BRILL

Multisensory Research 32 (2019) 499–519

MULTISENSORY RESEARCH

brill.com/msr

Differences in Emotion Recognition From Body and Face Cues Between Deaf and Hearing Individuals

Chiara Ferrari [1,*], **Costanza Papagno** [1,2], **Alexander Todorov** [3] **and Zaira Cattaneo** [1,4]

[1] Department of Psychology, University of Milano-Bicocca, Milan 20126, Italy
[2] CeRiN and CIMeC, University of Trento, Rovereto 38068, Italy
[3] Department of Psychology, Princeton University, Princeton, USA
[4] IRCCS Mondino Foundation, Pavia, Italy

Received 21 October 2018; accepted 5 April 2019

Abstract

Deaf individuals may compensate for the lack of the auditory input by showing enhanced capacities in certain visual tasks. Here we assessed whether this also applies to recognition of emotions expressed by bodily and facial cues. In Experiment 1, we compared deaf participants and hearing controls in a task measuring recognition of the six basic emotions expressed by actors in a series of video-clips in which either the face, the body, or both the face and body were visible. In Experiment 2, we measured the weight of body and face cues in conveying emotional information when intense genuine emotions are expressed, a situation in which face expressions alone may have ambiguous valence. We found that deaf individuals were better at identifying disgust and fear from body cues (Experiment 1) and in integrating face and body cues in case of intense negative genuine emotions (Experiment 2). Our findings support the capacity of deaf individuals to compensate for the lack of the auditory input enhancing perceptual and attentional capacities in the spared modalities, showing that this capacity extends to the affective domain.

Keywords

Deafness, emotion, bodies, facial expressions, auditory deprivation, sign language

1. Introduction

Emotion recognition is a crucial capacity for developing social skills, and is often based on the integration of multiple sensory cues (Klasen *et al.*, 2012). Although vision usually plays a major role in driving emotion recognition,

* To whom correspondence should be addressed. E-mail: chiara.ferrari@unimib.it

DOI:10.1163/22134808-20191353

auditory cues — such as vocalizations and prosody — are also important in conveying the emotional state of other agents (Frühholz *et al.*, 2016). A few studies have investigated the effects of auditory deprivation on the development of social skills, including emotion recognition in the spared visual modality (e.g., Peterson *et al.*, 2016; Sidera *et al.*, 2017). Previous studies investigating the effects of auditory deprivation on the development of social and emotional abilities found that deaf children may show difficulties when interacting or communicating with hearing children (Greenberg and Kusché, 1989; Meadow *et al.*, 1981; Weisel *et al.*, 2005) and may report more loneliness than their hearing counterparts (Most, 2007). Reduced opportunities to converse with others (and delays in language acquisition) might negatively impact on the acquisition of social skills in deaf children, such as the understanding of others' mental states and emotion recognition (Ludlow *et al.*, 2010; Sidera *et al.*, 2017). However, in adulthood, the emerging picture seems different, with deaf individuals tending to be as accurate as hearing controls in recognizing and evaluating the valence of facial emotional expressions, although possibly relying on partially different strategies (Letourneau and Mitchell, 2011; McCullough *et al.*, 2005; Mestre *et al.*, 2015; Watanabe *et al.*, 2011). For instance, deaf observers tend to fixate the bottom half of the face more frequently than hearing controls during emotion recognition, finding it particularly difficult to infer emotional states (but not to recognize identity) when only the top part of the face is visible (Letourneau and Mitchell, 2011; but see Watanabe *et al.*, 2011). Deafness seems also to affect the typical pattern of hemispheric lateralization when processing facial emotional expressions, with the left hemisphere playing a larger role in deaf individuals compared to hearing ones (e.g., Letourneau and Mitchell, 2013; McCullough *et al.*, 2005), as in case of other perceptual and attentional tasks (e.g., Cattaneo *et al.*, 2014, 2016, 2018).

Most studies on visual emotional processing in the deaf have employed faces as stimuli. However, growing evidence suggests the importance of body signals in conveying affective information (for a review see De Gelder, 2009). Emotions can indeed be accurately recognized by looking at dynamic and static body stimuli in the absence of face information (e.g., Atkinson *et al.*, 2004; Aviezer *et al.*, 2012), and at very short presentation times (e.g., 200 ms; see Martinez *et al.*, 2015; Meeren *et al.*, 2005). Body emotional processing in the deaf has never been investigated. Consistent evidence suggests that deaf individuals may exhibit improved visual skills to compensate for the lack of the auditory input, like enhanced sensitivity in the peripheral visual field or improved visual motion detection (for reviews, Bavelier *et al.*, 2006; Pavani and Bottari, 2012; for recent evidence see Codina *et al.*, 2017; Stoll *et al.*, 2018). If on the one hand prior studies suggest that deaf individuals perform similarly to hearing controls in face emotion recognition, the former may pay more attention to body cues, usually falling more peripherally in the visual field when facing another person. Similarly, deaf individuals may be better at integrating body and face cues since, at least during sign language use, they have to simultaneously track hand gestures and face expressions. Moreover, emotional body postures, similarly to emotional vocalizations, can be perceived at a larger distance compared to face expressions (De Gelder, 2009; Smith and Schyns, 2009). Accordingly, paying more attention to body signals may be more strategic in real-life situations than focusing more on face expressions when the auditory sense is missing. In line with the above, deaf individuals may rely more on body cues when deciding about the emotion expressed by another agent, this possibly resulting in better emotion recognition when the body of the other agent is visible. To directly address this hypothesis, we tested deaf and control hearing participants on two tasks (the first involving discrimination of standard posed basic expressions, the second assessing evaluation of more natural positive and negative intense expressions) that have been used before to assess discrimination of bodily emotions (Aviezer *et al.*, 2012; Martinez *et al.*, 2015). In particular, in Experiment 1, we assessed whether and how deafness modulates the recognition of the six basic emotions when either the face, the body, or both the face and body are visible. In Experiment 2, we measured the weight of body and face cues in conveying emotional information when intense emotions are expressed, a situation in which face expressions alone may have ambiguous valence and body cues become more relevant (Aviezer *et al.*, 2012).

2. Experiment 1

In Experiment 1, we compared deaf participants and hearing controls in a task previously used by Martinez *et al.* (2015) in which — in a series of videoclips — different actors expressed an emotion with a body movement and a facial expression. Either the face or the body was masked in certain conditions, forcing the observer to infer the emotional state of the actor on the basis of facial or bodily cues alone.

