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Attentional Orienting to Social and Nonsocial Cues in Early Deaf Adults

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In 2 experiments we investigated attentional orienting to nonpredictive social and nonsocial cues in deaf observers. In Experiment 1a, 22 early deaf adults and 23 hearing controls performed a peripheral shape-discrimination task, while uninformative central gaze cues validly and invalidly cued the location of the target. As an adaptation to the lack of audition, we expected deaf adults to show a larger impact of gaze cuing on attentional orienting compared with hearing controls. However, contrary to our predictions, deaf participants did not respond faster to cued compared with uncued targets (gaze-cuing effect; GCE), and this behavior partly correlated with early sign language acquisition. Experiment 1b showed a reliable GCE in 13 hearing native signers, thus excluding a key role of early sign language acquisition in explaining the lack of GCE in the response times of deaf participants. To test whether the resistance to uninformative central cues extends to nonsocial cues, in Experiment 2 nonpredictive arrow cues were presented to 14 deaf and 14 hearing participants. Both groups of participants showed a comparable arrow-cuing effect. Together, our findings suggest that deafness may selectively limit attentional-orienting triggered by central irrelevant gaze cues. Possible implications for plasticity related to deafness are discussed.

Keywords: gaze-cueing, arrow-cueing, social-cognition, deafness, plasticity

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People with profound bilateral deafness interact with the environment very efficiently, despite the lack of auditory input. Research in the last 20 years has revealed that this skill involves reorganization of the mechanisms underlying visual attention, ultimately inducing enhanced attentional deployment to the peripheral visual field in deaf adults compared with hearing controls (Chen, He, Chen, Jin, & Mo, 2010; Chen, Zhang, & Zhou, 2006; Proksch & Bavelier, 2002; Scott, Karns, Dow, Stevens, & Neville, 2014; see for a review Pavani & Bottari, 2012; Proksch & Bavelier, 2002). However, to what extent these attention-related changes impact on social contexts remains largely unexplored. To investigate this issue, we examined spatial-orienting of attention elicited by eye-gaze direction of others (see Frischen, Bayliss, & Tipper, 2007 for a review on the topic) as well as in response to attentional cues without social valence, that is, directional arrows (Eimer, 1997; Friesen, Ristic, & Kingstone, 2004) in early deaf adults compared with hearing controls.

In gaze-cuing paradigms, participants are typically presented with a central face, whose gaze is directed to the right or to the left in each trial (Driver et al., 1999; Friesen & Kingstone, 1998, 2003; Friesen et al., 2004; Khurana, Habibi, Po, & Wright, 2009; Quadflieg, Mason, & Macrae, 2004; Tipples, 2005). The task is to detect or discriminate a peripheral target, appearing either on the same side indicated by eye-gaze (cued location) or on the opposite side (uncued location). Results have robustly shown that participants respond much faster when gaze direction congruently cues target location, compared with when gaze direction is incongruent with respect to the target (gaze-cuing effect; GCE). Crucially, GCE is also observed when gaze direction is entirely unpredictive of the position of the upcoming target (Friesen & Kingstone, 1998; Tipples, 2005), or even when it is counterpredictive with respect to target location (Driver et al., 1999; Friesen et al., 2004; Galfano et al., 2012). This led to the proposal that attentional orienting exerted by these social cues is automatic (Frischen et al., 2007) and not modulated by more complex information like emotional ex-

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pressions (Bayliss, Frischen, Fenske, & Tipper, 2007). This latter notion is corroborated by results reporting GCE in the contralesional hemifield of neglect patients (Vuilleumier, 2002), as well as in autistic individuals with deficits in the domain of social cognition (Swettenham, Condie, Campbell, Milne, & Coleman, 2003; but see Marotta et al., 2013). However, more recently a debate has developed regarding the complete automaticity of the GCE (Ricciardelli, Carcagno, Vallar, & Bricolo, 2013), as certain features typically observed for automatic orienting of attention such as inhibition of return, occur much later in time compared with the canonical phenomenon (Frischen & Tipper, 2004). Furthermore, top–down modulations on GCE have been documented, particularly in relation to inferred communicative intentions (Böckler, Knoblich, & Sebanz, 2011; Senju, Csibra, & Johnson, 2008) and in relation to gazer's status (Dalmaso, Pavan, Castelli, & Galfano, 2012; Jones et al., 2010; Ohlsen, van Zoest, & van Vugt, 2013).

In the deaf population, given the reduced or absent auditory input, gaze direction may greatly benefit the ability to direct attention to the same object and location attended by the social partner. Moreover, gaze direction may also convey important information about the surrounding visual environment during social interactions. For instance, deaf people may follow gaze shifts of their social partner as an alerting cue for events occurring in the surrounding space. We therefore predicted greater sensitivity to this type of social cues (i.e., larger GCE) in deaf participants compared with hearing controls.

In addition, eye-movement research in deaf people has documented a clear preference for the eye area when observing faces. For instance, Emmorey, Thompson, and Colvin (2009) have compared eye gaze in deaf native signers and hearing beginning signers during comprehension tasks on signed narratives. Deaf signers fixated primarily on or near the eyes, whereas hearing participants fixated primarily on or near the mouth. Similar results also emerged when comparing eye movements of deaf and hearing participants in a nonlinguistic task of emotion valence recognition in static faces (Watanabe, Matsuda, Nishioka, & Namatame, 2011). We thus hypothesized that lifelong sign language experience might further modulate the magnitude of the GCE in the deaf population. Specifically, we predicted that deaf participants with earlier acquisition of sign language (Mayberry & Lock, 2003) and higher signing proficiency should be more sensitive to gaze shifts as a cue for orienting their spatial attention.

Experiment 1a

Method

Participants. Twenty-two early bilateral deaf adults (*M* age = 28 years old; *SD* = 5; hearing loss ≥70 dB in the better ear; no other diseases linked to deafness) were recruited by the ISTC-CNR personnel to participate in this research and were tested in ISTC-CNR laboratories. Twenty-three hearing controls (*M* age = 24 years old; *SD* = 3.4) also took part in the study. All participants had normal or corrected-to normal vision. The Ethical Committee of the University of Trento approved the study and all participants signed an informed-consent form and received a reimbursement of 7 euros for their participation. Whenever needed a fluent signer explained consent procedures and experimental instructions in Italian Sign Language (LIS).

