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Environmental learning of social cues: evidence from enhanced eye-gaze cueing in deaf children

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Running head: GAZE CUEING IN DEAF CHILDREN

ABSTRACT

The susceptibility to gaze cueing in deaf children aged 7 to 14 years old (N=16) was tested using a non-linguistic task. Participants performed a peripheral shape-discrimination task, while uninformative central gaze cues validly or invalidly cued the location of the target. To assess the role of sign language experience and bilingualism in deaf participants, three groups of age-matched hearing children were recruited: bimodal bilinguals (vocal and sign-language, N=19), unimodal bilinguals (two vocal languages, N=17) and monolinguals (N=14). Although all groups showed a gaze-cueing effect and were faster to respond to validly than invalidly cued targets, this effect was twice as large in deaf participants. This result shows that atypical sensory experience can tune the saliency of a fundamental social cue.

Gaze direction is one of the most important social cues in human interactions. It is the basis of joint attention mechanisms and plays a fundamental role in language acquisition. Adults and children tend to automatically shift attention towards the direction of gaze and this behavioural reaction has been extensively investigated using a simple cue-target paradigm. In this paradigm the central cue is a schematic or more natural picture of a face with diverted gaze looking to the left or right (Driver et al., 1999; Friesen & Kingstone, 1998, 2003; Khurana, Habibi, Po, & Wright, 2009; Quadflieg, Mason, & Macrae, 2004; Tipples, 2005). Participants are asked to detect or discriminate a peripheral target, appearing either on the side indicated by the eye-gaze (cued location) or on the opposite side (uncued location). When gaze direction correctly cues the side of the target location, participants are faster compared to when the gaze cues the incorrect side. This difference in performance can be measured in response times or accuracy and has been termed the gaze-cue effect (GCE). Notably, the GCE emerges when gaze direction is entirely unpredictive of the position of the upcoming target (Friesen & Kingstone, 1998; Tipples, 2005), and even when it is counterpredictive with respect to target location (Driver et al., 1999; Friesen, Ristic, & Kingstone, 2004; Galfano et al., 2012).

Although the GCE is a very robust phenomenon, its absence has been noted in populations with atypical pattern of development. For example, a lack of gaze-cueing has been reported in high-functioning autistic individuals (Ristic et al., 2005), subclinical individuals who rated high on the autism quotient (Bayliss & Tipper, 2005), and participants with Asperger's syndrome who do not show gaze-induced inhibition of return (Marotta et al., 2013). The absence of social cuing in these populations points to an innate development of an eye-gaze direction module in the brain. However, it has been argued (e.g., Corkum &

Moore, 1998; Moore & Corkum, 1994; Triesch, Teuscher, Deák, & Carlson, 2006; Kuhn et al., 2015) that typical development of gaze cueing may also rely on learning multisensory associations between gaze related cues and environmental contingencies (e.g., observing a gaze shift and detecting the presence of a sound at the gazed location).

An example in which reduced effectiveness of gaze cues can be selectively attributed to the interactions with the environment was reported by Heimler and colleagues (2015). In their work they investigated attentional performance of deaf adults in a gaze cueing paradigm and observed that this population responded equally fast to the target regardless of whether gaze-direction was validly or invalidly pointed towards the target (Heimler et al., 2015). Thus, like high-functioning autistic individuals, deaf adults did not show a GCE, yet unlike the case of autistic individuals this lack of gaze-cueing was unlikely the consequence of an innate disability in processing social cues. Heimler and colleagues (2015) interpreted this result as evidence of an acquired control strategy. In order to reduce distractibility during interpersonal interactions, deaf observers learn to resist gaze-cues deaf adults; this can be considered an adaptive development that takes a life-time of learning. For deaf individuals, face-to-face contacts are essential in linguistic communications, both when processing oral language through lip-reading, and when processing sign-language. Indeed, evidence suggests that deaf signers preferentially fixate on the face during signed conversation (e.g., Agrafiotis, Canagarajah, Bull, & Dye, 2003; Emmorey, Thompson, & Colvin, 2009; Muir & Richardson, 2005). In this respect, changes in the interpretation of social cues in the deaf population may stem from their use of a language that is perceived through vision and the associated adaptive experiences with the environment, rather than developmental brain anomalies.

