tendency to mathematically derive the facial dimensions *a posteriori* from the generated MDS, rather than to *a priori* preselect them on a psychological basis.

In the present study a new approach to the study of MDS was adopted according to which facial dimensions are defined *before* they are integrated into the model. According to this approach, the MDS dimensions (which were not originally specified by Valentine (1991)) must first be defined by tangible, ecologically valid entities; and subsequently the faces ought to be placed in the MDS on the basis of their value in each dimension. The MDS may thus serve as a basis for testing the model on a variety of face recognition tasks.

A significant limitation of the present approach is that if one fails to *a priori* include an important dimension in the rating set, it cannot emerge as a relevant dimension in the factor analysis. By contrast, the other four approaches derive the facial dimensions *a posteriori,* thus allowing any possible set of dimensions to emerge, and the focus is then on their interpretation. The approach adopted in the present study is similar to the other approaches in which it requires computation of similarity among faces, but it varies from the other approaches since the observer was required to focus on one dimension at a time rather than to make a global assessment of similarity.

1.3. Facial features as a priori MDS dimensions

The natural candidates to serve as dimensions are facial features which have been shown to play a major role in face recognition; particularly in feature-based face encoding (Farah, Wilson, Drain, & Tanaka, 1998; Saumier, Arguin, & Lassonde, 2001), in recognition of other-race faces (Ellis, Deregowski, & Shepherd, 1975; MacLin & Malpass, 2003; Nachson & Catz, 2003), and in examination of the relative importance of inner and outer facial features (Campbell et al., 1999; Nachson, Moscovitch, & Umilta, 1995; Rhodes, 1988; Want, Pascalis, Coleman, & Blades, 2003).

Some researchers (Chang et al., 2002; Valentine & Bruce, 1986b) have proposed that certain facial features (ears, eyes, cheekbones, nose and eyebrows) be considered as MDS dimensions. Others (Johnston, Kanazawa, Kato, & Oda, 1997; Rhodes, 1988) added the dimensions of race, gender and age. However, there is still a debate as to whether or not race, gender and age are essential dimensions for face recognition or unessential but parallel dimensions (e.g., Baudouin & Gallay, 2006; Baudouin & Tiberghien, 2002; Bruce & Young, 1986).

In fact, race, gender and age may be considered multiple-featured attributes rather than single-featured dimensions. For example, male and female faces differ in both eyebrow and chin size (Baudouin & Tiberghien, 2002). Furthermore, in contrast to the superior recognition of faces among one's own race (e.g., Walker & Hewstone, 2006), gender (e.g., Lewin & Herlitz, 2002; Rehnman & Herlitz, 2006) and age (e.g., Anastasi & Rhodes, 2005; Wright & Stroud, 2002), there is no evidence for superiority in the recognition of faces possessing the same eye color or nose shape as those of the observer. Thus, although important for face recognition, race, age, and gender do not function in the same manner as single facial features. Moreover, we use single-featured dimensions in order to categorize faces in terms of their race, gender or age, but not the other way around. For example, we use the shape of the eyes, the sizes of the eyebrows and the chin in order to decide if a given face belongs to a female or to a male, but we do not attribute a big nose to a face based on its gender or race (e.g., MacLin & Malpass, 2003). Therefore, the construction of the MDS in the present study was based on single-featured dimensions that are relevant for face recognition rather than on multiple or general facial characteristics.

2. Experiment I

In Experiment I, subjective rankings of faces on each of the dimensions of the MDS, were obtained (Busey, 1998). This method enabled to locate each face on a psychologically meaningful scale based on participants' experience.

2.1. Method

2.1.1. Participants

Two-hundred and ten university students (half males and half females) participated in the experiment. Participants' ages ranged between 17 and 31 years (*M*: 22.97, *SD*: 2.38).

2.1.2. Stimuli and material

2.1.2.1. Faces. Two hundred frontal, unfamiliar Caucasian faces aged 20–30 years (half males and half females) with neutral expression and no distinctive features (such as glasses, beards or