Before starting the experiment, all deaf participants completed a questionnaire aimed at collecting anamnestic information concerning deafness and linguistic background (see Table 1 for selected relevant information acquired through the questionnaire). In addi-

Table 1
Selected Anamnestic Information About Deaf Participants and Corrected Scores in the Raven's Progressive Matrices

Deaf participants	Age	Degree of deafness: Right ear	Degree of deafness: Left ear	Age of diagnosis (years)	Hearing aid usage	Raven's Progressive Matrices scores
1	34	Profound	Profound	1	No	123
2	33	Profound	Profound	Birth	1 ear	118
3	23	Profound	Profound	Birth	No	120
4	23	Severe	Severe	Birth	No	110
5	32	Profound	Profound	Birth	No	110
6	25	Profound	Profound	3	2 ears	127
7	25	Profound	Profound	Birth	No	108
8	29	Profound	Profound	1	2 ears	128
9	22	Severe	Severe	3	2 ears	120
10	22	Severe	Severe	1	2 ears	110
11	27	Severe	Severe	1	2 ears	125
12	27	Profound	Severe	Birth	1 ear	128
13	25	Severe	Profound	3	1 ear	110
14	29	Profound	Profound	2	2 ears	125
15	34	Severe	Severe	2	2 ears	112
16	24	Profound	Profound	6/8 months	2 ears	106
17	26	Profound	Profound	5/6 months	2 ears	127
18	43	Profound	Profound	2	No	128
19	32	Severe	Severe	2	2 ears	127
20	27	Profound	Profound	3 months	2 ears	114
21	27	Profound	Profound	2	1 ear	127
22	28	Profound	Severe	Birth	No	108

Note. For the variable degrees of deafness, *profound* means a loss ≥90 DB in that ear, and *severe* means a loss ≥ 70 DB in that ear. The questionnaire was developed by the National Research Council (ISTC-CNR) personnel.

tion, deaf participants performed the Raven's Progressive Matrices test, to ensure that none of the participants score below the pathological cutoff. No deaf participant was excluded from the study based on this criterion (see Table 1 for individual scores).

Furthermore, in a separate and dedicated experimental session, deaf participants also completed a comprehension and a sentence repetition task created ad hoc for assessing linguistic proficiency in LIS at the moment of testing (see the online supplementary material for further details). In the present work, we used LIS scores (see Table 2) for correlational analyses with the GCE of participants.

Stimuli and procedure. Figure 1 shows the stimuli used in the study as well as the trial sequence. The face was taken from a face database (Oosterhof & Todorov, 2008). The two directional gaze images (gaze left and right), and eyes closed condition were created from the straight-ahead gaze (see Figure 1) using Photoshop. On half of the trials the target appeared on the side indicated by gaze (cued trials), and in the remaining half of trials the target appeared on the opposite side (uncued trials). Crucially, gaze-cue direction was not predictive of target location. Two stimulus onset asynchronies (SOA; 250 ms; 750 ms) between gaze-cue and target appearance were randomly used in each trial to detect any changes in the properties of GCE over time. Note that each trial could include one of two types of precue face stimuli (eyes open; eyes closed; each appearing on half of the trials). In the eyes-open precue trials, the appearance of the gaze-cue produced apparent visual motion. Instead, the trials with the eyes-closed precue did not. This additional precue manipulation was introduced to control for possible performance differences between deaf and hearing participants attributable to visual motion processing, which has been repeatedly shown to be enhanced as a consequence of deafness (Codina et al., 2011; Hauthal, Sandmann, Debener, & Thorne, 2013; Neville & Lawson, 1987; Shiell, Champoux, & Zatorre, 2014). If the presence of visual motion modulates the magnitude of the GCE in deaf adults, we should observe enhanced GCE in the eyes-open precue trials compared with the eyes-closed precue trials.

Table 2

Age of Acquisition of Italian Sign Language (AoA of LIS) and Z Scores of Deaf Participants in the LIS Tests

Deaf participant	AoA of LIS (years)	Comprehension: LIS	Sentence repetition: LIS
1	3	−1,33	0,59
2	15	−1,33	0,42
3	Native	1,29	0,77
4	Native	0,24	0,06
5	2	−0,81	0,77
6	21	1,29	−00,66
7	Native	1,81	01,31
8	24	0,76	0,59
9	7	0,24	−00,66
10	8	0,24	—
11	20	−1,33	−1,20
12	Native	0,24	−0,48
13	20	0,24	0,06
14	20	0,24	−1,20
15	18	0,24	0,42
16	—	−1,85	−2,63
17	26	−1,85	−0,48
18	17	0,24	−0,48
19	6	−0,28	0,59
20	Native	−0,28	−1,20
21	18	0,24	0,95
22	Native	0,76	1,31

Note. In the "AoA of LIS" column, a dash indicates that sign language was unknown. In the "Sentence repetition: LIS" column, a dash indicates that a particular value is missing. These values were used in correlation analysis with the gaze-cuing effect.

Participants performed a peripheral discrimination task. They were instructed to fixate the central face, to ignore gaze cues because uninformative, and to indicate as fast and as accurately as possible whether the target diamond missed the top or the bottom part, independently of the side of the screen in which the target appeared (see Figure 1). Responses were given by pressing the up/down arrow keys on the computer keyboard. The experiment comprised 16 practice trials and 320 experimental trials divided in 16 blocks. At the end of each block participants received feedback on the average reaction times (RTs) and on the percentage of correct responses.

Results

Two hearing participants and two deaf participants were excluded from the analyses. One hearing participant was excluded due to too many mistakes (more than one third of trials); one hearing participant and one deaf participant were excluded because they were outliers with respect to the GCE distribution of their groups (i.e., their overall GCE on RTs were more than 2.5 *SD*s from the mean of their group); one deaf participant was excluded because mean RTs were more than 2.5 *SD* slower compared with the mean of the group. All analyses were thus conducted on 21 hearing controls and 20 deaf participants. Anticipation trials (i.e., RTs <100 ms; hearing mean: 0%; deaf mean: 1%) and missed trials (i.e., trials where no-response was given; hearing mean: 1%; deaf mean: 1%) were excluded from further analyses. Direct *t* tests comparisons showed no difference between groups for the proportions of excluded trials. Among the remaining trials, the mean of correct RTs falling within ±3 *SD*s from the participant mean, was inserted into a mixed, repeated measure ANOVA with precue type (eyes closed; eyes open), SOA (250 ms; 750 ms), congruency (cued; uncued) as within-participant variables, and group (hearing; deaf) as between-participants variable. GCE was calculated as the difference in RTs (or accuracy) between uncued and cued trials. All post hoc analyses were conducted using the Newman–Keuls test.

This analysis revealed a main effect of SOA, caused by faster RTs in the 750-ms SOA trials compared with the 250-ms SOA trials, $F(1, 39) = 55.03$ $p < .00001$, $\eta_p^2 = 0.58$, and a main effect of congruency, $F(1, 39) = 10.60$ $p = .002$, $\eta_p^2 = 0.21$. The main effect of group did not reach significance, $F(1, 39) = 0.39$, $p = .53$ excluding overall differences in RTs between the two groups. Most important, a significant interaction between congruency and group emerged, $F(1, 39) = 5.09$, $p = .03$, $\eta_p^2 = 0.12$ (see Figure 2A; see also Table 3). Hearing participants were significantly faster for cued ($M = 671$ ms; $SE = 20$) compared with uncued trials ($M = 693$ ms; $SE = 21$; $p = .0005$; GCE = 22 ms). By contrast, no significant difference between cued ($M = 698$ ms; $SE = 20$) and uncued trials ($M = 702$ ms; $SE = 22$; $p = .5$; GCE = 4 ms) emerged for deaf participants. No other factor reached significance (all other F values < 0.96).