The present study set out to investigate the malleability of social attention in deaf children (Corina & Singleton, 2009). Previous studies have examined gaze-following in deaf children to investigate the mechanisms used by sign language dyads (mother-child, or teacher-child) to achieve joint attention through vision alone (e.g., Crume & Singleton, 2008; Lieberman, Hatrak, & Mayberry, 2014). In this work, following gaze or head-movements was behaviourally relevant for the child, as it helped extracting meaningful information from the environment. Here, we tested the impact of gaze-cueing in directing children's spatial attention, in a context in which participants are explicitly informed that gaze-cueing is entirely task irrelevant. If the reduced GCE in deaf adults emerges as result of a progressively acquired adaptive strategy, as proposed by Heimler and colleagues (2015), this must be learned through experience and might not exist in young deaf children. Supporting evidence for this hypothesis has been found in a selective attention task with digits tested on deaf and hearing children (Dye & Hauser, 2014). Unlike older deaf and hearing children (9-13 years old), the younger deaf group (6-8 years old) performed poorly in the selective attention task, revealing a greater difficulty in controlling visual attention resources. Therefore, we predicted that in the present study deaf children may show stronger gaze cueing effect compared to their hearing peers.

To test this hypothesis, we recruited one group of deaf children (aged 7 to 14 years old; mean age 9 years old) and three groups of age-matched hearing controls. All deaf children were bilinguals and attended mainstream schools that used special teaching curricula in which teaching occurred in both Italian and Italian Sign Language (Lingua dei Segni Italiana, LIS). The first control group comprised hearing bimodal bilingual children who were enrolled in the same schools and attended the same classes as their deaf peers. The second and the third control group comprised unimodal bilingual children (i.e., speakers of two languages) and monolingual children recruited from a regular mainstream school that did not have sign language in their curricula.

Based on the idea that early deafness in young children drives differential gaze-cuing performance, we developed two hypotheses. First, young deaf children might perform similar to deaf adults and be less susceptible to gaze-cue information compared to the three control groups. This result would replicate the performance of the deaf adults (Heimler et al., 2015) and would suggest that deafness might be related to decreased sensitivity to this type of social cue from early on in development. Alternatively and second, young deaf children might show enhanced gaze-cuing compared to the three other control groups. This pattern would suggest an enhanced sensitivity to this type of social information for young deaf observers.

METHODS

Participants

Four groups of children were recruited for the study (see Table 1). One group of deaf children with bilingual experience (Italian and Italian Sign Language, N=16) and three groups of hearing children, with either bimodal bilingual experience (N=19), unimodal bilingual experience (N=17), or monolingual experience (N=14). For all participants, we collected an anamnestic questionnaire, completed by their parents, that included questions aimed at reconstructing the linguistic history of the children and their families. Each participant was tested also in the Raven Coloured Progressive Matrices (CPM) as a test of non-verbal intelligence and the Corsi test (both forward and backward; De Renzi and Nichelli, 1975) as a test for visuo-spatial memory (see Table 1). For all participants criteria of inclusion in the study were (1) normal or correct to normal vision, (2) no previous history of neurological or psychiatric diseases, (3) scores within the normal range for the Corsi test and above the IV class for the Raven CPM. Groups did not differ in the Corsi test scores (forward: $F(3,54) = 0.69$, $p > 0.05$; backward: $F(3,62) = 2.38$, $p > 0.05$). In the Raven CPM a between-group difference emerged ($F(3,62) = 3.64$, $p = 0.02$), caused by higher percentiles for bimodal than unimodal bilinguals ($p = 0.02$ on Tukey post-hoc test; all other between groups comparisons p-values > 0.1). The study was approved by the Ethical Committee of the University of Trento (protocol 2012-020).

< Table 1 >

All participants were recruited after an agreement with the directors of the schools and only the children whose parents or legal tutors signed the informed consent were included in the study. Deaf and hearing bimodal bilingual children were recruited from two state schools (Istituto Comprensivo di Cossato, Biella, Italy; Scuola dell'Infanzia Primaria, 173° Circolo Didattico, Roma, Italy). Both these state schools use both Italian and Italian Sign Language (LIS) for education. Specifically, sign language interpreting is present for all subjects taught in Italian, for the benefit of both deaf and hearing students. In addition, some of the weekly activities are provided only in sign language. Children attending these school attended elementary classes of the 3rd Grade (N=15), 4th Grade (N=3), 5th Grade (N=11) or 7th Grade (N=6). Hearing monolingual and hearing unimodal bilingual children were recruited from two classes of a state school (Istituto D'Azeglio, Verona). These two groups attended elementary classes of the 3rd Grade (N=17) or the 5th Grade (N=14).