2.1. Methods

2.1.1. Participants

Thirty-six profoundly deaf Caucasian individuals (18 F, mean age = 35.0 years, SD = 11.7; mean education = 15.2 years, SD = 2.7) and thirty-six normally hearing Caucasian subjects (18 F, mean age = 35.0 years, SD = 11.6; mean education = 15.6, SD = 2.8) participated in the study. Deaf and normally hearing participants were matched for age [$t(70) < 1$, $p = 0.98$] and education [$t(70) < 1$, $p = 0.45$]. All deaf participants had bilateral severe (i.e., between 71 and 90 dB) or profound (>91 dB) hearing loss and were early deaf (they lost their hearing within the first three years of life), with the exception of three participants who were clinically classified as deaf at age 6 ($n = 1$) and 8 ($n = 2$, see Table 1 for details). Seven deaf participants were early signers (because of having either one or both deaf parents) and proficiently used Italian Sign Language (LIS) (but were also capable of lip-reading and some oral communication). An additional seven deaf participants reported to moderately use LIS, which was, however, learned later in life (mean age of LIS acquisition for this group = 21.5 years, SD = 4.2). The remaining deaf participants ($n = 22$) were non-signers (they reported not to know sign language). All deaf participants used prosthetic devices (at least to one ear) and reported to refer to lip-reading to understand oral speech. All participants had normal or corrected-to-normal vision. The experiment was approved by the local ethical committee and participants were treated in accordance with the Declaration of Helsinki. Data of one deaf participant (Subject 33 in Table 1) could not be properly collected due to technical problems that were detected only at the end of the experiment; data of this participant are therefore not considered in the analysis.

2.1.2. Stimuli and Procedure

Participants were seated comfortably at a table in front of a 16-inch desktop computer (at an approximate distance of 57 cm). They were presented with short videos (1 s duration) displaying three Caucasian actors and two actresses (one Caucasian and one Asian) expressing one of the six basic emotions (anger, disgust, fear, happiness, sadness, and surprise). The videos were the same as used in Martinez *et al.* (2015) who recorded professional actors while enacting each emotion as naturally as possible. These videos were then graphically edited with a masking tool to show only the face or only the body for the entire duration of the clip. There were three types of videos: 1) intact/full videos (in which both the face and body of the actor expressing the emotion was visible); 2) videos with *visible faces and masked bodies* (in which only the face of the actor expressing the emotion was visible); 3) videos with *visible bodies and masked faces* (in which only the body of the actor expressing the emotion was visible). The videos used in the three conditions (intact, *face-only*, and *body-only*) were the same but in the masked conditions, either the face or the body was selectively visible for the entire duration of the clip (see Fig. 1 for some examples of the stimuli used). The three types of videos were presented in different experimental blocks. Each block consisted of 30 videos (five videos for each of the six selected emotions, randomly presented within each block) so that a total of 90 videos was presented in the entire experiment. The order of the experimental blocks was pseudo-randomized: the *intact* videos were always presented *after* the ‘masked’ videos; *face-only* and *body-only* videos were presented in counterbalanced order across participants, as in the study of Martinez and colleagues (2015). After viewing each clip,

Table 1.
Characteristics of deaf participants

Subj	Sex	Age (years)	Educational level (years)	Age at onset of deafness	LIS use (age of acquisition)
1*	M	21	13	3 years	Moderately fluent (20 years)
2*	M	23	13	1 year	Fluent (childhood)
3*	M	24	13	Birth	Fluent (childhood)
4*	M	19	13	8 years	Moderately fluent (20 years)
5	F	57	18	3 years	No
6	M	26	18	Birth	No
7	M	30	13	8 months	No
8	M	18	13	Birth	No
9	M	20	13	Birth	No
10	F	59	18	8 years	No
11	F	48	18	Birth	No
12*	M	53	18	Birth	No
13	F	29	13	Birth	Moderately fluent (19 years)
14	M	57	13	Birth	No
15	F	26	13	Birth	Fluent (childhood)
16	M	47	13	Birth	No
17	F	35	13	Birth	Fluent (childhood)
18	F	46	13	3 years	No
19	F	43	13	Birth	No
20	M	53	8	Birth	No
21	M	39	13	Birth	Fluent (childhood)
22	M	30	18	3 months	No
23	M	46	13	Birth	No
24	F	32	18	Birth	No
25	F	29	18	Birth	No
26	F	27	18	Birth	No
27	F	25	13	Birth	No
28	F	30	18	1 month	Moderately fluent (24 years)
29	M	35	18	Birth	No
30	F	36	18	Birth	No
31	F	25	18	Birth	Fluent (childhood)
32	M	38	18	1 year	Moderately fluent (30 years)
33	M	32	15	Birth	no
34	F	39	13	6 years	Fluent (childhood)
35	F	38	18	Birth	Moderately fluent (20 years)
36	F	25	18	2 years	Moderately fluent (18 years)
37**	M	31	13	3 years	Moderately fluent (29 years)

*Data collected only for Experiment 1.
**Data collected only for Experiment 2.

Figure 1. Sample still frames from video clips of happiness for the face-*only*, body-*only* and intact (face + body) conditions (from left to right).

participants had to indicate on a response sheet which emotion each video expressed, and their response was recorded by the experimenter on a keyboard. Participants could respond within 10 s from the end of the clip but they were encouraged to provide an intuitive (and hence possibly fast) judgment. In the response sheet the name of each of the six basic emotions (anger, disgust, fear, happiness, sadness, and surprise) was written in capital letters (black ink, 12-point Arial font), so as to be easily identifiable. The order of the (names of the) six emotions on the response sheet was randomized across participants to avoid any possible spatial bias to systematically interfere with the response. E-Prime 2.0 (Psychology Software Tools, Inc., Pittsburgh, PA, USA) was used for stimuli presentation and data recording.

2.1.3. Statistical Analyses

We computed both the standard/raw (e.g., the percentage of correct responses to a specific emotion) and unbiased hit rates (Wagner, 1993). Unbiased hit rates (Hu) are calculated by subtracting the proportion of hits expected by chance from the proportion actually observed, and by dividing this difference by the proportion expected by chance. Hu rates are considered a better measure of recognition sensitivity than standard hit rates (Wagner, 1993) because they allow to control for response biases (i.e., when participants predominantly respond with one emotion category), and have been used in several prior studies on emotion recognition (e.g., Hawk *et al.*, 2009; Martinez *et al.*, 2015). Here, we report the results of the standard hit rates, but we also note when these analyses are discrepant with the analyses of the Hu. Standard hit rates were submitted to a repeated-measures ANOVA with clip type (*intact*, *face-only*, and *body-only* videos) and emotion (anger, disgust, fear, happiness, sadness, and surprise) as within-subject factors, and group (deaf *vs.* hearing) as between-subjects factor.