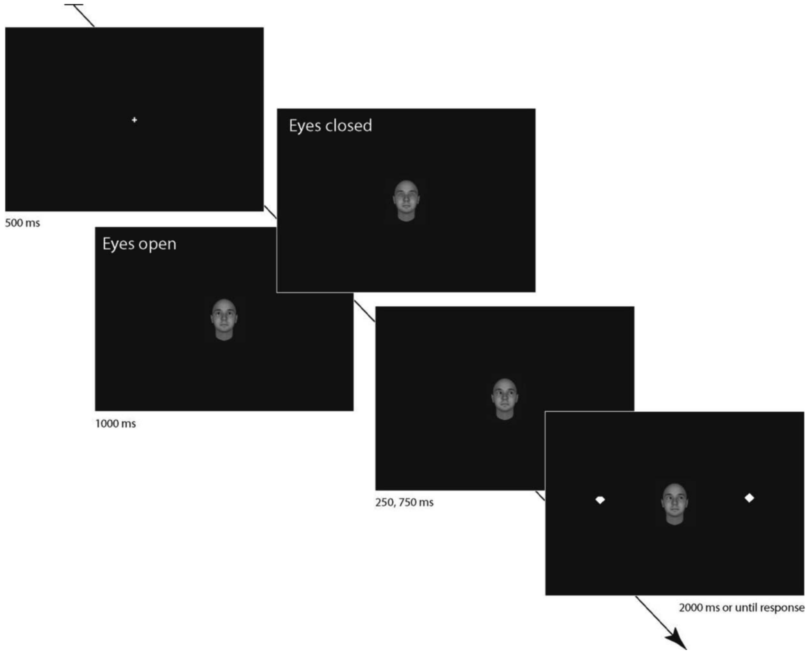

Figure 1. Trial sequence and stimuli. Participants sat at a distance of approximately 60 cm from the center of a computer monitor (34 × 27 cm; resolution 1024 × 768; refresh rate 60 Hz). Each trial began with central fixation (500 ms). A precue stimulus (7.5 × 11 cm) lasting 1000 ms (a face with eyes-open gazing straight ahead or a face with the eyes closed) always preceded the face with shifted gaze (cue-stimulus, 7.5 × 11 cm). After 250 ms or 750 ms (stimulus onset asynchrony), the target (1 × 1 cm) stimulus appeared at an eccentricity of 11 cm (2,000 ms or until response). In this example an uncued trial is shown: the gaze is directed to the right, whereas the target (cut diamond) appears on the left.

A similar analysis on percentage of errors as dependent variable did not reveal any effect related to the group variable (all *F* values related to the group variable <1.38). In particular, the two-way interaction between group and congruency did not reach significance, $F(1, 39) = 0.12$, $p = .73$ (see Figure 2A, bottom panel). Only the main effect of congruency, $F(1, 39) = 7.39$, $p = .009$, $\eta_p^2 = 0.16$; GCE = 1%, and the main effect of precue type reached significance, $F(1, 39) = 4.48$, $p = .04$, $\eta_p^2 = 0.1$. Post hoc analyses

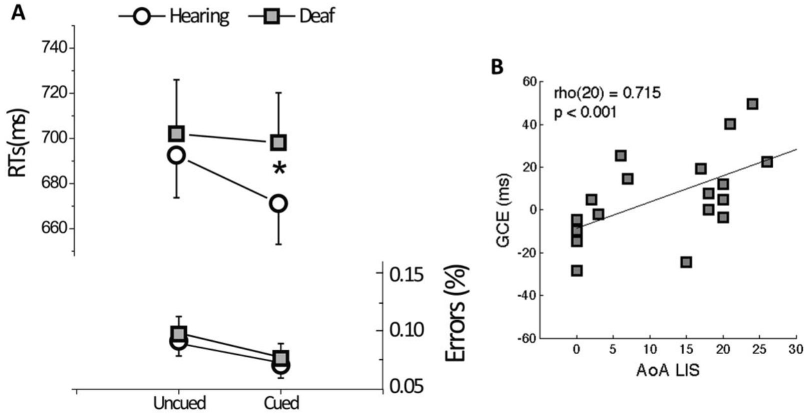

Figure 2. Results: Gaze-cue. Panel A, top: Mean reaction times (RTs) for uncued and cued trials, as a function of experimental group. Whereas hearing participants show the typical gaze-cuing effect (GCE; i.e., faster responses for cued compared with uncued trials), deaf participants did not (i.e., no difference in the speed of responses between cued and uncued trials). Panel A, bottom: Mean percentage of errors for uncued and cued trials, as a function of experimental group. Both groups show a comparable GCE (i.e., more errors to uncued compared with cued trials). Panel B: Correlation between age of acquisition of sign language (AoA LIS) and GCE in deaf participants for the 250 ms stimulus onset asynchronies. In the graph ρ value and the corresponding *p* value are also reported.

Table 3
Mean Reaction Times (RTs) and Mean Percentage of Errors (and Corresponding SEs) Together With Mean Gaze-Cueing Effect (GCE) Reported Separately for Hearing and Deaf Participants

SOA 250

	Uncued				Cued					
	RTs (ms)	*SE* (ms)	Errors (%)	*SE* (%)	RTs (ms)	*SE* (ms)	Errors (%)	*SE* (%)	GCE (ms)	GCE (%)
Hearing	704.85	19.44	0.09	0.01	680.70	18.28	0.07	0.01	24.14	0.02
Deaf	717.43	25.08	0.09	0.02	712.55	22.68	0.08	0.02	4.88	0.01

SOA 750

	Uncued				Cued					
	RTs (ms)	*SE* (ms)	Errors (%)	*SE* (%)	RTs (ms)	*SE* (ms)	Errors (%)	*SE* (%)	GCE (ms)	GCE (%)
Hearing	680.16	18.88	0.10	0.02	661.67	18.44	0.07	0.01	18.49	0.03
Deaf	687.02	23.25	0.11	0.02	683.99	21.96	0.07	0.01	3.03	0.04

Note. Precue data are collapsed. SOA = stimulus onset asynchrony.

revealed that all participants made significantly more errors when they were presented with the eyes-open precue ($M = 13\%$; $SE = 1\%$) compared with the eyes-closed precue ($M = 11\%$; $SE = 1\%$; $p = .04$).

To examine the role of sign language experience in modulating the GCE measured in RTs for deaf participants, Spearman's correlations were conducted between GCE and performance in both of the sign-language tasks, for each level of SOA. None of these correlations reached significance. However, there was a significant correlation between self-reported AoA of LIS (see Table 2) and the magnitude of GCE for the 250-ms SOA, $\rho(20) = 0.715$, $p < .001$ (see Figure 2B). Deaf participants who reported to have acquired LIS later in life showed greater GCE in RTs compared with deaf participants who acquired LIS earlier in life. No significant correlation between AoA of LIS and GCE was observed for the 750-ms SOA, $\rho(20) = 0.11$, $p = .96$.

Discussion: Experiment 1a

In line with previous studies, hearing participants were faster and more accurate when responding to cued compared with uncued trials (i.e., GCE). Contrary to our predictions, however, deaf participants did not show a larger GCE than hearing controls. In fact, their GCE was less consistent across dependent measures: It was reliable in the accuracy measure, but was absent in response times. The lack of GCE for response times in the deaf population was unaffected by the SOA between eye-gaze shift and target appearance (i.e., 250; 750 ms; see Table 3). Likewise the different precue conditions (eyes open vs. eyes closed) did not modulate the emergence of GCE in the deaf group, thus excluding a role of enhanced visual motion processing (Codina et al., 2011; Hauthal et al., 2013; Neville & Lawson, 1987; Shiell et al., 2014) in mediating gaze-cue responses in the deaf population. The evidence that deaf participants had a reliable GCE for errors (see Figure 2A and see Table 3), which did not differ in magnitude from hearing controls, suggests that their performance is affected by gaze cues to some extent. Note however, that the accuracy in Experiment 1a was very high for both groups of participants, thus the pattern of the results on errors rate was based on a small proportion of the overall trials. Overall, the absence of GCE in response times clearly indicates a less consistent GCE in the deaf participants tested in the present study. Furthermore, even though we can only speculate regarding the reason for this discrepancy across dependent variables, it should be noted that the typical GCE is described in most previous studies in terms of RTs rather than errors.

