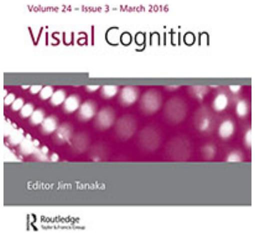

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Investigating the face inversion effect in a deaf population using the Dimensions Tasks

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ABSTRACT

Early experience can change the way people process faces. Early deafness provides deaf children with the opportunity to learn sign language, which is likely to alter their face processing strategy. The goal of the current study was to investigate whether early deafness, combined with the sign language experience, was able to change the face processing strategy using the Dimensions Task. In the Face Dimensions Task, configural and featural information were parametrically and independently manipulated in the eye and mouth region of the face. The manipulations for configural information involved changing the distance between the eyes or the distance between the mouth and the nose. The manipulations for featural information involved changing the size of the eyes or the size of the mouth. Similar manipulations were applied in the House Dimensions Task, with top and bottom windows treated as eyes and mouth. In the Face Dimensions Task, both the signing deaf and hearing participants showed a larger inversion effect in the mouth condition than the eye condition. However, as compared to hearing participants, deaf participants showed smaller inversion effect in the mouth condition, because their performance in the inverted mouth condition was not compromised by inversion to the same extent as the hearing participants. In the House Dimensions Task, this effect was not present, suggesting that it was face specific. This effect could be explained by the redistributed attentional resources from the centre to peripheral visual fields of deaf participants.

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Deaf; face inversion effect; Dimensions Task

Faces are important objects in our everyday life. We can extract a variety of information from a face, such as identity, gender, age, race, and state of mind, which are all critical clues for our social lives. Due to their social importance, face processing skill occurs very early on in development. Face processing behaviour emerges during the first 30 minutes of life (Johnson, Dziurawiec, Ellis, & Morton, 1991), continues to develop later on and peaks at the age of 30 years (Germine, Duchaine, & Nakayama, 2011; Lawrence et al., 2008). Because of the importance of early experience with faces, it is not surprising that when early visual experience is deprived, the development of face processing will be compromised (Gandhi, Kalia, Chatterjee, & Sinha, 2013; LeGrand, Mondloch, Maurer, & Brent, 2001, 2004; see Maurer, Mondloch, & Lewis, 2007, for a review).

An interesting, yet unsettled, empirical issue is whether the development of face processing is subject to early deprivation of the input in non-visual channels such as the auditory channel. There is evidence showing that the deprivation of auditory input can result in the redistribution of attentional resources across the visual field. For example, several studies showed that deaf participants had enhanced attention to the information at their peripheral visual field, but possessed less attentional resource at their centre visual field as compared to the hearing controls (Armstrong, Neville, Hillyard, & Mitchell, 2002; Bavelier et al., 2000, 2006; Bosworth & Dobkins, 2002; Buckley, Codina, Bhardwaj, & Pascalis, 2010; Codina, Buckley, Port, & Pascalis, 2011; Dye, Hauser, & Bavelier, 2009; Lore & Song, 1991; Neville & Lawson, 1987; Proksch & Bavelier, 2002; Stivalet, Moreno, Richard, Barraud, & Raphel, 1998; see Bavelier & Neville, 2002; Bavelier, Dye, & Hauser, 2006, for reviews). This cross-channel compensation effect was consistent with the findings using neural-imaging methods that enhanced activities in the auditory cortex were observed when processing visual information for deaf participants as compared to the hearing controls (for a review, see Bavelier & Neville, 2002).

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In terms of face processing, deaf signers and hearing signers showed differences as compared to the hearing controls. Deaf individuals performed better than hearing non-signers on tasks that required the recognition of faces presented under different viewpoints and lighting conditions (Bettger, Emmorey, McCullough, & Bellugi, 1997). Similarly, Arnold and Murray (1998) found that both deaf signers and hearing signers performed better in the face matching task, but not the object matching task as compared to hearing non-signers. Arnold and Mills (2001) also found the superiority of signers (both deaf and hearing) over non-signers in the location memory task of faces and shoes.