Anamnestic characteristics of deaf participants are reported in Table 1S. All deaf participants experienced profound to moderate deafness, acquired deafness in the first 3 years of life (5 were congenitally deaf; for the others, mean age of detection in months was 8.0±10.3). All deaf participants except three had at least one deaf parent, 13 used one or two hearing aids, none used a cochlear implant. They all knew and used LIS: 10 were native signers and learned sign language at home, the remaining six acquired it between 2 and 12 years of age either at home, at school or attending speech-therapy using a bimodal bilingual approach. All but one reported that LIS was their preferred language, and parents rated the children's confidence in LIS on a 5-point scale in the range between confident to extremely confident (4.6±0.6). A similar rating referred to Italian revealed less confidence overall (3.3±0.9, $t(15) = 5.37$, $p < 0.001$). Nonetheless, all children were enrolled in speech therapy, attended a main stream school in which teachers (most of them hearing) use predominantly Italian to convey school contents, and reported reading Italian 1.1±0.8 hours/day an average.

Hearing participants in the bimodal bilingual group were born from hearing families and spoke Italian as mother tongue (see Table S2). They learned LIS in the very first years of school (age of first exposure to LIS in years: 3.8±1.3) and used it daily or once a week, at school, with friends, and occasionally with family members. When asked which language they would use when meeting deaf people speaking LIS and Italian, all reported they would approach them with LIS or LIS/Italian. The children's confidence in LIS ranged between confident to very confident (3.6±0.6). A similar rating referred to Italian was between very confident and extremely confident (4.3±0.8, $t(18) = 3.09$, $p = 0.006$).

Hearing participants in the unimodal bilingual group had at least one of the two parents speaking a foreign language (Romanian, Serbo-Croatian, Albanian or Urdu; see Table S3). All children regularly spoke the foreign language at home, and mostly reported it as mother tongue. The children's confidence in Italian ranged between very confident and extremely confident (4.8±0.4).

Stimuli, apparatus and procedure

In the experiment participants responded to a visual shape in the periphery, presented shortly after the appearance of a central face with straight-ahead or diverted gaze (same paradigm as in Heimler et al., 2015). The face stimulus was taken from a face database (Oosterhof & Todorov, 2008). The two directional gaze images (gaze left and right) were created from the straight-ahead gaze (see Figure 1) using Photoshop.

The trial started with the presentation of a white fixation cross on a black background for 500 ms. This was followed by the presentation of male face gazing straight ahead with the nose in the position of central fixation for 1000 ms. In the Neutral blocks this stimulus remained unchanged; in the Gaze-cue blocks, a second face was presented with the eyes directed either to the left or to the right. The latter condition resulted in apparent motion of the eyes that was perceived by all participants as an eye-gaze shift. Importantly, leftwards and rightwards gaze shifts occurred with equal probability. Regardless of the experimental block (i.e., Neutral or Gaze-cueing), after an inter-stimulus-interval of either 250 or 750 ms two lateralised stimuli appeared at symmetrical peripheral locations on either side of the face (400 pixels from centre of screen). Stimuli were diamond shapes (pixels covered): one missed the upper or lower portion (target), the other was a whole diamond (distractor). Target and distractor were delivered simultaneously to avoid automatic capture of attention to one or the other side of fixation. Both peripheral stimuli and the face remained on screen until response, or up to 2000 ms. 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. Gaze-direction, target-position, target-response and SOA were all randomly varied within blocks of trials.

< Figure 1 >

During the visual discrimination experiment, participants sat at a table in front of a monitor of 34x27 cm with a resolution of 1024x768 pixels, at a viewing distance of approximately 55 cm. Their head was not restrained by any means and they used a keyboard to respond with their right hand. The experiment consisted of 2 sessions: one Gaze-cueing session of 8 blocks, and one Neutral session of 2 blocks. Each block comprised 32 trials. One practice block of 12 trials preceded each of the sessions. Participants were instructed to keep their gaze in the central area of the screen and press the up-arrow key with their index finger when the diamond missed its upper tip, or the down arrow key with their thumb when it missed its lower tip. All participants were instructed to respond as fast and as accurately as possible. Participants received a feedback in the centre of the screen after each trial (a minus sign when the answer was incorrect, a plus sign when it was correct); they also received feedback on mean accuracy and RTs at the end of each block. For this experiment, we used a Dell laptop as the main computer. Data are available at: osf.io/y3srk.

All experiments were conducted in a quiet and dedicated room, inviting each child out of the classroom during school hours. The experimental session always began with the visual discrimination experiment, followed by the Corsi test and the Raven Coloured Progressive Matrices test. Participants were allowed to take breaks when needed and the whole session lasted approximately 45 minutes.