Based on previous reports showing that early signers predominantly allocate attention to the eye region of the face (Emmorey et al., 2009; Watanabe et al., 2011), we predicted that early deaf signers and deaf participants with a high level of sign language proficiency should be particularly sensitive to gaze shifts. However, this was clearly not the case. None of the linguistic measures we acquired (see Table 2) correlated with the magnitude of the GCE. Furthermore, we found a positive correlation between the AoA of sign language and the absence of GCE in response times of deaf participants. That is, the earlier deaf participants acquired sign language, the smaller the GCE. This correlation was significant only for the short SOA trials.

One way to account for this seemingly counterintuitive sign language finding is by hypothesizing that early sign language acquisition may change the way in which gaze shifts are interpreted. In sign languages, the eye area carries linguistic information in addition to attention-orienting ones (Emmorey, 2002). In particular, eye-gaze shifts serve to indicate role shifting among characters during narrations (Pizzuto, 2007) and to mark locations in space associated with objects and locative (Thompson, Emmorey, & Kluender, 2006). For instance, to indicate role-shifting while signing a story about two friends, a signer would move always the eyes in one direction to refer to one of the two characters, and in the other direction to refer to the other one. In this context, orienting spatial attention toward the direction of gaze could be detrimental for efficient linguistic interaction, because no relevant information will appear at the gaze-cued location. If indeed the absence of GCE in deaf participants mainly arises from early exposure to sign language rather than from deafness per se, hearing native signers may similarly resist the GCE.

Experiment 1b

To investigate the hypothesis that the absence of GCE in the deaf group reflects early sign language acquisition rather than auditory deprivation, we tested a group of hearing native signers (i.e., hearing adults born from deaf signing parents; also termed children of deaf adults [CODAs]) in exactly the same task described above. If early acquisition of sign language is the determinant factor in modulating GCE, reduced or abolished GCE should emerge also in this hearing population.

Method

Participants, stimuli, and procedure. Thirteen hearing native signers (i.e., CODAs; mean age = 28.2; $SD = 5.3$) took part in Experiment 1b. All participants reported to have normal or corrected-to-normal vision, they signed an informed-consent form and received a reimbursement of 7 euros for their participation in the study. Stimuli and procedure were identical to Experiment 1a.

Results

Based on the same criteria reported in the Results section of Experiment 1a, no CODA participant was excluded. Therefore we performed the analyses on 13 CODAs. Anticipation trials (i.e., RTs <100 ms; mean: 0%) and missed trials (i.e., trials where no-response was given; mean: 1%) were excluded from further analyses. Among the remaining trials, the mean of correct RTs falling within ±3 *SD*s from the participant mean, was inserted into a repeated measure ANOVA with Precue Type (eyes closed; eyes open), SOA (250 ms; 750 ms) and congruency (cued; uncued) as within-participant variables. Post hoc analyses were conducted using the Newman–Keuls test. This analysis yielded a significant main effect of SOA due to faster RTs in the 750-ms SOA trials compared with the 250-ms SOA trials, ($F(1, 12) = 45.00$, $p = .00002$, $\eta_p^2 = 0.79$. Most important, the main effect of congruency also reached significance, $F(1, 12) = 7.28$, $p = .02$, $\eta_p^2 = 0.38$. CODAs, like hearing participants were significantly faster for cued ($M = 726.43$ ms; $SE = 22.99$) compared with uncued trials ($M = 741.28$ ms; $SE = 24.86$; $p = .02$; GCE = 15 ms). No other factor reached significance (all other F values <0.84). A similar analysis conducted using percentage of errors as dependent variable revealed no significant main effect or interaction (all F values <3.39).

To fully appreciate between-groups difference in terms of GCE for RTs, Figure 3 depicts GCE for hearing, deaf, and CODA participants, plotting the overall GCE observed in each single participant, together with the corresponding group-mean GCE values. The GCE of CODA (M GCE = 15 ms) appears midway between the averaged GCE observed in hearing nonsigners (M GCE = 22 ms) and in deaf participants (M GCE = 4 ms; see Figure 3). This pattern of results was confirmed by planned t tests corrected for multiple comparisons with Bonferroni correction, which did not show differences in overall GCE measures between CODAs and hearing participants, $t(1, 32) = 0.69$, $p = 1.00$, nor between CODAs and deaf participants, $t(1, 31) = -1.69$, $p = .62$.

Finally, given that we did not observe any modulation of GCE when errors were taken into account in the CODAs, we also tested whether the overall GCE in errors was smaller in CODAs compared with the other two groups. This comparison revealed no difference in GCE neither between hearing controls and CODAs, $t(1, 32) = 0.78$, $p = .4$ nor between deaf participants and CODAs, $t(1, 32) = 1.37$, $p = .17$.

Discussion: Experiment 1b

Experiment 1b showed that hearing native signers do present a significant GCE in RTs. This finding suggests that the less consistent GCE reported in deaf participants compared with hearing controls in Experiment 1a, is unlikely related to early sign-language acquisition alone (see also Bosworth & Dobkins, 2002; Dye, Hauser, & Bavelier, 2009; Proksch & Bavelier, 2002). This raises the possibility that the GCE result in deaf participants might be related to changes in the properties of attentional orienting determined by auditory deprivation. Reduced benefits from attentional cues have been previously documented in deaf participants, using nonsocial stimuli delivered in the periphery of the visual field to attract attention. For instance, Bosworth and Dobkins (2002) used informative peripheral cues to direct spatial attention toward the location of the upcoming stimulus. The results revealed that deaf signers benefit less from predictive peripheral cues compared with both hearing native-signers and nonsigners controls. The authors interpreted this result as evidence in favor of enhanced attentional resources devoted to the periphery of the visual field in the deaf population (Chen et al., 2010; Proksch & Bavelier, 2002). Other studies using similar paradigms further strengthened this conclusion, eventually proposing that deaf adults reorient their spatial attention to the visual periphery faster than hearing controls (Chen et al., 2006; Colmenero, Catena, Fuentes, & Ramos, 2004).