One way to investigate the difference in face processing between hearing and deaf participants is to study the face inversion effect in those two groups. The Face Inversion Effect is a well-established phenomenon in the face processing literature. When faces are turned upside down, their recognition is disproportionately impaired relative to the recognition of inverted non-face objects (e.g., airplanes, stick figures, birds, cars) (Yin, 1969). To explain the face inversion effect, it has been argued that inversion disrupts the holistic processes that are especially suited for the recognition of upright faces relative to other non-face objects. In holistic face processing, the features of a face (e.g., eyes, nose, mouth) are combined with spacing information in a unified holistic representation. When a face is inverted, holistic processing is impaired, forcing the observer to process the face not in terms of its whole, but based on its individual features (e.g., Farah, Tanaka, & Drain, 1995; Maurer, Grand, & Mondloch, 2002; Rossion, 2008, 2009; Sergent, 1984; Tanaka, Kaiser, Hagen, & Pierce, 2014a; Xu & Tanaka, 2013; Yin, 1969, but see Richler, Mack, Palmeri, & Gauthier, 2011; Susilo, Rezlescu, & Duchaine, 2013). Bettger et al. (1997) found that deaf participants showed larger inversion effect in the face recognition task. Similarly, DeHeering, Aljuhanay, Rossion, and Pascalis (2012) found that deaf individuals showed an increased inversion effect for faces, but not for non-face objects. These findings indicated that deaf participants process faces differently as compared to hearing controls.

One plausible explanation of the disproportionate face inversion effect was that upright faces elicit a relatively large "perceptual field" in which facial information can be extracted in both the central and peripheral regions of attention while inverted faces elicit smaller "perceptual field" in which facial information can only be extracted in the central region of attention (Rossion, 2009; Tanaka et al., 2014). The perceptual field theory applies well to the hearing individuals (VanBelle, DeGraef, Verfaillie, Rossion, & Lefèvre, 2010), however, as discussed in the previous paragraphs, it was possible that, in deaf participants, the decreased perceptual field size could be compensated by their enhanced peripheral visual field attention. Therefore, when processing inverted faces, deaf participants might show different patterns of behaviour.

The purpose of the current paper is to study this difference in face processing between deaf and hearing participants by investigating the size of the face inversion effect in several different dimensions of face processing. In the current study, the Face Dimensions Task was used to study the size of the inversion effect across different regions of the face. In the Face Dimensions Task, information in the eye and mouth regions was manipulated independently in a step-wise fashion (Bukach, LeGrand, Kaiser, Bub, & Tanaka, 2008). Therefore, information processing in the different regions (eye vs. mouth) can be investigated independently in the perception of upright and inverted faces. The Face Dimensions Task has been used in testing the face inversion effect using both psychophysics method (Tanaka et al., 2014a) and eye tracking method (Xu & Tanaka, 2013). It has been used to study face processing in infants (Quinn & Tanaka, 2009), children (Tanaka et al., 2014b) and special populations such as people with autism spectrum disorder (Wolf et al., 2008) and prosopagnosia (Bukach et al., 2008; Rossion, Kaiser, Bub, & Tanaka, 2009). Previous research using the Face Dimensions Task with typically developed hearing adults (Tanaka et al., 2014a; Xu & Tanaka, 2013) found a larger inversion effect in the information processing of the mouth region than the eye region. This disproportionate inversion effects across regions was face specific, because the same effect was not present when houses were used as the stimuli. In the current study, the Face Dimensions Task will be used to test the difference in the face inversion effect of deaf and hearing participants and the House Dimension Task will be deployed as a control task. Based on previous studies using the Dimensions Task (Tanaka et al., 2014a; Xu & Tanaka, 2013), a smaller inversion effect in deaf participants was expected because the shrinkage of perceptual field could be compensated by the enhanced peripheral visual field attention when processing mouth on inverted faces in deaf participants.

Method

Participants

Forty hearing (25 females) and 35 deaf (14 females) participants were recruited to participate in this study. The hearing participants were all undergraduate students in the Department of Special Education of East China Normal University. All deaf participants were students in the Nanjing Technical College of Special Education. The ages between the hearing ($M = 20.35$, $SE = 0.33$) and deaf ($M = 19.80$, $SE = 0.72$) participants were not significantly different ($t_{73}=0.72$, $p = .47$). All deaf participants were fluent in Chinese Sign Language and the hearing loss of each deaf participant was greater than 80 dB.