2.2. Results

The analysis on standard hit rates (see Fig. 2) revealed a significant main effect of clip type, $F(2, 138) = 570.51$, $p < 0.001$, $\eta_p^2 = 0.89$, a significant main

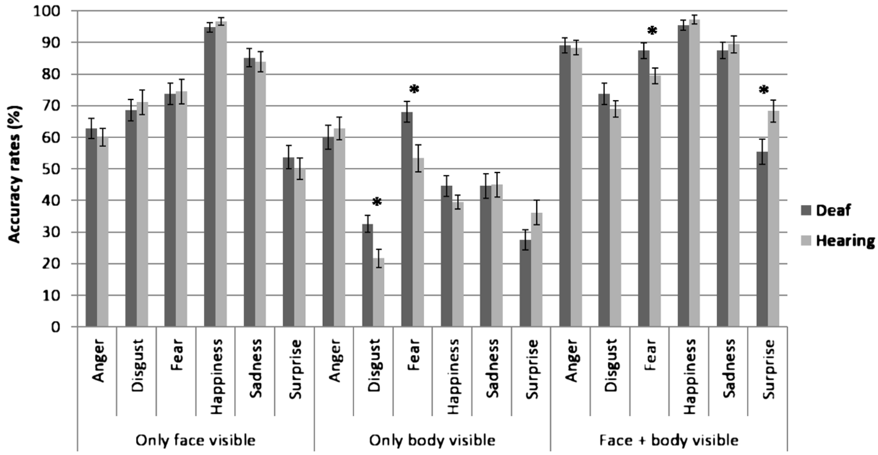

Figure 2. Recognition standard accuracy rates (%) as a function of clip type (*face-only*, *body-only*, *intact face + body*), emotion (anger, disgust, fear, happiness, sadness and surprise) and group (deaf *vs.* hearing subjects). Deaf participants outperformed hearing ones in recognizing disgust and fear when only the body was visible. When both the body and the face of the actors were visible, fear was also recognized better by deaf than hearing participants, whereas the opposite pattern was found for surprise (but note that these effects were not fully significant when analyzing unbiased hits Hu). Error bars represent ± SEM. Asterisks indicate a significant difference between deaf and hearing participants ($p < 0.05$).

effect of emotion, $F(5, 345) = 59.04$, $p < 0.001$, $\eta_p^2 = 0.46$, and a significant interaction of emotion by clip type, $F(10, 690) = 29.99$, $p < 0.001$, $\eta_p^2 = 0.30$. The main effect of group was not significant, $F(1, 69) < 1$, $p = 0.51$. The interactions of emotion by group, $F(5, 345) = 2.33$, $p = 0.042$, $\eta_p^2 = 0.03$, and emotion by group by clip type, $F(10, 690) = 2.45$, $p = 0.007$, $\eta_p^2 = 0.03$, reached significance. The interaction of clip type by group was not significant, $F(2, 138) = 1.20$, $p = 0.30$.

Post-hoc comparisons (Bonferroni–Holm correction applied) showed that emotion recognition was overall worse in the *body-only* condition compared to both the *intact* condition (all ps < 0.001) and the *face-only* condition (all ps $<$ 0.001, with the exception of anger). Anger was recognized similarly from face and body cues, $p = 1.00$; however, when considering the unbiased hit rates the face was still significantly more informative than the body in leading to anger recognition, $t(70) = 3.57$, $p < 0.001$. The presence of the body in the *intact* condition enhanced recognition compared to *face-only* videos for the emotions anger, fear and surprise (all ps < 0.001).

Post-hoc t-tests (Bonferroni–Holm correction applied) clarified that group effects were due to an advantage of deaf over hearing participants in the *body-only* condition for recognition of disgust, $t(69) = 2.73$, $p = 0.024$, and fear, $t(69) = 2.70$, $p = 0.027$ (these differences were still significant when considering the unbiased hit rates, revealing that they were not due to differences in response biases between the two groups). A deaf advantage with fear was also visible in the *intact* condition, $p = 0.050$, but not when considering the unbiased hit rates ($p = 0.13$). In turn, hearing participants outperformed deaf ones in recognizing surprise in the *intact* condition, $t(69) = 2.45$, $p = 0.051$; however this advantage disappeared when considering the unbiased hit rates, $p = 0.22$ (in fact reflecting a greater tendency of hearing participants to recognize as 'surprise' other emotions, especially fear).

We also performed an exploratory analysis to look at the possible influence of sign language use on emotion recognition in the deaf sample. To this aim, we carried out an ANOVA on standard hit rates of deaf participants with clip type (*intact* video, *face-only* video and *body-only* video) and emotion (anger, disgust, fear, happiness, sadness, and surprise) as within-subjects factors, and sign language use (14 signers, irrespective of proficiency *vs.* 21 non signers) as between-subjects factor. The interaction of emotion by sign language reached significance, $F(5, 165) = 2.48$, $p = 0.034$, $\eta_p^2 = 0.07$. However, *post-hoc* t-tests (Bonferroni–Holm correction applied) did not reveal any significant difference between signers and non-signers in recognizing any particular emotion (all ps > 0.26), the significant interaction likely depending on subtle differences in the way the various emotions were recognized within each group. No other effects reached significance (clip type by sign language, $p = 0.54$ and clip type by sign language by emotion, $p = 0.34$). Results of this analysis should be interpreted with caution though considering the small sample size and the different LIS fluency levels of deaf participants included in the 'signers' category (see Table 1).

3. Experiment 2

In Experiment 2 we adopted a paradigm previously used by Aviezer and colleagues (2012), consisting in the presentation of emotional congruent and incongruent face-body compounds (e.g., a winning face on a losing body) obtained by recording professional players while winning or losing a point during important matches. Using these stimuli the authors showed that, in case of intense emotional situations, face expressions may be ambiguous and observers tend to pay more attention to the bodies to disambiguate the emotion expressed (Aviezer *et al.*, 2012).

3.1. Methods

3.1.1. Participants

Thirty-two profoundly deaf individuals (18 F, mean age = 36.0 years, SD = 11.0; mean education = 15.3 years, SD = 2.8) and a control group composed of thirty-two hearing individuals (18 F, mean age = 36.1 years, SD =

10.8; mean education = 15.8 years, SD = 2.8) participated in the study. Deaf and hearing participants were matched for sex, age and education [$t(62) < 1$, $p = 0.96$ for age and $t(62) < 1$, $p = 0.43$ for education]. All participants in Experiment 2 took part also in Experiment 1, except for one deaf participant (a profoundly deaf signer, with prosthesis device, who had acquired sign language later in life) and one normal hearing participant who participated only in Experiment 2. Of the 31 deaf participants that took also part in Experiment 1, five were early signers, six had acquired sign language later in life and the others were non-signers (see Table 1). The experiment was approved by the local ethical committee and participants were treated in accordance with the Declaration of Helsinki.