In light of these previous findings, the results reported in Experiment 1a may reflect the enhanced ability of the deaf population to allocate attentional resources to the periphery of the visual scene. In other words, deaf participants may be less susceptible to eye-gaze shifts because they can monitor and process peripheral visual information more efficiently than hearing controls. If this is the case, however, reduced cuing effects in deaf participants need not be specific for social/linguistic cues (eye-gaze shifts) and should emerge also for nonsocial/linguistic cues, such as central arrows. Note that gaze and arrow cues share the *ecologic* factor of existing in real life situations as potential cues for directing attention in space (for similar manipulations comparing gaze and arrow cues in hearing participants, see Brignani, Guzzon, Marzi, & Miniussi, 2009; Stevens, West, Al-Aidroos, Weger, & Pratt, 2008;

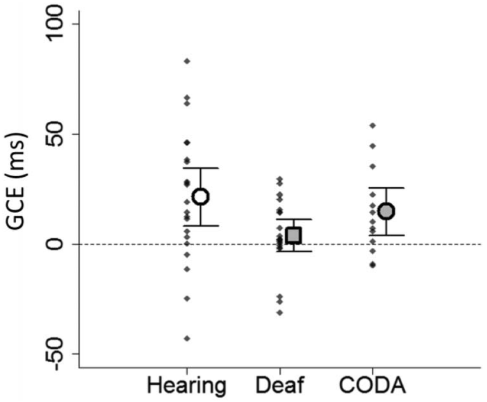

Figure 3. Individual overall gaze-cuing effect (GCE) in response times reported for hearing, deaf, and children of deaf adults (CODA) participants along with the corresponding group GCE mean and 95% confidence intervals.

Tipples, 2008). One previous study in the literature compared the responses of deaf and hearing participants to peripheral targets, while central arrows appeared at the center of the screen (Parasnis & Samar, 1985). In validly cued trials, the response speed advantage was comparable in deaf and hearing participants. In contrast, in invalidly cued trials, the response speed costs were smaller for deaf participants compared with hearing controls. Note, however, that this group difference emerged only under foveal load, when central arrows were embedded in a cluster of five black crosses. In the no foveal load condition, performance of deaf and hearing participants was entirely comparable. This result, then, is not completely conclusive in answering to the question of whether or not an advantage for deaf individuals in monitoring and processing peripheral visual information emerges also for central arrow cues. Moreover, it should be noted that the central arrows in the Parasnis and Samar (1985)study were predictive of target location (i.e., participants knew that on 80% of the trials the target appeared on the side indicated by the arrow). By contrast, in our approach central gaze stimuli were entirely unpredictive.

Experiment 2

In Experiment 2 we tested a group of hearing nonsigners and a group of deaf signers in an arrow-cue paradigm. The task was identical to the one adopted in Experiment 1a and 1b, with the sole exception that the central cue was now a directional arrow. If attention orienting effects are reduced or absent in deaf compared with hearing participants also for this type of nonsocial central cue, we could conclude that deaf adults have an unspecific advantage in covertly orienting to peripheral information. In contrast, if the impact of arrow cues on attention orienting is comparable between the two groups, one might conclude that attentional orienting to gaze cues is specifically modified in deaf signers.

Method

Participants. Fourteen hearing adults (*M* age = 28.57; *SD* = 4.85) and 14 early bilateral deaf adults (*M* age = 31.36; *SD* = 5.79; hearing loss ≥70 dB in the better ear; no other diseases linked to deafness; see Table 4 for selected relevant information acquired through a questionnaire delivered before starting the experiment) took part to the experiment. Nine deaf participants also took part to the gaze-cue experiment (see Table 4). The Ethical Committee of the University of Trento approved the study and all participants signed an informed-consent form and received a reimbursement of 7 euros for their participation. Whenever needed a fluent signer explained consent procedures and experimental instructions in LIS.

Stimuli and procedure. Figure 4 shows the stimuli used in this experiment as well as the trial sequence. Crucially, and similarly to the gaze-cuing task, arrow-cue direction was never predictive of target location. On half of the trials the target appeared on the side indicated by the pointing-arrow (cued trials), and in the remaining half of trials the target appeared on the opposite side (uncued trials). Two stimulus onset asynchronies (SOA; 250 ms; 750 ms) between arrow-cue and target appearance were randomly used in each trial to detect any changes in the properties of arrow-cuing effect (ACE) over time.

Participants performed a peripheral discrimination task. Similarly to the gaze-cue task, they were instructed to fixate the precue segment, to ignore arrow-cues because uninformative, and to indicate as fast and as accurately as possible whether the target diamond missed the top or the bottom part, independently of the side of the screen in which the target appeared. Responses were given by pressing the up/down arrow keys on the computer keyboard. The experiment comprised 16 practice trials and 160 experimental trials divided in 8 blocks of 20 trials. At the end of each block participants received feedback on the average RTs and on the percentage of correct responses.

Results

Based on the same criteria for excluding participants we reported in the Results section of Experiment 1a, analyses could be conducted on all participants. Anticipation trials (i.e., RTs <100 ms; hearing mean: 0%; deaf mean: 0%) and missed trials (hearing:

Table 4
Selected Anamnestic Information About Deaf Participants and Scores in the Raven's Progressive Matrices

Deaf participants	Age	Degree of deafness: Right ear	Degree of deafness: Left ear	Age of diagnosis (years)	Actual hearing aid Usage	AoA of LIS (years)	Raven's progressive matrices scores	Gaze-cue task
1	26	Profound	Profound	1	2 ears	24	128	Done
2	35	Profound	Profound	5/6 months	2 ears	26	127	Done
3	27	Profound	Profound	2	2 ears	20	125	Done
4	25	Profound	Profound	Birth	1 ear	15	118	Done
5	33	Profound	Profound	Birth	No	Native	108	Done
6	30	Profound	Profound	18 months	No	3	120	
7	28	Profound	Profound	Birth	No	Native	108	Done
8	24	Profound	Profound	Birth	No	Native	120	Done
9	29	Profound	Profound	2	1 ear	18	127	Done
10	44	Profound	Profound	2	No	17	128	Done
11	41	Severe	Profound	Birth	1 ear	Native	—	
12	25	Profound	Profound	<1 year	No	Native	—	
13	35	Profound	Profound	3	2 ears	25	—	
14	35	Profound	Profound	3	No	19	—	

Note. For the variable degree of deafness, *profound* means a loss ≥90 DB in that ear, and *severe* means a loss ≥70 DB in that ear. The questionnaire was developed by the ISTC-CNR personnel. In the last column of Table 4, we report participants who performed also the gaze-cue task. A dash indicates that Raven Matrices Test could not be performed.