Stimuli

In the Face Dimensions Task, the stimuli were created using the greyscale pictures of three male and three female children's faces (age range 9–12 years old). The images were cropped at each side of the head and no jewellery, glasses, makeup, or facial markings (e.g., freckles, moles, etc.) were present on the face. The faces were 300 pixels in width by 400 pixels in height. The eyes or mouth of each face was modified either featurally (i.e., size) or configurally (i.e., distance). As a result, there are four dimensions of change in the experiment, namely featural eyes, featural mouth, configural eyes, and configural mouth. Each dimension of change consisted of five faces including the original face, and four incrementally varied face images. In total, there are 20 faces created based on each original face and 120 face stimuli in total (see Figure 1 for an example). In the featural condition, the location and the shape of the eye or the mouth are kept unchanged, and the size of the eyes or mouth was manipulated by resizing the original feature by 80%, 90%, 110%, or 120%. Due to the nature of the manipulations in the featural condition, changing the size of the eyes or the mouth while maintaining their original positions necessarily induce some configural changes. The magnitude of these changes was as follows: Within the eye condition, the inter-ocular distance varied in increments of four pixels between each level of change; in the mouth condition, the distance from the philtrum varied in increments of two pixels. In the configural condition, the distance between the features was modified. Within the configural eye condition, the inter-ocular distance was modified by increasing and decreasing this measure by 10 (approximately 16% of the original distance) and 20 pixels relative to the primary face. Configural mouth modifications involved shifting the mouth upwards and downwards vertically by five (approximately 16% of the original distance) and 10 pixels. The size and shape of the features were held constant. For every dimension along the five-step continua, the differences between faces that are separated by three steps in the continuum should be relatively "easy" to detect, faces separated by two steps should be "medium" and differences between faces separated by only one step should be "difficult" to detect.

The stimuli used in the House Dimensions Task were comparable to those in the Face Dimensions Task, except that six house images were used in place of faces (Figure 2). Most plants and other decorative items were removed from the images with some shrubs left to maintain a realistic representation of houses. The primary house images had a pair of small windows near the top and a single, larger, window near the bottom. These windows were used as analogues of the eyes and mouth, respectively. Similar to the faces, configural and featural modifications were made to the windows of the houses, to create four images within each condition, using the procedures described in the face task. In the featural condition, the size of either the pair of top windows or the single bottom window was manipulated. The four secondary house images in each condition had windows that were 60%, 80%, 120%, and 140% of the size of the primary windows. In both conditions, the position of the centre points of the windows remained constant. In the top-window condition, the distance between the two windows varied by 2.5 to 5.0 pixels per degree of change; in the bottom window condition, the vertical distance between the inferior edge of the top windows and the superior edge of the bottom window varied by 1.5 to 2.5 pixels per degree of change. To create stimuli for the configural condition, the spacing between the windows was manipulated. In the top-window

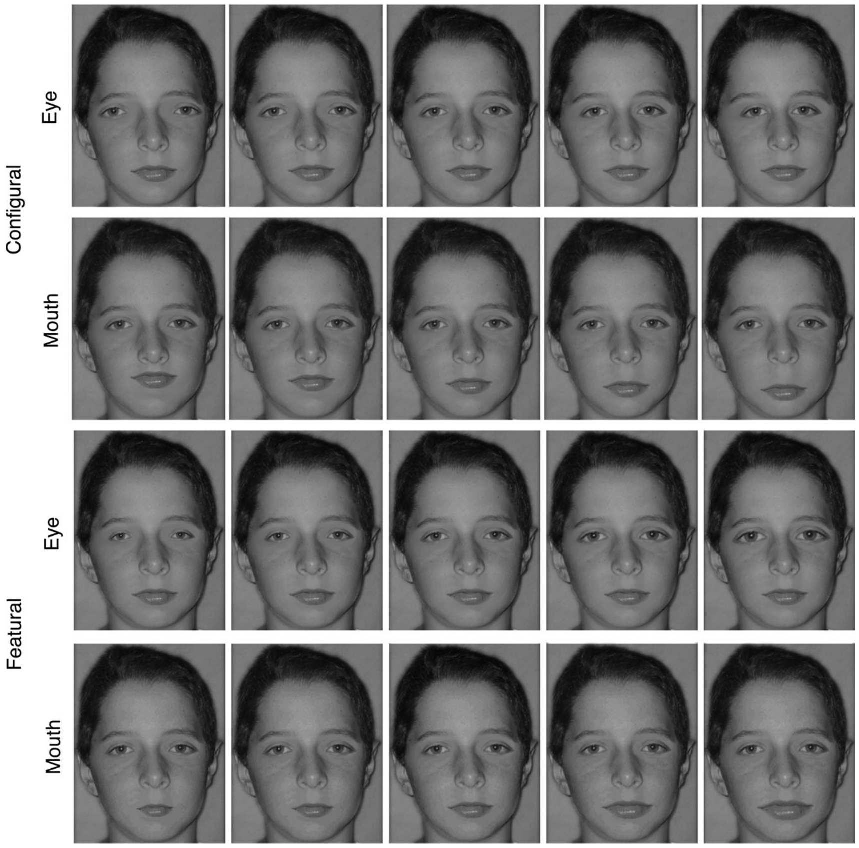


Figure 1. Example stimuli from the Face Dimensions Task. From left to right, the difference between any two adjacent images refers to one step of change. The changes could be the distance between the eyes (Configural eye), the distance between the nose and the mouth (Configural mouth), the size of the eyes (Featural eye) and the size of the mouth (Featural mouth).

condition, the distance between the upper windows was increased or decreased by 20 or 40 pixels, and in the bottom window condition, the window was shifted vertically up or down by 20 or 40 pixels. The stimuli were 400 pixels in width by 425 pixels in height.