3.1.2. Stimuli and Procedure

Stimuli and procedure were similar to those used in Aviezer *et al.* (2012), and consisted of static images depicting 20 professional tennis players photographed immediately upon either winning or losing the final match points of the finals of Wimbledon and the Australian open. Ten images depicted losing players and 10 images depicted winning players. Twenty additional images were created by combining the faces of the ten losing players with the bodies of the winning players and vice versa (see Fig. 3 for an example). The same faces appeared twice, once combined with a congruent-valenced body and once with an incongruent-valenced body. In this way, four groups of images were created: 10 original winner images (winning face on winning body), 10 original loser images (losing face on losing body), 10 compound imaged composed by a losing face on a winning body, and 10 compound images composed of a winning face on a losing body (see Aviezer *et al.*, 2012 for details on graphical manipulation and validation of the images). These 40 critical trials were diluted with 80 filler trials depicting original images of winners ($n = 20 \times 2$ repetitions) and losers ($n = 20 \times 2$ repetitions). Filler images were included with the aim to dilute critical trials and make the graphical manipulations less visible to the participants (in line with Aviezer *et al.*, 2012). Participants were seated comfortably at a table in front of a 16-inch desktop computer (at an approximate distance of 57 cm) and presented with the images one at a time. Each trial started with the presentation of a fixation cross (1 sec duration) in the middle of the screen, followed by the presentation of the player's picture. Participants were first instructed to indicate whether the emotion expressed by the depicted player was negative or positive (two forced-alternatives) by pressing one of two keys on a keyboard. After this first response, the same image remained on the screen and participants had to rate the valence of the emotion on a Likert scale (1–9) (where 1 represented a very negative emotion and 9 a very positive emotion) presented below each

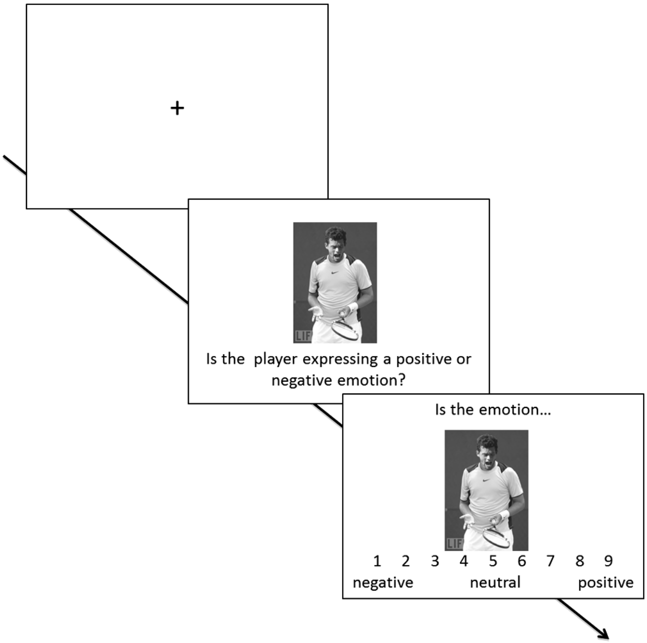

Figure 3. Schematic overview of an experimental trial showing a compound composed by a winning face matched with a losing body. Each trial started with a fixation cross on a white background (1 sec duration), after which the image of the player appeared (centrally presented). Participants had to indicate whether the emotion expressed by the player was negative or positive (force-choice response) and to what extent the emotion was negative or positive on a 1–9 Likert scale. Responses were self-paced.

image (see Fig. 3). The image remained on the screen until participants' response. Responses were self-paced although participants were instructed to rely on their gut judgments. E-Prime 2.0 (Psychology Software Tools, Inc., Pittsburgh, PA, USA) was used for stimuli presentation and data recording.

3.2. Results

The percentage of positive responses ('*This emotion is positive*', i.e., number of stimuli subjectively perceived by the observer as expressing a positive emotion) and the mean valence from the Likert ratings were calculated for each participant in each experimental condition. These dependent variables were analyzed *via* a repeated-measures ANOVA with body valence (winning body *vs.* losing body) and face valence (winning face *vs.* losing face) as within-subjects factors, and group (deaf *vs.* hearing) as a between-subjects factor. Filler trials were not included in the analysis.

The ANOVA on the percentage of positive responses (see Fig. 4A) revealed a significant main effect of body valence, $F(1, 62) = 827.69$, $p <$

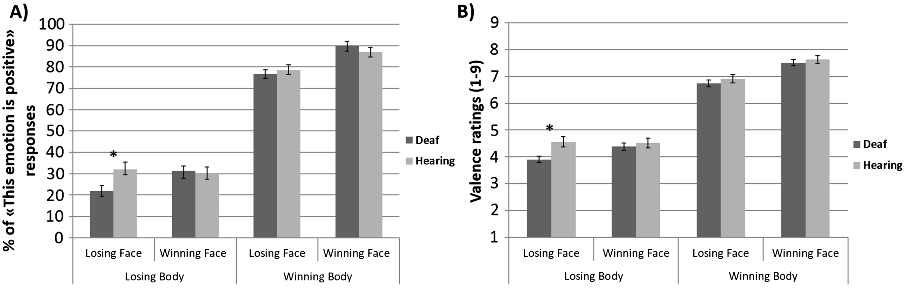

Figure 4. **(A)** Percentage of positive responses, and **(B)** mean valence ratings (1–9 Likert scale; 1: very negative emotion, 9: very positive emotion) of deaf and hearing participants as a function of valence (losing *vs.* winning) of the body and of the face in classifying players as expressing a positive or a negative emotion. Overall, the emotional valence of the body weighted more than that of the face in driving evaluation of both deaf and hearing participants. Nonetheless, when players had a losing body, the expression of the face did not affect final decisions in hearing participants, whereas it modulated responses of deaf participants. Asterisks indicate significant differences between groups ($p < 0.05$).

0.001, $\eta_p^2 = 0.93$, and a significant main effect of face valence, $F(1, 62) = 7.61$, $p = 0.008$, $\eta_p^2 = 0.11$. The main effect of Group was not significant, $F(1, 62) < 1$, $p = 0.43$. The interactions of face valence by body valence, $F(1, 62) = 29.40$, $p < 0.001$, $\eta_p^2 = 0.32$, and face valence by body valence by group, $F(1, 62) = 8.47$, $p = 0.005$, $\eta_p^2 = 0.12$, were significant. None of the other interactions reached significance (ps > 0.18). As expected, when the face and the body were both of a losing or of a winning player, winning players were overall classified as expressing a positive emotion significantly more often than losing players. In incongruent conditions, the body weighted more than the face in driving the judgment in both deaf and hearing individuals (see Fig. 4A), in line with Aviezer *et al.*'s findings (2012). The significant three-way interaction of face valence by body valence by group was analyzed by looking at the simple main effects of face valence and group within each body valence. For winning bodies, the analysis revealed a significant main effect of face valence, $F(1, 62) = 45.89$, $p < 0.001$, $\eta_p^2 = 0.43$, indicating that winning bodies combined with winning faces were classified as positive significantly more often than winning bodies combined with losing faces. Neither the main effect of group, $F(1, 62) < 1$, $p = 0.82$, nor its interaction with face valence, $F(1, 62) = 2.40$, $p = 0.13$, were significant. For losing bodies, the main effect of group was not significant, $F(1, 62) = 1.76$, $p = 0.20$; the main effect of face valence only approached significance, $F(1, 62) = 3.48$, $p = 0.07$, and the interaction of face valence by group was significant, $F(1, 62) = 6.82$, $p = 0.011$, $\eta_p^2 = 0.10$. Whereas the valence of the face did not affect hearing participants' responses when classifying players with losing bodies, $t(31) < 1$, $p = 0.61$, deaf observers judged players with losing bodies as expressing a positive emotion significantly less frequently when paired with a losing face than with a winning face, $t(31) = 3.26$, $p = 0.003$. Accordingly, deaf participants perceived players with both losing face and losing body as expressing a positive emotion significantly less frequently than hearing participants, $t(62) = 2.31$, $p = 0.024$.