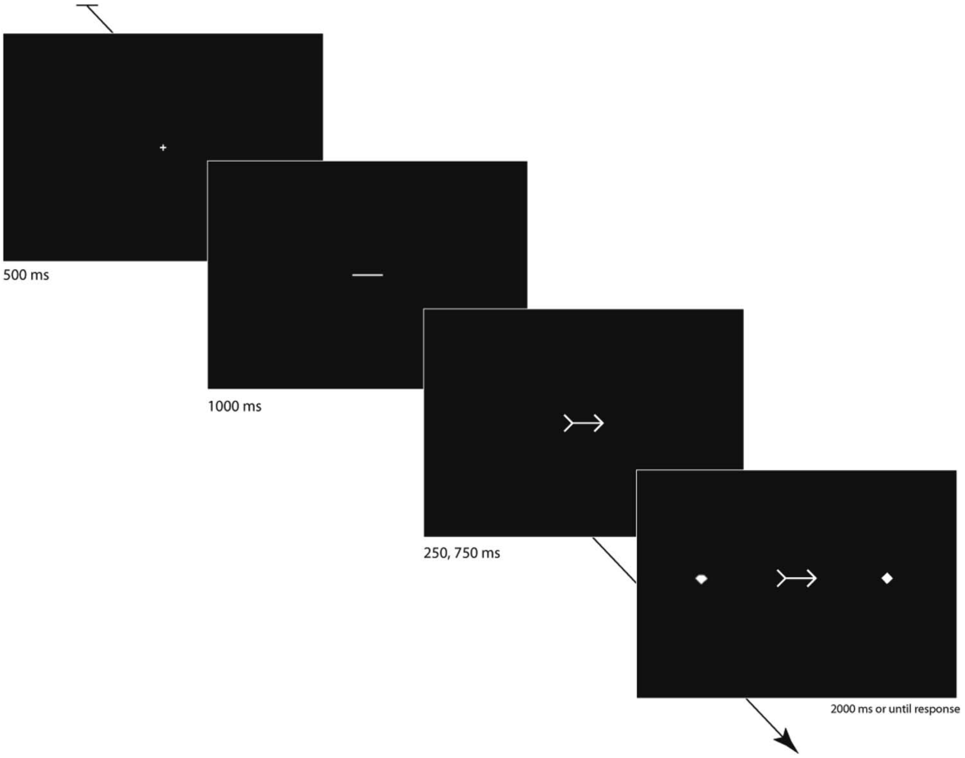

Figure 4. Trial sequence and stimuli. Participants sat at a distance of approximately 60 cm from the center of a computer monitor (34 × 27 cm; resolution 1,024 × 768; refresh rate 60 Hz). Each trial began with central fixation (500 ms). A precue stimulus (2.2 cm) lasting 1000 ms (an horizontal bar presented at the center of the screen) always preceded the directional arrow (cue-stimulus, 3.5 cm). After 250 ms or 750 ms (stimulus onset asynchrony), the target (1 × 1 cm) stimulus appeared at an eccentricity of 11 cm (2,000 ms or until response). In this example an uncued trial is shown: the arrow is pointing to the right, whereas the target (cut diamond) appears on the left.

0%; deaf mean: 0%) were excluded from further analyses. Among the remaining trials, the mean of correct RTs falling within ±3 *SD*s from the participant mean, was inserted into a mixed, repeated measure ANOVA with SOA (250 ms; 750 ms), congruency (cued; uncued) as within-participant variables, and group (hearing; deaf) as between-participants variable. ACE was calculated as the difference in RTs (or accuracy) between uncued and cued trials. All post hoc analyses were conducted using the Newman–Keuls test. This analysis revealed a significant main effect of SOA, due to overall faster responses to the 750-ms SOA trials compared with the 250-ms SOA trials, $F(1, 26) = 48.14$, $p < .000001$, $\eta_p^2 = 0.65$. Also the main effect of congruency reached significance, $F(1, 26) = 15.21$, $p = .0006$, $\eta_p^2 = 0.37$, caused by overall faster responses to cued ($M = 678.51$ ms; $SE = 15.50$) compared with uncued trials ($M = 706$ ms, $SE = 19.24$, ACE = 27.49 ms; $p = .0001$). Similarly to Experiment 1a, the main effect of group did not reach significance, $F(1, 26) = 0.88$, $p = .35$, thus excluding differences between the two groups in terms of overall RTs performance. Crucially, unlike Experiment 1a, ACE emerged independently of group. The two-way interaction between congruency and group did not reach significance, $F(1, 26) = 0.79$, $p = .38$ (see Figure 5 and Table 5 for mean RTs in each experimental condition). No other factor was significant (all other F values <0.88).

A similar analysis on percentage of errors as dependent variable revealed only a significant main effect of congruency, $F(1, 26) = 5.03$, $p = .03$, $\eta_p^2 = 0.16$; ACE = 2%. There was also a slightly significant main effect of SOA, $F(1, 26) = 4.12$, $p = .053$, $\eta_p^2 = 0.14$ (see Table 5 for mean percentage of errors in each experimental condition). No other factor reached significance (all other F values <3.07).

Finally, to sum up and directly compare the results from the gaze-cue and the arrow-cue experiments, we reanalyzed the RTs data separately for both groups using task (gaze-cue; arrow-cue) as between-participants variable and congruency (cued; uncued) as within-participant variable. In the deaf group the two-way interaction between congruency and task reached significance, $F(1, 32) = 6.71$, $p = .01$, $\eta_p^2 = 0.17$ (see Figure 6A), whereas this same interaction was not significant in the hearing group ($p = .99$; see Figure 6B).

General Discussion

Eye-gaze shifts are strong cues for orienting spatial attention. In the present study we tested the impact of this potent social cue on covert attention orienting of early deaf adults. We intuitively hypothesized that when monitoring the surrounding environment during social

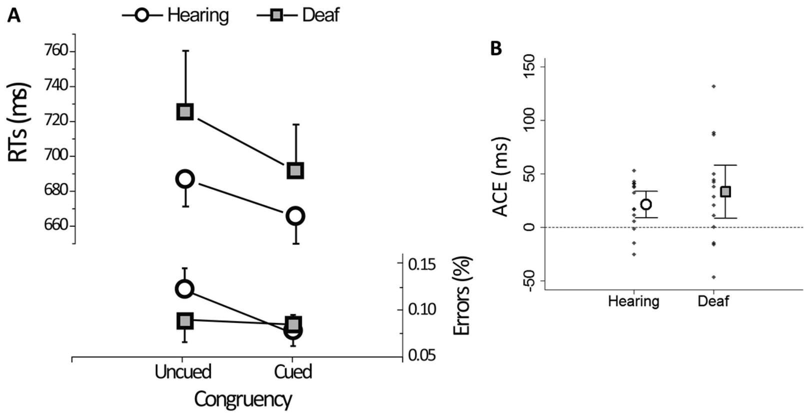

Figure 5. Results: Arrow-cue. Panel A, top: Mean reaction times (RTs) for uncued and cued trials, as a function of experimental group. Both hearing and deaf participants show the classic ACE effect (i.e., faster responses for cued compared with uncued trials). Panel A, bottom: Mean percentage of errors for uncued and cued trials, as a function of experimental group. Both groups show a comparable ACE (i.e., more errors in uncued compared with cued trials). Panel B: Individual overall arrow cuing effect (ACE) reported separately for hearing and deaf participants along with the corresponding group ACE mean (hearing = 21.32 ms; deaf = 33.39 ms) and 95% confidence intervals.

interactions deaf people would rely more on gaze direction than their hearing peers. Thus, we predicted a stronger GCE in early deaf compared with hearing adults.

Our empirical data disconfirmed this prediction, as we found no evidence of increased GCE in deaf participants compared with hearing controls. On the contrary, GCE was less consistent in deaf compared with hearing participants. Whereas hearing participants showed the expected GCE both in response times and accuracy, the deaf group showed no GCE when response times were considered (Experiment 1a). To clarify this unexpected finding, we pursued two lines of investigation. The first one examined the contribution of sign language experience to the absence of GCE measured in the RTs of deaf adults. A correlation analysis in Experiment 1a suggested a possible link between age of sign language acquisition and GCE magnitude in terms of response times (see Figure 2B). However, this correlation finding was partially ambiguous as it reached significance only for the short SOA (250 ms) between the eye-gaze shift and target appearance, but was not observed when the SOA was long (750 ms). In addition, none of the sign-language proficiency measures (comprehension and repetition tasks) we collected correlated with the magnitude of GCE. Experiment 1b was specifically designed to further examine the role of early sign language acquisition in modulating GCE and involved testing a group of hearing native-signers in the same gaze-cue task. We showed that GCE was comparable between hearing native-signers and hearing nonsigners, regardless of the SOA. In sum, our current findings suggest that the lack of GCE in the response times of deaf participants cannot be explained by sign language experience alone.