Procedure

This research was approved by the ethics board of the East China Normal University. The procedure was explained and informed written consent was obtained from the participants prior to the testing and a complete debriefing was given on completion. A same-different paradigm was used. Participants were told that they would be presented with two images in sequence on a computer monitor, and they were asked to determine whether these images were identical. They were directed to respond as quickly and accurately as possible using keys labelled "same" and "different" on a serial response box. We emphasized to participants that in order to respond "same" the two pictures should be physically identical. Within each trial, a fixation cross was displayed for 250 ms, followed by the first stimulus and the second stimulus presented for 500 ms each, with a 500 ms noise mask displayed in between. The second stimulus remained on the screen until the participant responded, for a maximum of 3000 ms. Trials were separated by 1500 ms. In each trial, the two stimuli were presented either both upright or both inverted. Stimuli were centred horizontally on the screen and positioned vertically so that the nose or the centre of the house was at the centre of the screen in both upright and inverted trials. Participants perform the face task first followed by the house task. Participants were tested using the computer software E-Prime Version 2.0. Several different computers were used but participants were always seated at the appropriate distance where the stimulus were 10.0° by 13.2° in visual angle. Participants always completed the face condition first, followed by the house condition.

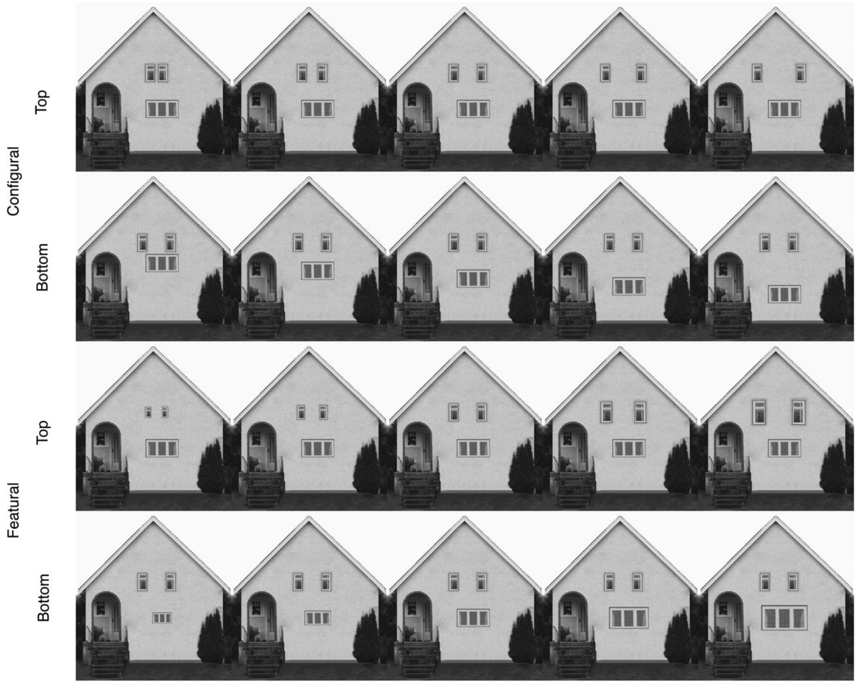


Figure 2. Example stimuli from the House Dimensions Task. From left to right, the difference between any two adjacent images refers to one step of change. The changes could be the distance between the top windows (Configural top), the distance between the nose and the bottom window (Configural bottom), the size of the top windows (Featural top) and the size of the bottom window (Featural bottom).

Design

In the Face Dimensions Task, four within-subjects independent factors were manipulated: Type (configural or featural), Region (eyes or mouth), Orientation (upright or inverted), and Level (easy, intermediate, or difficult). The "easy" trials were separated by three degrees of difference along the continuum, the "medium" trials by two degrees and "difficult" trials by one degree. Half of the trials were "same" trials and half were "different" trials. All the conditions were counter balanced and evenly distributed into four blocks with 576 trials in total. The exact same conditions were used in the House Dimensions Task.