Consistent with the previous analysis, the ANOVA on the 1–9 Likert scores (see Fig. 4B) revealed a significant main effect of body valence, $F(1, 62) = 598.03$, $p < 0.001$, $\eta_p^2 = 0.91$, and face valence, $F(1, 62) = 17.01$, $p < 0.001$, $\eta_p^2 = 0.22$. The main effect of group was not significant, $F(1, 62) = 3.07$, $p = 0.08$. The interactions of face valence by body valence, $F(1, 62) = 66.33$, $p < 0.001$, $\eta_p^2 = 0.52$, and face valence by body valence by group, $F(1, 62) = 5.83$, $p = 0.019$, $\eta_p^2 = 0.09$, were significant. None of the other interactions reached significance (ps > 0.08). The pattern resembled the one reported for the positive/negative classification in the previous analysis, with body valence weighting more than face valence in driving participants' evaluation. The significant three-way interaction of face valence by body valence by group was analyzed by looking at the simple main effects of face valence and group within each body valence. For winning bodies, the only significant effect was the main effect of face valence, $F(1, 62) = 91.13$, $p < 0.001$, $\eta_p^2 = 0.60$, indicating that winning bodies combined with winning faces received more positive judgments than winning bodies combined with losing faces. The main effect of group, $F(1, 62) < 1$, $p = 0.42$, and its interaction with face valence, $F(1, 62) < 1$, $p = 0.72$, were not significant. For losing bodies, the main effect of face valence, $F(1, 62) = 5.36$, $p = 0.024$, $\eta_p^2 = 0.08$, and its interaction with group, $F(1, 62) = 6.81$, $p = 0.009$, $\eta_p^2 = 0.11$, reached significance; the main effect of group, $F(1, 62) = 3.60$, $p = 0.063$, was not significant. The significant two-way interaction indicated that whereas the valence of the face did not affect hearing participants' responses when classifying players with losing bodies, $t(31) < 1$, $p = 0.77$, deaf observers judged players with losing bodies as less happy when paired with a losing face than with a winning face, $t(31) = 3.35$, $p = 0.002$. Accordingly, deaf participants perceived players with both losing face and losing body as expressing a less positive emotion than hearing participants, $t(62) = 2.89$, $p = 0.006$.

As in Experiment 1, we also carried out an exploratory analysis on the possible effect of sign language use on the performance of deaf participants. A repeated-measures ANOVA with body valence (winning body *vs.* losing body) and face valence (winning face *vs.* losing face) as within-subjects factors, and sign language use as between-subjects factor was carried out on the number of positive responses and valence ratings of deaf participants. The main effect of sign language was not significant, nor it significantly interacted with any of the variables included in the analysis (all ps > 0.40 for the number of positive responses and all ps > 0.21 for valence ratings).

4. Discussion

In this study, we assessed whether deafness affects the way individuals infer emotional states by looking at others' body postures and movements, beyond the information conveyed by the face. Our results show that deaf and hearing individuals weight face and body information differently in certain conditions, with deaf participants being more accurate in recognizing bodily emotions that signal a potential threat (like fear and disgust, Experiment 1) and in integrating face and body information to classify intense negative emotions (Experiment 2).

In Experiment 1, the simultaneous availability of body and face cues facilitated recognition of emotions compared to when only the body or only the face was visible in all participants, in line with prior evidence on hearing individuals (Martinez *et al.*, 2015). Moreover, for both hearing and deaf participants, faces alone were more diagnostic than bodies alone in emotion recognition, with the only exception of anger that was similarly recognized in the two conditions (as in Martinez *et al.*, 2015; see also Abramson *et al.*, 2017). Critically though, deaf participants outperformed hearing ones in recognizing two specific emotions — fear and disgust — from body information. Fear and disgust are signals of a potentially harmful situation and vocalizations may be especially informative for these emotions, in particular for fear (Bänziger *et al.*, 2009; Hawk *et al.*, 2009; Levitt, 1964). In light of this, deaf participants' advantage in visually recognizing fear and disgust from body cues may reflect compensatory mechanisms driven by the absence of complementary information from the auditory channel, as found for other non-emotional tasks (for reviews see Bavelier *et al.*, 2006; Pavani and Bottari, 2012; Rinaldi *et al.*, 2018). However, this explanation should apply to anger recognition as well (for which in turn we did not report any group difference), anger also signaling a potentially harmful situation. It is possible that the higher reliance of hearing participants on body cues for anger compared to the other emotions (also reported in Martinez *et al.*, 2015, and possibly reflecting an increased need to respond to a direct threat, see Springer *et al.*, 2007), masked group differences in recognizing angry bodies. An alternative explanation is suggested by previous studies indicating that visual processing of disgusted and fearful but not angry bodies rely on configural/holistic mode. Indeed, presenting emotional bodies upside-down (where inversion is known to selective affect configural processing, e.g., Van Belle *et al.*, 2010) seems to impair more recognition of fear and disgust than other emotions, including anger (Atkinson *et al.*, 2007). It may thus be that deaf individuals are particularly good in body emotion recognition when recognition relies more on configural processing or for more evolutionary salient emotions, but these hypotheses remain speculative at this stage and deserve further testing.

The analysis of the hit rates also revealed an advantage of hearing compared to deaf participants in recognizing surprise from intact videos, but this pattern was not found for unbiased hits and may reflect a response bias in hearing participants. Indeed, hearing participants tended to refer more often to the emotion surprise than deaf participants, a bias that was particularly evident for the emotion fear (which was erroneously classified as surprise more often by hearing than deaf participants). A confusion between fear and surprise has been previously reported (in hearing individuals) in facial emotion recognition, likely due to fear and surprise sharing several prototypical facial muscle movements (e.g., the inner and outer brow raiser, Roy-Charland *et al.*, 2014). Moreover, surprise and fear are typically expressed by body backwards movements (e.g., Dael *et al.*, 2012; De Meijer, 1989), also in the case of our clips, possibly further contributing to the confusion between the two, at least in hearing participants.