The second line of investigation we pursued concerned the specificity of the reduced cuing effect in deaf participants. To

Table 5
Mean Reaction Times (RTs) and Mean Percentage of Errors (and Corresponding SEs) Together With Mean Arrow-Cueing Effect (ACE) Reported Separately for Hearing and Deaf Participants

	Uncued				Cued					
	RTs (ms)	*SE* (ms)	Errors (%)	*SE* (%)	RTs (ms)	*SE* (ms)	Errors (%)	*SE* (%)	ACE (ms)	ACE (%)
SOA 250										
Hearing	704.77	16.62	0.12	0.03	682.30	17.59	0.08	0.02	22.47	0.04
Deaf	741.92	34.87	0.11	0.03	713.87	29.50	0.10	0.03	28.05	0.02
SOA 750										
Hearing	668.80	15.25	0.12	0.03	648.79	14.62	0.08	0.02	20.01	0.05
Deaf	708.53	36.32	0.07	0.02	669.08	24.80	0.08	0.02	39.45	−0.01

Note. SOA = stimulus onset asynchrony.

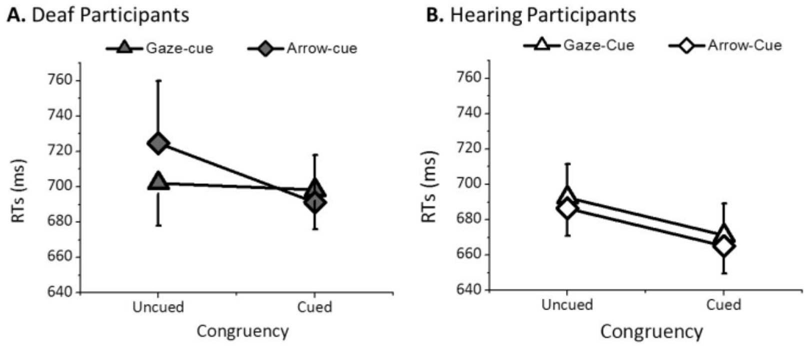

Figure 6. Comparison between reaction times (RTs) in Experiment 1a (gaze-cue) and in Experiment 2 (arrow-cue). Panel A: Although in the arrow-cue experiment deaf participants were significantly slower in the uncued trials compared with the cued trials (Newman–Keuls post hoc test, $p = .001$), in the gaze-cue experiment they showed no cost in RTs between cued and uncued trials. Panel B: Hearing participants did not show any difference in RTs between the gaze-cue and the arrow-cue experiment.

this aim, we ran a second experiment using central arrow cues, instead of eye-gaze cues. Experiment 2 revealed comparable ACE in deaf and hearing participants, suggesting that the absence of GCE for RTs we observed in Experiment 1a in the deaf group was specific to the nature of the cuing stimulus. This pattern of results also argues against an interpretation of the findings of Experiment 1a in terms of increased motivation in the deaf population. If deaf adults were merely more motivated than hearing controls to perform well in the tasks they should have been able to escape both GCE and ACE. Instead, the specificity of the reduced cuing effect in deaf adults points to a special role of eyes and faces in modulating spatial attention distribution in the deaf population.

Implications for the Literature on Deafness: Behavior

Changes in visual attention are a key finding in the literature on deaf cognition (Dye & Bavelier, 2010; Pavani & Bottari, 2012). Specifically, one of the core findings in this domain concerns the notion that deaf adults compared with hearing adults possess enhanced attentional resources devoted to the periphery of the visual field (Chen et al., 2010; Chen et al., 2006; Dye et al., 2009; Procksh & Bavelier, 2002). Based on this consistent previous literature, one may have predicted that enhanced peripheral attention may have played a similar role in modulating deaf participants' performance irrespective of the cue-type paradigm. However, the critical finding of the present study is the difference in the response to gaze versus arrow cues in deaf compared with hearing participants: deaf adults were able to filter out eye-gaze shifts signals more than hearing controls, yet both groups were equally susceptible to arrow cues. This latter result is particularly surprising when considered in the context of the literature on gaze and arrow cuing in the hearing population. Previous studies have occasionally shown a dissociation in orienting effects triggered by these two ecological cues showing that hearing people can resist arrow cues more easily than eye-gaze cues (Friesen et al., 2004; Ristic, Wright, & Kingstone, 2007). Note that this is opposite to the present results with deaf adults.

Why are deaf people able to resist eye-gaze cues more than arrow cues? The first consideration concerns the different training deaf participants may experience throughout the life span when they encountered these stimuli in everyday life. Regardless of the preferred communicative mode (i.e., sign language and/or lip reading), deaf people extract linguistic contents from facial expressions and lip-movements. These subtle facial modifications could remain undetected if attention strongly shifts to the periphery of the visual field every time the social partner shifts his or her gaze. In addition, in most cultures it is often expected for an addressee to gaze at the speaker's face (Emmorey, 2002), and this behavior may be particularly important in the deaf community given that all communications are face-to-face. Together, these factors may promote a strong predisposition to limit attention shifts from the social partner by maintaining attention more focused on the face. Such a predisposition, however, would not develop for directional arrows. In fact, differently from eye gazes, when directional arrows are present in everyday life (e.g., directional signs in the street) they generally prompt observers to shift their attention toward the indicated direction. In turn, deaf observers may never have needed to develop an increased ability to withhold attention shifting to directional arrows, ultimately being as susceptible as hearing adults to such attentional cues (but results may change when increasing the attentional load; see Parasnis & Samar, 1985).

The second consideration concerns the possible mechanisms subtending this ability to limit attentional shifts to gaze cues. During social interactions deaf may have the specific need to achieve a balance between the maintenance of spatial attention on faces, in order to assure the quality of communicative and social interactions, and the successful monitoring of the environment around them. Complete resistance to attentional disengagement from faces, may prevent efficient monitoring of the surroundings. The fact that deaf participants do not show a GCE in RTs but still do show a reliable GCE in errors rate, suggests that at least to some extent, gaze cues impact on their performance. Again, it should be noted that accuracy in Experiment 1a was very high for both groups of participants, thus the errors trials describe the performance on a small proportions of the overall trials. The question on which are the mechanisms driving the dissociation between the magnitude of GCEs in RTs and errors in the deaf population may yield a fruitful avenue for further research. Here we propose two speculative hypotheses.