Results

An ANOVA was conducted on the *d′* scores, with Stimulus (faces, houses), Level (easy, intermediate, difficult), Type (featural, configural), Region (eye, mouth) and Orientation (upright, inverted) as within-subjects factors and Group (hearing, deaf) as between-subjects factor (Table 1). The main effects of Stimulus ($F_{(1,\ 73)} = 73.83$, $p < .001$, $\eta^2 = 0.50$), Level ($F_{(2,\ 146)} = 441.11$, $p < .001$, $\eta^2 = 0.86$), Region ($F_{(1,\ 73)} = 33.67$, $p < .001$, $\eta^2 = 0.32$), Orientation ($F_{(1,\ 73)} = 107.04$, $p < .001$, $\eta^2 = 0.60$) and Group ($F_{(1,\ 73)} = 15.87$, $p < .001$, $\eta^2 = 0.18$) were all significant. Moreover, all of the interactions of interest were significant. To be specific, the two-way interaction between Stimulus and Orientation was significant ($F_{(1,\ 73)} = 76.96$, $p < .001$, $\eta^2 = 0.51$). Multiple comparisons showed that this interaction was driven by the significant inversion effect with face stimuli ($p < .001$), but not house stimuli ($p = .18$). Also, the two-way interaction between Stimulus and Group was significant ($F_{(1,\ 73)} = 6.76$, $p < .05$, $\eta^2 = 0.09$). Multiple comparisons suggested that although deaf participants performed worse than hearing controls in both face and house tasks (both $ps < .05$), their performance impairment was larger in the house condition than the face condition as compared to the controls ($p < .05$). Furthermore, the three-way interaction of Stimulus, Orientation and Group ($F_{(1,\ 73)} = 4.13$, $p < .05$, $\eta^2 = 0.05$) was significant. This interaction was driven by the fact that while no inversion effects were found for both groups with house stimuli, deaf participants showed a smaller inversion effect (i.e., the difference in *d′* between the upright and inverted condition) than the hearing participants with face stimuli. Furthermore, the four-way

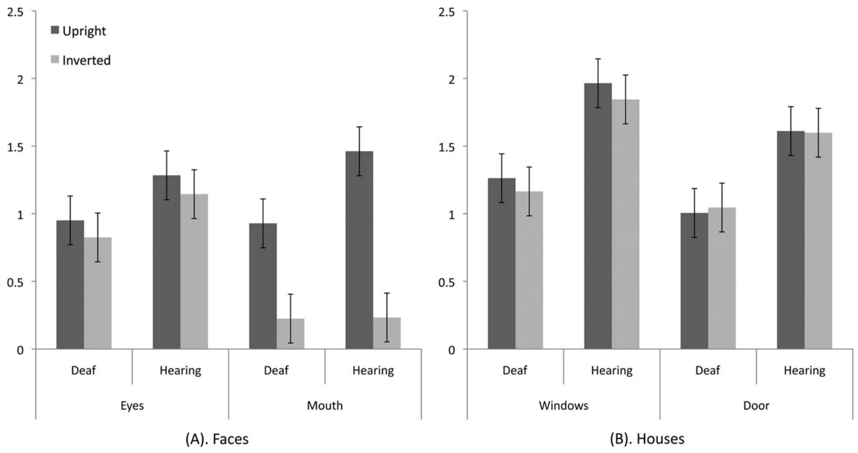
Table 1. Mean *d′* scores for different conditions in the Face and House Dimensions Task.

	Difficult				Intermediate				Easy			
	Configure		Featural		Configure		Featural		Configure		Featural	
	Eyes	Mouth	Eyes	Mouth	Eyes	Mouth	Eyes	Mouth	Eyes	Mouth	Eyes	Mouth
Face												
Hearing												
Upright	0.56 (0.09)	0.55 (0.09)	0.52 (0.09)	0.71 (0.09)	1.41 (0.13)	1.57 (0.13)	1.27 (0.13)	1.62 (0.12)	1.96 (0.16)	2.08 (0.14)	1.98 (0.16)	2.23 (0.14)
Inverted	0.51 (0.07)	0.07 (0.07)	0.54 (0.09)	0.08 (0.07)	1.18 (0.12)	0.15 (0.07)	1.28 (0.12)	0.25 (0.09)	1.62 (0.15)	0.31 (0.09)	1.75 (0.16)	0.54 (0.12)
Deaf												
Upright	0.30 (0.09)	0.22 (0.09)	0.32 (0.09)	0.42 (0.09)	1.00 (0.14)	0.79 (0.14)	1.02 (0.14)	1.07 (0.13)	1.50 (0.17)	1.54 (0.154)	1.57 (0.17)	1.54 (0.15)
Inverted	0.28 (0.08)	0.03 (0.08)	0.37 (0.09)	0.15 (0.08)	0.82 (0.13)	0.10 (0.08)	0.99 (0.13)	0.42 (0.09)	1.09 (0.16)	0.16 (0.09)	1.40 (0.17)	0.49 (0.11)
House												
Hearing												
Upright	1.20 (0.10)	1.09 (0.10)	1.21 (0.12)	0.75 (0.12)	2.05 (0.15)	1.89 (0.14)	2.26 (0.17)	1.62 (0.14)	2.42 (0.15)	2.30 (0.16)	2.66 (0.16)	2.03 (0.16)
Inverted	1.16 (0.11)	0.98 (0.12)	1.07 (0.12)	0.85 (0.12)	2.12 (0.16)	1.94 (0.15)	1.95 (0.17)	1.57 (0.16)	2.46 (0.16)	2.23 (0.17)	2.30 (0.17)	2.02 (0.16)
Deaf												
Upright	0.76 (0.11)	0.79 (0.11)	0.83 (0.13)	0.47 (0.12)	1.32 (0.16)	1.14 (0.15)	1.40 (0.18)	0.98 (0.15)	1.67 (0.16)	1.43 (0.17)	1.60 (0.17)	1.23 (0.17)
Inverted	0.81 (0.12)	0.82 (0.13)	0.74 (0.13)	0.65 (0.13)	1.26 (0.17)	1.20 (0.16)	1.29 (0.18)	0.93 (0.17)	1.35 (0.17)	1.45 (0.18)	1.54 (0.18)	1.22 (0.17)