Although in our study we were not interested in the influence of ethnicity on emotion recognition, it is worth mention that one of the actresses appearing in the videos of Experiment 1 (that we took from Martinez *et al.*, 2015) was Asian. Own *vs.* other-race effects in facial emotion recognition have been consistently reported (for a review see Scherer *et al.*, 2011), but they cannot apply to body emotion recognition when the bodies used prevent identification of ethnicity (as in our videos). In Experiment 1, deaf and hearing participants differed in body emotion recognition only (when considering the unbiased hit rates), ruling out any possible effects of ethnicity in contributing to group differences. Moreover, we had no a-priori reason to expect ethnicity-related different effects in emotion recognition by our deaf and hearing participants as they were all Caucasian and lived in the same area, being similarly exposed to a multi-ethnic environment.

In our second experiment, we found that the body was overall more diagnostic than the face in driving positive *vs.* negative classification of genuine intense emotions in both deaf and hearing individuals, in line with prior evidence (Aviezer *et al.*, 2012; see also Kret *et al.*, 2013). However, when both the face and the body expressed a negative intense emotion, deaf participants were more prone than hearing individuals to consider face expression in their evaluation (reflecting an increased face-body integration). In interpreting these findings it is worth mentioning that classification of players with a losing body and a losing face was overall less accurate (mean accuracy: 70%) than that of players with a winning body and a winning face (mean accuracy: 90%). In this view, the better classification of deaf participants may again reflect compensatory mechanisms in the visual modality in situations in which the emotion expressed is more ambiguous (Bavelier *et al.*, 2006; Bottari *et al.*, 2010; Heimler and Pavani, 2014).

Moreover, in Experiment 2 we used as stimuli genuine intense expressions. Real-life facial expressions are inherently more ambiguous than those produced *ad hoc* for an experiment purpose, with their recognition being more susceptible to concomitant contextual factors (e.g., Fernández-Dols and Crivelli, 2013; for a review see Aviezer *et al.*, 2017). The ambiguity somehow inherent to genuinely expressed emotions can then be further emphasized when the emotion is very intense (as for Aviezer *et al.*, 2012's stimuli; see also Wenzler *et al.*, 2016, that showed that facial expressions of both adults and children evoked during highly intense situations are often not diagnostic for the valence of the emotion). Since Aviezer *et al.* (2012) only employed genuine and very intense facial expressions (of tennis players participating in prestigious tournaments), from their work it is not possible to disentangle whether emotional valence ambiguity derives from emotions being very genuine or very intense. The same applies to Experiment 2 in our study, in which we used the same stimuli as Aviezer *et al.* (2012). Results of Experiment 2 show that deaf individuals may be more accurate in emotion recognition (at least in case of an intense negative emotion related to failing in an important sport competition) by somehow better integrating face and body cues. A similar advantage for the deaf may also emerge in case of genuinely expressed less intense (more ordinary) emotions, but this remains to be empirically investigated. Indeed, further research is needed to clarify the extent to which the type of emotion expressed by body and face cues, its valence, its intensity and genuineness, but also its adaptive importance (in an evolutionary perspective) possibly affect compensatory mechanisms in emotion recognition associated to the lack of auditory input.

Overall, the significant differences we observed between hearing and deaf participants in our experiments were not driven by the use of sign language, with deaf signers and non-signers performing similarly. We only reported a significant interaction between sign language use and emotion type in Experiment 1: *post-hoc* comparisons did not reveal though any significant difference between signers and non-signers in recognizing any specific emotion, with the interaction likely reflecting subtle differences in the way the various emotions were recognized within each group. However, our group of signers was not homogenous: only seven deaf subjects were proficient signers and learned LIS early in childhood because of having either one or both deaf parents, whilst the other seven deaf signers reported to moderately use LIS that they acquired in early adulthood (see Table 1). In light of this spurious sample, the analyses we carried out as a function of sign language use should be considered as exploratory and deserve further empirical testing.

Finally, in interpreting our results, it is also worth referring to neuroimaging findings suggesting that auditory and association regions can be remapped in the early deaf to support enhanced performance in several visual tasks such as discrimination of directional motion or face processing (e.g., Benetti *et al.*, 2017, 2018; Retter *et al.*, in press; for reviews, see Bavelier *et al.*, 2006; Dormal and Collignon, 2011; Pavani and Bottari, 2012). The advantage showed by deaf individuals in emotional processing in our study might tap on similar cross-modal plasticity mechanisms, an aspect that deserves further investigation. Moreover, whilst in our sample of deaf participants auditory deprivation mostly occurred before three years of age, future studies may compare the effects of early- *vs.* late-onset deafness on emotion recognition. Indeed, whereas the effects of onset of the sensory deprivation on brain/behavior reorganization have been extensively studied in case of blindness (e.g., Bedny *et al.*, 2010, 2012; Cattaneo *et al.*, 2007; Collignon *et al.*, 2013; Dormal *et al.*, 2016; Voss *et al.*, 2004, 2008; for reviews see Cattaneo *et al.*, 2008; Maurer *et al.*, 2005), effects related to age at onset of deafness have only been so far marginally considered, and mainly in the context of cochlear implant use (Fengler *et al.*, 2017; Gallego *et al.*, 2016). At the neural level, an early study (Sadato *et al.*, 2004) showed that recruitment of the auditory cortex during visual processing was larger in early than in late deaf individuals; furthermore, animals models report that crossmodal activation of primary auditory cortex differs depending on deafness onset (e.g., Chabot *et al.*, 2015). Whether and how age at deafness onset affects brain reorganization phenomena and behavioral performance remains to be systematically investigated.

To summarize, our results show that deafness may be associated to an enhanced capacity to discriminate certain body emotions but also to a better ability to integrate body and face cues when the emotion expressed by the face is ambiguous (as in case of intense emotions). Our findings support prior evidence on the capacity of deaf individuals to compensate for the lack of the auditory input enhancing perceptual and attentional skills in the spared modalities (Bavelier *et al.*, 2006; Pavani and Bottari, 2012), showing that this extends to the affective domain.

Acknowledgements

We are grateful to Pio Istituto dei sordi di Milano, ENS of Bergamo, and AFA of Cantù for their help in recruiting and providing support to test deaf participants.

Funding

This work was supported by Italian Ministry of Education, University and Research (PRIN 2015WXAXJF) and by Italian Ministry of Health (Ricerca Corrente 2017, IRCCS Mondino Foundation, Pavia) to Z.C.

References

Abramson, L., Marom, I., Petranker, R. and Aviezer, H. (2017). Is fear in your head? A comparison of instructed and real-life expressions of emotion in the face and body, *Emotion* **17**(3), 557–565.

Atkinson, A. P., Dittrich, W. H., Gemmell, A. J. and Young, A. W. (2004). Emotion perception from dynamic and static body expressions in point-light and full-light displays, *Perception* **33**, 717–746.

Atkinson, A. P., Tunstall, M. L. and Dittrich, W. H. (2007). Evidence for distinct contributions of form and motion information to the recognition of emotions from body gestures, *Cognition* **104**(1), 59–72.