RESULTS

Neutral condition

To compare neutral conditions between groups we entered response times in the block in which no gaze cueing was presented in an Analysis of Variance (ANOVA) with stimulus-onset asynchrony (SOA, 250 or 750 ms) as within-participant variable and Group (hearing monolingual, hearing unimodal bilingual, hearing bimodal bilingual, deaf bilingual) as between-participant variable. For analyses on response times, only correct trials were considered (94.1% of total trials). Trials in which a response was anticipated (i.e., RTs< 100 ms, 1% of all trials), a response was slower than 2.5 standard deviation from the participants mean (1%) and trials without a response (1%) were excluded.

The analysis on RTs revealed no main effect or interaction (all F-values < 1.3). Adding age (in months) as covariate in the analysis revealed a main effect of this variable ($F(1,64) = 21.54$, $p < 0.0001$), caused by the inverse relationship between age and response time: the older the child the faster the response time ($r = -0.48$, p < 0.0001). An effect of age on saccadic RTs during a gaze-cueing task has been previously been observed comparing children in three age groups (3-5, 6-7 and 8-10 years old; Gregory, Hermens, Facey, & Hodgson, 2016). However, no interaction between the covariate and group emerged, indicating that this negative correlation was detected for all groups. A similar analysis on accuracy also revealed no main effect or interaction (all F-values < 1) and no correlation with age.

Gaze cueing condition

To compare gaze cueing effects between groups we entered response time for each participant in an ANOVA with Validity and SOA as within-participant factor and Group as between-participant factor. The analysis on RT revealed a main effect of validity, $F(1, 62) = 49.31$, $p < .001$, $\eta_p^2 = .44$, caused by longer RTs for invalid (mean = 973 ms, SD = 20) compared to valid conditions (mean = 925 ms, SD = 19). There was also a main effect of SOA, $F(1, 62) = 53.12$, $p < .001$, $\eta_p^2 = .46$, caused by faster RTs for long (mean = 928 ms, SE = 19) compared to short SOAs (mean = 970 ms, SE = 20).

Most importantly, the interaction between Validity and Group was significant, $F(3, 62) = 4.91$, $p = .004$, $\eta_p^2 = .19$. As can be seen in Figure 2, the interaction was caused by the gaze cue effect being larger in deaf participants (mean = 94 ms, SE = 13) compared to all other groups of children (hearing monolingual: mean = 26 ms, SE = 21; hearing unimodal bilingual: mean = 29 ms, SE = 12; hearing bimodal bilingual: mean = 44 ms, SE = 10; $p < 0.01$ on Tukey HSD post-hoc test). Adding age (in months) as covariate in this analysis did not alter the pattern of results, nor revealed significant changes in the GCE as a function of Age in either of the groups. To compare RTs of valid and invalid conditions across groups with respect to the neutral condition we also computed for each participant the difference between valid and invalid RTs (collapsed across SOAs) and the corresponding value in the neutral condition. A mixed ANOVA with experimental condition (invalid or valid; within-participants) and group as variables revealed a 2-way interaction, $F(3,61) = 3.83$, $p = 0.014$, caused by larger difference between conditions specifically in deaf participants.

< Figure 2 >

A similar ANOVA conducted on accuracy data was comparable to the pattern of results observed for response times (see Figure 3). The analysis revealed a main effect of validity, $F(1, 62) = 4.84$, $p = .032$, $\eta_p^2 = .07$, caused by lower accuracy in invalid (mean = 94%, SE = 1%) compared to valid trials (mean = 96%, SE = 1%) overall. There was also a main effect of SOA, $F(1, 62) = 4.75$, $p = .033$, $\eta_p^2 = .07$, caused by better performances for long (mean = 95%, SE = 1%) than short SOAs (mean = 94%, SE = 1%). However, unlike for the RT measure, there was no reliable interaction between Validity and Group, $F(3, 62) = 1.86$, $p = .146$, $\eta_p^2 = .08$. As for response times, adding Age as a covariate in the analysis did not did not alter the pattern of results, nor revealed significant changes in GCE as a function of Age in either of the groups.

To explore potential relationships between non-verbal intelligence and the Gaze Cueing Effect we conducted two separate non-parametric correlations between the class obtained in the Raven matrices and the GCE measured in RTs and accuracy. Neither of these correlations reached significance. Similarly, none of the measures obtained in the Corsi test correlated with the measures in RTs and accuracy.