Note: Numbers in brackets refer to the standard errors.

interaction of Stimulus, Orientation, Region and Group ($F_{(1,\ 73)} = 5.48$, $p < .05$, $\eta^2 = 0.02$) was significant (Figure 3). Visual inspections on Figure 3 suggested that this interaction was driven by the fact that there was smaller inversion effect in mouth conditions in deaf participants as compared to the hearing participants, but not in all the other conditions including the eye condition and all the conditions in the house task.

In order to verify this observation, ANOVAs were conducted with Level (easy, intermediate, difficult), Type (featural, configural), Region (eye, mouth) and Orientation (upright, inverted) as within-subjects factors and Group (hearing, deaf) as between-subjects factor, for face and for house stimuli separately. With face stimuli, the main effects of Level ($F_{(2,\ 146)} = 280.31$, $p < .001$, $\eta^2 = 0.79$), Region ($F_{(1,\ 73)} = 25.74$, $p < .001$, $\eta^2 = 0.26$), Orientation ($F_{(1,\ 73)} = 143.98$, $p < .001$, $\eta^2 = 0.66$), Type ($F_{(1,\ 73)} = 12.02$, $p < .01$, $\eta^2 = 0.14$) and Group ($F_{(1,\ 73)} = 10.10$, $p < .01$, $\eta^2 = 0.12$) were all significant. The interaction between Orientation and Group was significant ($F_{(1,\ 73)} = 8.15$, $p < .01$, $\eta^2 = 0.11$). Multiple comparisons showed that hearing participants had larger inversion effect than deaf participants ($p < .01$). A further investigation of this interaction indicated that this difference in the size of inversion effect was rooted from the difference in the mouth condition. This was evident from the significant three-way interaction of Region, Orientation and Group ($F_{(1,\ 73)} = 7.34$, $p < .001$, $\eta^2 = 0.17$). Multiple comparisons showed that this interaction was driven by the larger inversion effect in the mouth region in hearing participants ($M = 1.23$, $SE = 0.09$) than deaf participants ($M = 0.70$, $SE = 0.10$) ($p < .001$). None of the other interactions involved with Orientation and Group were significant. It was worth noting that visual inspection suggested that the smaller inversion effect of the deaf group in the inverted mouth condition might be subject to the floor effect in the inverted mouth condition. However, *t*-tests showed that the *d′* scores in the inverted mouth condition were significantly larger than chance level of 0 in both deaf ($t_{34} = 5.06$, $p < .00005$) and hearing groups ($t_{39} = 4.44$, $p < .0001$), eliminating the possibility that the smaller inversion effect in the mouth region of deaf participants was driven by the floor effect of their performance in the inverted mouth condition. Moreover, with house stimuli, the critical interaction between Orientation and Group was not significant,



(A). Faces (B). Houses

Figure 3. The *d′* scores for the (A) Face Dimensions Task and the (B) House Dimensions Task across Region and Orientation for hearing and deaf participants. The darker bars refer to the upright condition and lighter bars refer to the inverted condition. Error bars stand for the 95% confidence interval.

Table 2. Mean response time for correct trials only in the Face and House Dimensions Task, collapsed across the variable of Type.