Aviezer, H., Trope, Y. and Todorov, A. (2012). Body cues, not facial expressions, discriminate between intense positive and negative emotions, *Science* **338**(6111), 1225–1229.

Aviezer, H., Ensenberg, N. and Hassin, R. R. (2017). The inherently contextualized nature of facial emotion perception, *Curr. Opin. Psychol.* **17**, 47–54.

Bänziger, T., Grandjean, D. and Scherer, K. R. (2009). Emotion recognition from expressions in face, voice, and body: the Multimodal Emotion Recognition Test (MERT), *Emotion* **9**(5), 691–704.

Bavelier, D., Dye, M. W. and Hauser, P. C. (2006). Do deaf individuals see better?, *Trends Cogn. Sci.* **10**, 512–518.

Bedny, M., Konkle, T., Pelphrey, K., Saxe, R. and Pascual-Leone, A. (2010). Sensitive period for a multimodal response in human visual motion area MT/MST, *Curr. Biol.* **20**(21), 1900–1906.

Bedny, M., Pascual-Leone, A., Dravida, S. and Saxe, R. (2012). A sensitive period for language in the visual cortex: distinct patterns of plasticity in congenitally versus late blind adults, *Brain Lang.* **122**(3), 162–170.

Benetti, S., van Ackeren, M. J., Rabini, G., Zonca, J., Foa, V., Baruffaldi, F., Rezk, M., Pavani, F., Rossion, B. and Collignon, O. (2017). Functional selectivity for face processing in the temporal voice area of early deaf individuals, *Proc. Natl Acad. Sci. U.S.A.* **114**(31), E6437–E6446.

Benetti, S., Novello, L., Maffei, C., Rabini, G., Jovicich, J. and Collignon, O. (2018). White matter connectivity between occipital and temporal regions involved in face and voice processing in hearing and early deaf individuals, *Neuroimage* **179**, 263–274.

Bottari, D., Nava, E., Ley, P. and Pavani, F. (2010). Enhanced reactivity to visual stimuli in deaf individuals, *Restor. Neurol. Neurosci.* **28**(2), 167–179.

Cattaneo, Z., Vecchi, T., Monegato, M., Pece, A. and Cornoldi, C. (2007). Effects of late visual impairment on mental representations activated by visual and tactile stimuli, *Brain Res.* **1148**, 170–176.

Cattaneo, Z., Vecchi, T., Cornoldi, C., Mammarella, I., Bonino, D., Ricciardi, E. and Pietrini, P. (2008). Imagery and spatial processes in blindness and visual impairment, *Neurosci. Biobehav. Rev.* **32**(8), 1346–1360.

Cattaneo, Z., Lega, C., Cecchetto, C. and Papagno, C. (2014). Auditory deprivation affects biases of visuospatial attention as measured by line bisection, *Exp. Brain Res.* **232**(9), 2767–2773.

Cattaneo, Z., Cecchetto, C. and Papagno, C. (2016). Deaf individuals show a leftward bias in numerical bisection, *Perception* **45**(1–2), 156–164.

Cattaneo, Z., Rinaldi, L., Geraci, C., Cecchetto, C. and Papagno, C. (2018). Spatial biases in deaf, blind, and deafblind individuals as revealed by a haptic line bisection task, *Q. J. Exp. Psychol.* **71**(11), 2325–2333.

Chabot, N., Butler, B. E. and Lomber, S. G. (2015). Differential modification of cortical and thalamic projections to cat primary auditory cortex following early- and late-onset deafness, *J. Comp. Neurol.* **523**(15), 2297–2320.

Codina, C. J., Pascalis, O., Baseler, H. A., Levine, A. T. and Buckley, D. (2017). Peripheral visual reaction time is faster in deaf adults and British sign language interpreters than in hearing adults, *Front. Psychol.* **8**, 50.

Collignon, O., Dormal, G., Albouy, G., Vandewalle, G., Voss, P., Phillips, C. and Lepore, F. (2013). Impact of blindness onset on the functional organization and the connectivity of the occipital cortex, *Brain* **136**(9), 2769–2783.

Dael, N., Mortillaro, M. and Scherer, K. R. (2012). Emotion expression in body action and posture, *Emotion* **12**(5), 1085–1101.

De Gelder, B. (2009). Why bodies? Twelve reasons for including bodily expressions in affective neuroscience, *Phil. Trans. R. Soc. B Biol. Sci.* **364**(1535), 3475–3484.

De Meijer, M. (1989). The contribution of general features of body movement to the attribution of emotions, *J. Nonverb. Behav.* **13**(4), 247–268.

Dormal, G. and Collignon, O. (2011). Functional selectivity in sensory-deprived cortices, *Am. J. Physiol. Heart Circ. Physiol.* **106**(6), 2627–2630.

Dormal, V., Crollen, V., Baumans, C., Lepore, F. and Collignon, O. (2016). Early but not late blindness leads to enhanced arithmetic and working memory abilities, *Cortex* **83**, 212–221.

Fengler, I., Nava, E., Villwock, A. K., Büchner, A., Lenarz, T. and Röder, B. (2017). Multisensory emotion perception in congenitally, early, and late deaf CI users, *PLoS One* **12**(10), e0185821. DOI:10.1371/journal.pone.0185821.

Fernández-Dols, J. M. and Crivelli, C. (2013). Emotion and expression: naturalistic studies, *Emot. Rev.* **5**(1), 24–29.

Frühholz, S., Trost, W. and Kotz, S. A. (2016). The sound of emotions — towards a unifying neural network perspective of affective sound processing, *Neurosci. Biobehav. Rev.* **68**, 96–110.

Gallego, C., Martín-Aragoneses, M. T., López-Higes, R. and Pisón, G. (2016). Semantic and syntactic reading comprehension strategies used by deaf children with early and late cochlear implantation, *Res. Dev. Disabil.* **49–50**, 153–170.

Greenberg, M. T. and Kusché, C. A. (1989). Cognitive, personal, and social development of deaf children and adolescents, in: *Advances in Education. Handbook of Special Education: Research and Practice, Vol. 3. Low Incidence Conditions*, M. C. Wang, M. C. Reynolds and H. J. Walberg (Eds), pp. 95–129. Pergamon Press, Elmsford, NY, USA.

Hawk, S. T., van Kleef, G. A., Fischer, A. H. and van der Schalk, J. (2009). "Worth a thousand words": absolute and relative decoding of nonlinguistic affect vocalizations, *Emotion* **9**(3), 293–305.

Heimler, B. and Pavani, F. (2014). Response speed advantage for vision does not extend to touch in early deaf adults, *Exp. Brain Res.* **232**(4), 1335–1341.

Klasen, M., Chen, Y.-H. and Mathiak, K. (2012). Multisensory emotions: perception, combination and underlying neural processes, *Rev. Neurosci.* **23**(4), 381–392.

Kret, M., Stekelenburg, J., Roelofs, K. and de Gelder, B. (2013). Perception of face and body expressions using electromyography, pupillometry and gaze measures, *Front. Psychol.* **4**, 28. DOI:10.3389/fpsyg.2013.00028.

