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3D faces are recognized more accurately and faster than 2D faces, but with similar inversion effects

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ABSTRACT

Recognition of faces typically occurs via holistic processing where individual features are combined to provide an overall facial representation. However, when faces are inverted, there is greater reliance on featural processing where faces are recognized based on their individual features. These findings are based on a substantial number of studies using 2-dimensional (2D) faces and it is unknown whether these results can be extended to 3-dimensional (3D) faces, which have more depth information that is absent in the typical 2D stimuli used in face recognition literature. The current study used the face inversion paradigm as a means to investigate how holistic and featural processing are differentially influenced by 2D and 3D faces. Twenty-five participants completed a delayed face-matching task consisting of upright and inverted faces that were presented as both 2D and 3D stereoscopic images. Recognition accuracy was significantly higher for 3D upright faces compared to 2D upright faces, providing support that the enriched visual information in 3D stereoscopic images facilitates holistic processing that is essential for the recognition of upright faces. Typical face inversion effects were also obtained, regardless of whether the faces were presented in 2D or 3D. Moreover, recognition performances for 2D inverted and 3D inverted faces did not differ. Taken together, these results demonstrated that 3D stereoscopic effects influence face recognition during holistic processing but not during featural processing. Our findings therefore provide a novel perspective that furthers our understanding of face recognition mechanisms, shedding light on how the integration of stereoscopic information in 3D faces influences face recognition processes.

1. Introduction

Face recognition is an innate ability that is essential to our daily social interactions. Most of us are able to recognize and distinguish faces instantly, suggesting that faces are a special category of our visual expertise (Heisz, Watter, & Shedden, 2006; Maurer, Grand, & Mondloch, 2002; Richler, Mack, Gauthier, & Palmeri, 2009; Taubert, Apthorp, Aagten-Murphy, & Alais, 2011). Research largely supports that a face is processed holistically such that individual features are integrated and represented as a whole (Behrmann, Richler, Avidan, & Kimchi, 2014; Diamond & Carey, 1986; Maurer et al., 2002; Tanaka & Farah, 1993). Such holistic processing has been shown to be more important for recognition of faces than for other objects, as the resulting Gestalt representations help us make sense of the visual information and perceive different identities (Behrmann et al., 2014). This is in contrast to featural processing, where the visual stimulus is recognized based on its individual components (e.g., eyes, mouth, nose, face contour, colour, brightness, etc.) rather than as a whole (Diamond & Carey, 1986; Tanaka & Farah, 1993). Featural processing occurs when faces are inverted and subsequently processed more similarly to objects based on their individual features instead, hence leading to upside-down faces not being recognized as Gestalt representations with inherent identities (Farah, Wilson, Drain, & Tanaka, 1995; Rossion & Gauthier, 2002; Tanaka & Farah, 1993; Tanaka & Sengco, 1997). This is referred to as the "face inversion effect",

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whereby inversion deteriorates our face recognition ability drastically compared to the recognition of non-face stimuli (Yin, 1969).

The existing knowledge about face processing, however, is based on studies that examined 2-dimensional (2D) faces presented on computer screens and lacking the visual depth information inherent in real life faces. In contrast, 3-dimensional (3D) images provide greater depth and visual details (Häkkinen et al., 2008; Lambooij, IJsselsteijn, Bouwhuis, & Heynderickx, 2011), thereby leading to richer information of both individual features as well as the spatial interrelationship between them (configural information) (Schwaninger, Ryf, & Hofer, 2003), and thus a more "comprehensive" Gestalt representation. These enhanced featural and spatial details in 3D faces also provide additional visual information that could help to make the stimuli more closely resemble the real-life perceptions that our visual systems are attuned to. Based on these premises, it is expected that 3D details would provide an advantage over 2D images during face recognition for both holistic and featural processing.

To date, no published studies have examined the manner in which 3D stereoscopic faces influence the mechanisms of holistic and featural processing in face recognition. This study therefore aims to address this research gap by comparing the recognition of 3D stereoscopic and 2D faces in a classic face inversion paradigm (Tanaka & Farah, 1993; Yin, 1969). We examined to what extent the findings of the face inversion effect on 2D faces could be generalized to 3D faces, and aimed to understand processing that is involved more heavily for 3D faces. It is hoped that the findings from this study not only extend our current understanding of face recognition but also provide novel perspectives for research ideas that are enabled by the advancement of 3D technology.