	Configure		Featural	
	Eyes	Mouth	Eyes	Mouth
Face				
Hearing				
Upright	768.76 (23.77)	771.70 (24.77)	770.18 (24.77)	778.08 (24.09)
Inverted	794.04 (27.10)	825.58 (30.82)	797.21 (27.70)	810.84 (31.15)
Deaf				
Upright	746.86 (25.09)	753.77 (26.15)	737.83 (26.15)	754.62 (25.43)
Inverted	791.97 (28.60)	789.91 (32.54)	781.16 (29.2)	777.80 (32.88)
House				
Hearing				
Upright	713.29 (27.78)	708.11 (26.83)	698.02 (23.93)	711.59 (28.11)
Inverted	710.44 (28.25)	712.51 (27.08)	714.82 (28.67)	721.65 (28.53)
Deaf				
Upright	666.34 (29.33)	662.52 (28.32)	673.60 (25.26)	668.47 (29.67)
Inverted	668.10 (29.82)	666.83 (28.58)	656.66 (30.27)	665.23 (30.11)

Note: Numbers in brackets refer to the standard errors.

neither were all the other interactions involved with Orientation and Group.

Response time data was analysed with the correct trials only. Due to the low accuracy rate in the difficult conditions, the data was collapsed across the three Levels of difficulty.[1] Therefore, an ANOVA with Stimulus (faces, houses), Region (eye, mouth), Type (featural, configural), Orientation (upright, inverted) as within-subjects factors, and Group (hearing, deaf) as between-subjects factor, was conducted (Table 2). Only the main effects of Stimulus ($F_{(1,\ 72)} = 45.06$, $p < .001$, $\eta^2 = 0.39$) and Orientation ($F_{(1,\ 72)} = 12.95$, $p < .01$, $\eta^2 = 0.15$) were significant. However, none of the interactions involving Orientation and Group were significant.

Discussion

The goal of the current study was to investigate whether early deafness, combined with their sign language experience was able to change the face processing strategy used in the Dimensions Task where featural and configural information of the eye and mouth regions of face stimuli and the small window and door regions of house stimuli were parametrically manipulated. Overall, deaf participants performed worse than the hearing control participants on both the Face and House Dimensions Task. Both the hearing and deaf groups of participants showed similarities on the two tasks. For the Face Dimensions Task, both groups of participants showed a larger inversion

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[1] The data of one hearing participant was not included due to the fact that the accuracy in at least one of the conditions was 0, and therefore no trials could be selected to calculate response time.

effect in the mouth condition than in the eye condition. In the House Dimensions Task, both groups showed no inversion effect across all the conditions. Importantly, deaf participants showed a smaller inversion effect in the mouth condition as compared to hearing participants in the Face Dimensions Task, but not the House Dimensions task.

For the combined deaf and hearing groups, the absent of an inversion effect for the eye region and the presence of an inversion effect for the mouth region was consistent with previous studies where hearing adults were studied (Tanaka et al., 2014a; Xu & Tanaka, 2013) and children (Tanaka et al., 2014b). In the House Dimensions Task, deaf and hearing groups showed no difference in their discrimination of house features presented either in their upright or their inverted orientations. The absence of a house inversion effect was similar to the previous results obtained with hearing adults (Tanaka et al., 2014a). Similarly, overall, inversion has the same effect on the recognition strategies of deaf individuals as hearing individuals.

However, there were still important differences between deaf and hearing participants. First, deaf participants performed more poorly in the Face and House Dimensions Tasks than the hearing participants, as indicated by the significant main effect of Group. However, a significant interaction between Stimulus and Group suggested that this effect was smaller with face than house stimuli. Although deaf participants performed worse than hearing participants with both faces and houses stimuli, they were *less* impaired for faces than houses suggesting that faces provided a buffer against the perceptual deficits associated with deafness. Further investigations in the results in the face condition showed that, in the mouth region, the magnitude of the inversion effect for deaf participants was smaller than the inversion effect for hearing participants. Although the performance of deaf participants was worse than the control participants in the eye region, the magnitude of the inversion effect for the two groups was the same. Despite the group differences on the House Dimensions Task, the absolute size of the inversion effect for the windows and doors was the same in both groups, indicating that the inversion effect in the mouth region was not due to its location in the lower spatial region of the stimulus, but was face specific.