Letourneau, S. M. and Mitchell, T. V. (2011). Gaze patterns during identity and emotion judgments in hearing adults and deaf users of American Sign Language, *Perception* **40**(5), 563–575.

Letourneau, S. M. and Mitchell, T. V. (2013). Visual field bias in hearing and deaf adults during judgments of facial expression and identity, *Front. Psychol.* **4**, 319. DOI:10.3389/fpsyg.2013.00319.

Levitt, E. A. (1964). The relationship between abilities to express emotional meanings vocally and facially, in: *The Communication of Emotional Meaning*, J. R. Davitz (Ed.), pp. 87–100. McGraw-Hill, New York, NY, USA.

Ludlow, A., Heaton, P., Rosset, D., Hills, P. and Deruelle, C. (2010). Emotion recognition in children with profound and severe deafness: do they have a deficit in perceptual processing?, *J. Clin. Exp. Neuropsychol.* **32**(9), 923–928.

Martinez, L., Falvello, V. B., Aviezer, H. and Todorov, A. (2015). Contributions of facial expressions and body language to the rapid perception of dynamic emotions, *Cogn. Emot.* **30**, 939–952.

Maurer, D., Lewis, T. L. and Mondloch, C. J. (2005). Missing sights: consequences for visual cognitive development, *Trends Cogn. Sci.* **9**(3), 144–151.

McCullough, S., Emmorey, K. and Sereno, M. (2005). Neural organization for recognition of grammatical and emotional facial expressions in deaf ASL signers and hearing nonsigners, *Cogn. Brain Res.* **22**(2), 193–203.

Meadow, K. P., Greenberg, M. T., Erting, C. and Carmichael, H. (1981). Interactions of deaf mothers and deaf preschool children: comparisons with three other groups of deaf and hearing dyads, *Am. Ann. Deaf* **156**(4), 454–468.

Meeren, H. K. M., van Heijnsbergen, C. C. R. J. and de Gelder, B. (2005). Rapid perceptual integration of facial expression and emotional body language, *Proc. Natl Acad. Sci. U.S.A.* **102**, 16518–16523.

Mestre, J. M., Larrán, C., Herrero, J., Guil, R. and de la Torre, G. G. (2015). PERVALE-S: a new cognitive task to assess deaf people's ability to perceive basic and social emotions, *Front. Psychol.* **6**. DOI:10.3389/fpsyg.2015.01148.

Most, T. (2007). Speech intelligibility, loneliness, and sense of coherence among deaf and hard-of-hearing children in individual inclusion and group inclusion, *J. Deaf Stud. Deaf Educ.* **12**(4), 495–503.

Pavani, F. and Bottari, D. (2012). Visual abilities in individuals with profound deafness: a critical review, in: *Frontiers in the Neural Bases of Multisensory Processes*, M. M. Murray and M. Wallace (Eds). CRC Press, Boca Raton, FL, USA.

Peterson, C., Slaughter, V., Moore, C. and Wellman, H. M. (2016). Peer social skills and theory of mind in children with autism, deafness, or typical development, *Dev. Psychol.* **52**(1), 46–57.

Retter, T. L., Webster, M. A. and Jiang, F. (in press). Directional visual motion is represented in the auditory and association cortices of early deaf individuals, *J. Cogn. Neurosci.* DOI:10.1162/jocn_a_01378.

Rinaldi, L., Merabet, L. B., Vecchi, T. and Cattaneo, Z. (2018). The spatial representation of number, time, and serial order following sensory deprivation: a systematic review, *Neurosci. Biobehav. Rev.* **90**, 371–380.

Roy-Charland, A., Perron, M., Beaudry, O. and Eady, K. (2014). Confusion of fear and surprise: a test of the perceptual-attentional limitation hypothesis with eye movement monitoring, *Cogn. Emot.* **28**, 1214–1222.

Sadato, N., Yamada, H., Okada, T., Yoshida, M., Hasegawa, T., Matsuki, K. I., Yonekura, Y. and Itoh, H. (2004). Age-dependent plasticity in the superior temporal sulcus in deaf humans: a functional MRI study, *BMC Neurosci.* **5**(1), 56. DOI:10.1186/1471-2202-5-56.

Scherer, K. R., Clark-Polner, E. and Mortillaro, M. (2011). In the eye of the beholder? Universality and cultural specificity in the expression and perception of emotion, *Int. J. Psychol.* **46**(6), 401–435.

Sidera, F., Amadó, A. and Martínez, L. (2017). Influences on facial emotion recognition in deaf children, *J. Deaf Stud. Deaf Educ.* **22**(2), 164–177.

Smith, F. W. and Schyns, P. G. (2009). Smile through your fear and sadness: transmitting and identifying facial expression signals over a range of viewing distances, *Psychol. Sci.* **20**(10), 1202–1208.

Springer, U. S., Rosas, A., McGetrick, J. and Bowers, D. (2007). Differences in startle reactivity during the perception of angry and fearful faces, *Emotion* **7**(3), 516–525.

Stoll, C., Palluel-Germain, R., Gueriot, F.-X., Chiquet, C., Pascalis, O. and Aptel, F. (2018). Visual field plasticity in hearing users of sign language, *Vision Res.* **153**, 105–110.

Van Belle, G., De Graef, P., Verfaillie, K., Rossion, B. and Lefèvre, P. (2010). Face inversion impairs holistic perception: evidence from gaze-contingent stimulation, *J. Vis.* **10**, 10. DOI:10.1167/10.5.10.

Voss, P., Lassonde, M., Gougoux, F., Fortin, M., Guillemot, J.-P. and Lepore, F. (2004). Early- and late-onset blind individuals show supra-normal auditory abilities in far-space, *Curr. Biol.* **14**(19), 1734–1738.

Voss, P., Gougoux, F., Zatorre, R. J., Lassonde, M. and Lepore, F. (2008). Differential occipital responses in early-and late-blind individuals during a sound-source discrimination task, *Neuroimage* **40**(2), 746–758.

Wagner, H. L. (1993). On measuring performance in category judgment studies of nonverbal behavior, *J. Nonverbal Behav.* **17**(1), 3–28.

Watanabe, K., Matsuda, T., Nishioka, T. and Namatame, M. (2011). Eye gaze during observation of static faces in deaf people, *PLoS One* **6**(2), e16919. DOI:10.1371/journal.pone.0016919.

Weisel, A., Most, T. and Efron, C. (2005). Initiations of social interactions by young hearing impaired preschoolers, *J. Deaf Stud. Deaf Educ.* **10**(2), 161–170.

Wenzler, S., Levine, S., van Dick, R., Oertel-Knöchel, V. and Aviezer, H. (2016). Beyond pleasure and pain: facial expression ambiguity in adults and children during intense situations, *Emotion* **16**(6), 807–814.