It has yet to be established how the proposed advantages of enhanced visual details in 3D influence the mechanisms underpinning the holistic and featural processing involved in face recognition. Existing literature suggests that faces are processed over three different stages (Maurer et al., 2002). During the first stage, first-order processing occurs based on the general organization of the face's features (i.e. two eyes, above a nose, above a mouth), for the initial face detection. Subsequently, holistic processing occurs in the second stage where facial features are integrated to form a Gestalt representation. At the third stage, second-order processing takes place in which the variance between faces is analyzed, such as the distance between the eyes, to form accurate and distinct face representations (Diamond & Carey, 1986; Freire, Lee, & Symons, 2000; Taubert et al., 2011). Holistic face recognition is therefore based on how basic attributes are spatially arranged to form the prototypical representation of a face (Diamond & Carey, 1986; Taubert et al., 2011). When faces are presented upside-down, however, it disrupts the spatial relationship among the facial features (the first-order information), slowing down face detection and impairing holistic face processing consequently (Farah, Wilson, Drain, & Tanaka, 1998; Farah et al., 1995; Maurer et al., 2002; Sekuler, Gaspar, Gold, & Bennett, 2004; Tanaka & Farah, 1993; Yin, 1969). As a result, inverted faces are recognized as an amalgamation of facial parts rather than as a congruent face.

A substantial number of studies have manipulated the upright or inverted orientation of faces as a reliable method of eliciting holistic or featural processing (Itier & Taylor, 2002; Leder & Carbon, 2006; Rossion et al., 1999; Sekuler et al., 2004; Tanaka & Farah, 1993; Tanaka & Sengco, 1997; Taubert et al., 2011). It is typically shown that holistic processing contributes to greater face recognition accuracy and faster response time, as it facilitates the formation of a coherent representation of a face (Itier & Taylor, 2002; Jacques, D'Arripe, & Rossion, 2007; Rossion et al., 1999; Tanaka & Farah, 1993; Taubert et al., 2011). On the other hand, inversion leads to an increase in cognitive demand due to the disruption of first-order information (Behrmann et al., 2014; Maurer et al., 2002; Rock, 1974), resulting in lower accuracy and slower reaction times during featural processing (Itier & Taylor, 2002; Jacques et al., 2007; Jiang, Dricot, Blanz, Goebel, & Rossion, 2009; Maurer et al., 2002; Rossion et al., 1999; Tanaka & Farah, 1993; Tanaka & Sengco, 1997; Taubert et al., 2011).

Results from event-related potential (ERP) studies focusing on the face-sensitive N170 modulation have corroborated the behavioral findings. In particular, the amplitude and latency of N170 are thought to index the degree and onset of early structural encoding of faces (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Bentin, Deouell, & Soroker, 1999; Eimer, Kiss, & Nicholas, 2010; Heisz et al., 2006; Itier & Taylor, 2002; Jacques et al., 2007; Maurer et al., 2002). Studies have consistently shown that N170 has a later onset for inverted faces compared to upright faces, supporting the notion of delayed processing speed for inverted faces (Heisz et al., 2006; Itier & Taylor, 2002, 2004; Jacques et al., 2007; Rossion & Gauthier, 2002; Rossion et al., 1999, 2000; Sadeh & Yovel, 2010). Moreover, these studies have also shown a larger N170 amplitude (more negative) for inverted faces compared to upright ones, suggesting more complex structural encoding for inverted relative to upright faces (Bentin et al., 1996; Eimer et al., 2010; Heisz et al., 2006; Itier & Taylor, 2002; Maurer et al., 2002; Rossion et al., 1999, 2000; Sekuler et al., 2004). Taken together, results from both behavioral and ERP studies provide convincing evidence that upright faces are associated with higher accuracy and shorter processing time due to less complex structural encoding compared to inverted faces (Eimer et al., 2010; Itier & Taylor, 2002; Jacques et al., 2007; Rossion et al., 1999, 2000). Here, we employed the face inversion paradigm to investigate whether such holistic and featural processes in 2D face recognition are similarly engaged during processing of 3D faces.

As aforementioned, 3D stereoscopic images provide greater depth and visual details compared to their 2D counterparts (Häkkinen et al., 2008; Lambooij et al., 2011). Therefore, it is expected that 3D faces would provide (i) enriched configural information between facial features which could be beneficial to holistic processing, and (ii) richer visual details of the individual facial parts which could be beneficial to featural processing (Liu, Collin, & Chaudhuri, 2000). In order to test for these differences and their effects on holistic and featural processing during face recognition, participants completed a delayed face-matching task for 2D and 3D faces that were presented upright or inverted.

Given the premise that 3D provides greater visual depth information, it is expected that the information providing first-order structure would thus be enhanced, thereby facilitating holistic processing. We hypothesized that 3D upright faces would be recognized faster and with greater accuracy than 2D upright faces. Similarly, it is expected that 3D would facilitate featural processing due to the increased richness of visual details in local information. Therefore, individual facial parts are surmised to be more easily discernible, leading to the prediction that 3D inverted faces would also be recognized faster and with greater accuracy than 2D inverted faces. For inverted faces, since first-order information is disrupted when faces are presented upside-down, we hypothesized that the inversion effects would be observed regardless of whether the faces are shown in 2D or 3D.

2. Methodology

2.1. Participants

Twenty-four undergraduates and two recent graduates, with normal or corrected-to-normal vision, were recruited from four local universities in Singapore – Nanyang Technological University, National University of Singapore, Singapore Management