Why did both groups of participants showed no inversion effect in the eye conditions? According to the perceptual field theory, upright faces elicit relatively large "perceptual field" in which facial information can be extracted in both the central and peripheral regions of attention, while inverted faces elicit relatively small "perceptual field" in which facial information processing is limited to one feature at a time (Rossion, 2009). Previous studies (Tanaka et al., 2014a) using the Dimensions Task showed that, when processing inverted faces, attention is spontaneously drawn to the eye features at the expense of processing information in the mouth region. Therefore, despite the smaller "perceptual field" when processing inverted faces, changes in the eye region were still detected. This pattern was found in both the hearing and deaf participants, indicating that they both exhibited the eye bias when processing inverted faces, suggesting that the mouth bias of deaf participants due to their lip reading experience (Letourneau & Mitchell, 2011; McCullough & Emmorey, 1996; Mitchell, Letourneau, & Maslin, 2013; Watanabe, Matsuda, Nishioka, & Namatame, 2011) was only applicable to upright faces, but not inverted faces.

Why did deaf participants show smaller inversion effect in the mouth condition? In order to interpret this group difference in the size of the inversion effect in the mouth condition, it is necessary to study the source of the inversion effect. The inversion effect is calculated from the difference between the performance in the upright condition and the inverted condition. Therefore, a smaller inversion effect could be due to either a higher performance in the inverted condition, or a lower performance in the upright condition. The results from the Face Dimensions Task showed although deaf participants performed worse than the hearing controls in all conditions, their performance in the inverted mouth condition showed less impairment. Although the d' score of the deaf participants was low (0.23), the performance was significantly higher than chance level indicating that it was not a floor effect. Thus, deaf participants' performance in the inverted mouth conditions was not impacted to the same degree as the hearing controls did. This finding was supported by both the "perceptual field theory" and the evidence that deaf individuals had enhanced peripheral visual field attention. According to the perceptual field theory, upright faces elicit relatively large "perceptual field" in which facial information can be extracted in both the central and peripheral regions of attention (Rossion, 2009). With this large perceptual field, participants could detect changes in the mouth (eye) region even when they were attending to the eye (mouth) region of upright faces (Xu & Tanaka, 2013). When faces are inverted, hearing participants can only rely on their central regions of attention due to the contraction of the "perceptual field" and, therefore, when they were attending to the eye (mouth) region of the inverted faces, they were not able to detect changes in the mouth (eye) region in their peripheral region of attention. Deaf participants, however, due to the sign language experience, possessed greater attentional resources in the periphery visual field as compared to hearing participants (Armstrong et al., 2002; Bavelier et al., 2000, 2006; Bosworth & Dobkins, 2002; Buckley et al., 2010; Codina et al., 2011; Dye et al., 2009; Lore & Song, 1991; Neville & Lawson, 1987; Proksch & Bavelier, 2002; Stivalet et al., 1998). Therefore, when processing inverted faces, although the "perceptual field" was also smaller as compared to when processing upright faces, deaf participants were still able to utilize some of the peripheral visual field attentional resources to detect the changes. Consequently, their performance in the mouth condition was not vulnerable to inversion to the same degree as the hearing controls.

In contrast to previous studies where deaf participants demonstrated a larger face inversion effect than hearing participants (Arnold & Mills, 2001; Arnold & Murray, 1998; Bettger et al., 1997), the current study found that deaf participants showed a *smaller* face inversion effect. Differences in experimental tasks might account for contrasting effects. In the Dimensions Task, participants attend to and discriminate relatively fine details in the size and spacing of facial features. Performance is susceptible to attentional cueing where participants are more likely to detect changes if they attend to the region of the change than if their attention is directed to another region (Barton, Keenan, & Bass, 2001; Tanaka et al., 2014a; Xu & Tanaka, 2013). In contrast, the previous studies examined either recognition or matching of different facial identities where the task emphasizes whole face processing. Thus, the divergent findings might be due to different cognitive demands involved in attending to specific details of a single face identity versus making judgments about multiple face identities.

It should be noted that the current study was not able to address the issue of whether the difference between the deaf and hearing group was due to deaf participants' sign language experience. In order to test this hypothesis, the experience of sign language should be controlled for, such as measuring the years of experience or the level of proficiency of sign language. Another approach is to recruit hearing signers (i.e., those who serve as professional interpreters or are born to deaf parents) or deaf non-signers (i.e., those who receive cochlear implantation in early ages and are capable of hearing and verbal language).

In conclusion, using the Dimensions Task, the current study found that deaf participants had a smaller inversion effect in the information processing of the mouth region than hearing participants when processing faces. This difference was not present when processing houses, suggesting that this effect was face specific. Further analysis indicated that the smaller inversion effect in the mouth region process could be explained by redistributed attentional resource from the centre to peripheral visual fields of deaf participants. Future studies need to further investigate whether this effect was derived from the sign language experience by testing hearing signers and deaf non-signers with the same tasks and compare the pattern of their performance with the deaf signers and hearing non-signers.

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