One first possibility is that deaf adults may learn to reorient their spatial attention faster than hearing controls when gaze cues are presented (see Chen et al., 2006, and Colmenero et al., 2004, for a similar proposal with nonsocial cues). Such behavior may limit the impact of attentional shifts triggered by gaze cues on social interactions, but would not necessarily prevent the processing of the information conveyed by these potent cues (hence the reliable GCE in errors). When responding to arrow cues instead, this type of mechanism does not come into play because it is not necessary (i.e., in real life deaf adults do not have any need to maintain their attention on arrows). A second possibility concerns the role of overt and covert orienting in response to gaze cues. Although we instructed participants to maintain their eyes on the center of the screen and refrain from gaze-following behavior, we did not monitor their eye movements. If one assumes that both deaf and hearing participants failed to inhibit saccades toward the gaze-cue direction in a proportion of trials, the errors could be interpreted primarily as the result of such overt gaze following. Saccades toward the gaze-cue direction during an invalid trial would most probably imply reduced information about the target and increased chances of a wrong answer. If these assumptions are correct, the lack of GCE in RTs may reflect a modified covert attentional mechanism that assures to deaf observers the high-quality of social interactions by enabling them to maintain their spatial attention focused on the faces of social partners. Instead, occasional overt orienting to gaze cues, which costs seem to be comparable between deaf and hearing participants, may serve in the deaf population the fundamental need of monitoring the external environment during social interactions.

Overall, the present study, highlights the benefit of investigating attention orienting in more ecological valid settings in the deaf population in order to understand in greater detail how deaf adults deploy their spatial attention in everyday life (see also Hauthal, Neumann, & Schweinberger, 2012). A lot of interesting questions remain to be explored in this area of research. For instance, it would be particularly interesting to establish whether the GCA and ACE in the deaf population follow a developmental trajectory (Dye, 2014; Dye & Hauser, 2014). If for instance, the lack of GCE we have documented in the response times of deaf adults is the effect of a control strategy that deaf adults have acquired during their life to maximize the quality of their social interactions, we predict that this form of resistance may be less evident (or absent) in young deaf children. On the contrary, the trajectory development of ACE should be comparable between deaf and hearing children.

In addition, in the present study we documented the properties of GCEs using static faces, not conveying any linguistic message. It may be interesting to expand the current findings to explore whether reduced GCE in deaf participants may be even more pronounced when the observer knows that the face can occasionally produce communicative behavior, or belongs to a person who knows sign language (vs. a nonsigner). It may also be interesting to further test the properties of such reduction by strengthening the communicative-social context. Studies on the hearing population showed increased GCE when the gazer established eye contact with the participant compared with when he or she did not (Bristow, Rees, & Frith, 2007). Similar increases in GCE were reported also when the participant observed the gazer making eye contact with someone else (i.e., two gazers making eye contact with each other) compared with when the two gazers were looking away from each other (Böckler et al., 2011). It could be interesting to test whether or not deaf adults would show a different magnitude of GCE in these cases. Finally, future studies could also investigate to what extent the ability of deaf adults to limit GCE might generalize to other social cues, such as head, body, or finger orientations. Such an approach could shed light on the intrinsic nature of this effect and disambiguate whether it is specific to eye gaze, or instead it extends to any directional social-cue.

Implications for the Literature on Deafness: Plasticity

The present findings may broaden the current perspectives on plastic changes related to deafness as they suggest the involvement of acquired top–down control in sensory deprivation induced plasticity. Behavioral studies to date have placed great emphasis on bottom–up mechanisms when aiming to explain the impact of auditory deprivation on stimulus processing (Buckley, Codina, Bhardwaj, & Pascalis, 2010; Neville & Lawson, 1987; Stevens & Neville, 2006). Furthermore, research on the neurofunctional correlates of deafness-induced changes have largely focused on characterizing the contribution of early sensory processing, unraveling plastic changes occurring within the visual system starting from the retina onward (Bavelier et al., 2001; Bottari, Caclin, Giard, & Pavani, 2011; Codina et al., 2011; Hauthal, Thorne, Debener, & Sandmann, 2014), as well as cross-modal recruitment of the auditory regions (Bottari et al., 2014; Finney, Fine, & Dobkins, 2001; Karns, Dow, & Neville, 2012; Scott et al., 2014; Shiell, Champoux, & Zatorre, 2015). This literature has mainly explained the documented changes in terms of strengthen feed-forward mechanisms of visual information processing. Our findings instead suggest the intriguing proposal that plasticity related to deafness may also trigger systematic top–down (feedback) inhibitory modulations within the visual system (see also Heimler et al., 2015, for a similar proposal using an overt attention paradigm). Studies on the hearing population suggest that gaze processing relies on an extensive network of brain areas that include regions dedicated to gaze analysis, such as the right superior temporal sulcus (Kingstone, Tipper, Ristic, & Ngan, 2004) or bilateral parietal regions, as well as extrastriate visual cortices (Engell et al., 2010; Hietanen, Nummenmaa, Nyman, Parkkola, & Hamalainen, 2006; Nummenmaa & Calder, 2009; Tipper, Handy, Giesbrecht, & Kingstone, 2008). The present behavioral results may suggest that connections (both bottom–up and top–down) between higher brain regions involved in gaze processing and extrastriate visual cortices may be strengthened as a consequence of early deafness. Future studies could directly address this idea. Taken together, the present findings highlight the necessity to embrace an approach that aims at unraveling the interplay between top–down and bottom–up brain modifications in experience-dependent plasticity exerted by bilateral deafness. Such an approach should consider the wholesale reorganization of multiple brain networks, thus overcoming the limitation of taking into account only the modifications occurring in sensory systems.

Implications for Orienting to Social and Nonsocial Cues

The present findings have two relevant implications for the literature on GCE. First, they provide evidence that gaze cuing can be controlled to some extent, thus implying that gaze cuing is not an entirely automatic phenomenon. Evidence in favor of the automaticity of the GCE originated from a variety of studies (see Galfano et al., 2012 for review): GCE has been documented when gaze-cue stimuli are processed outside conscious awareness (Sato, Okada, & Toichi, 2007), when the gaze shift is conflicting with other cue stimuli in the scene (Kuhn & Kingstone, 2009), or when a concomitant secondary task has to be carried out (Law, Langton, & Logie, 2010). Our main finding that deaf adults do not show GCE in RTs, argues against the unavoidable automatic nature of this form of attentional-orienting. Our result, instead, opens the possibility that even the automaticity of a potent social cue can be substantially resisted (e.g., Böckler et al., 2011; Ohlsen et al., 2013).

The second implication concerns the ongoing debate on whether or not the effects on performance elicited by arrow and gaze cues are driven by similar underlying attentional processes (Galfano et al., 2012; Ristic et al., 2007; Stevens et al., 2008). Our findings show that arrow cuing can be observed in the absence of GCE, ultimately suggesting that these two cue-types may tap on partially different spatial-orienting processes (Marotta, Lupiáñez, Martella & Casagrande, 2012) and may rely on partially distinct brain networks (Engell et al., 2010; Hietanen et al., 2006; Kingstone et al., 2004).

Conclusions

Taken together, the results of the present study show that deaf adults can resist gaze cuing more than hearing controls. This result ultimately suggests that the susceptibility to gaze cues can be reduced. This manifestation of cognitive control may reflect an acquired ability of deaf people to maintain their visual spatial attention focused on faces. Such behavior may in turn improve their social and communicative interactions. This novel finding also emphasizes the importance of considering top–down together with bottom–up brain modifications when aiming at unraveling experience-dependent plasticity exerted by bilateral deafness—or more generally plasticity exerted by any form of sensory deprivation.

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