DISCUSSION

Deaf children showed enhanced gaze-cuing compared to the control groups of hearing children. This result emerges clearly in RT, with a supporting numerical trend observed also in accuracy. While the magnitude of the GCE effect in RTs for hearing controls was in line with previous reports using similar paradigms in children of similar age – 31 ms in the present study compared to 33 ms reported for 9-12 years old (Jingling, Lin, Tsai, & Lin, 2015) and 25 ms reported for 9-10 years old (Lin, Jingling, & Lin, 2012) – the GCE measured in deaf children was three times as large with a mean of 94 ms. The GCE in deaf children was also much larger compared to even younger hearing children – 40 ms in 6-8 years old (Jingling et al., 2015) and approximately 50 ms in 4-6 years old (Ristic, Friesen,

& Kingstone, 2002; see also Table 1 in Jingling et al., 2015). Independent of deafness, the effect of gaze-cue decreases with age such that young children tend to show stronger gaze-following than adults (Gregory et al., 2016; Jingling et al., 2015; Kuhn et al., 2011; Neath, Nilsen, Gittsovich, & Itier, 2013). Kuhn et al. (2015) have linked the attenuated response to social gaze to the growing ability to inhibit reflexive responses and the development of cognitive control (Dempster, 1992). Finding that deaf children are less able to ignore the gaze-cue, might suggest that they may be in the process of learning how to best control the allocation of their selective attention resources in daily life (Dye & Hauser, 2014). An alternative possibility is that deaf children show enhanced gaze cueing because they are more sensitive to this type of social information, increasing the relative saliency of this specific cue. The continuous monitoring of the environment through vision, may give greater saliency to external cues – either social or non-social – for deaf compared to hearing children (Lieberman, Hatrak, & Mayberry, 2011, 2014). While adults may profit from reduced susceptibility to gaze shifts, prompt orienting to gaze may help deaf children interpret the social environment beyond linguistic interactions alone (e.g., in playing contexts). Whichever the mechanism underlying the observed enhanced gaze following in young deaf children, it seems that the development of deaf children is characterized by two concurrent phenomena: (1) changes in bottom-up processing driving perceptual enhancements (e.g., enhanced processing for stimuli at the visual periphery, as in Dye et al. 2009; or increased sensitivity to gaze shifts as in the present study) (2) changes in top-down control to adequately deal with the modified perceptual functions, i.e., improvement in cognitive control.

The present results emphasize the importance of experience in the processing of gaze as social cue. Automatic and reflexive orienting in response to gaze has been taken as evidence for the existence of innate and hard-wired eye gaze detectors in the brain which supports an innate saliency for this crucial social cue (Baron-Cohen, 1995). However, researchers have also remarked the importance of learned associations from the environment. This perspective is based on the idea that infants learn that monitoring their caregiver's direction of gaze allows them to predict the locations of interesting objects or events in their environment (Moore & Corkum, 1994). Accordingly, gaze-cueing is the result of flexible associative learning processes between a salient biological cue and multisensory environmental contingencies (Corina & Singleton, 2009; Corkum & Moore, 1998; Moore & Corkum, 1994; Triesch, Teuscher, Deák, & Carlson, 2006). Environmental learning accounts of cueing effects posit that other socially salient cues can develop through development. For instance, it has been shown that finger pointing can trigger covert attention orienting, even when the hand-cue is completely non-predictive of target location (Ariga & Watanabe, 2009; Gregory & Hodgson, 2012; Tomonaga & Imura, 2009; see also, Daum, Ulber, & Gredebäck, 2013). In fact, a recent study on 137 hearing children (aged 3-10 years old) found stronger effects of hand-pointing compared to eye-gaze cueing across all age ranges (Gregory et al., 2016). In addition, hand pointing may be a stronger cue for attention also in hearing infants (Butterworth & Itakura, 2000; Deák, Walden, Yale Kaiser, & Lewis, 2008). In future studies it might be interesting to examine whether similar deafness-related enhancements emerge for other salient social cues, such as finger pointing, possibly hypothesising a more prominent role of sign language experience.

While the potential influence of bilingualism on performance was not the primary focus of the present study, our data are able to speak to this issue given that we tested three different hearing control groups each with distinct language skills (i.e., monolingual, unimodal bilingual and bimodal bilingual). On the one hand, based on the idea that bilingual children might be more sensitive to social cues (Yow et al., 2017, Yow & Markman, 2015), one would have predicted a larger gaze-cue effect for bilingual children compared to monolingual children. On the other hand, work on bilingualism and cognitive control using the flanker task show that bilingual children are better able to inhibit irrelevant distracting information compared to the monolingual children (Bialystok, 2015). Accordingly, bilingual children would be predicted better able to ignore the irrelevant information of the gaze-cue and show a smaller gaze-cue effect. However, our results did not support either of these two hypotheses. We found no modulation of GCE related to bilingualism, regardless of whether it was unimodal or bimodal bilingual experience. This suggests that the increased GCE in deaf children is likely due to the social experience of deafness, not sign language experience. However, a potential limitation here is the degree to which the ability of sign-language in our bimodal bilingual children was equivalent of that of deaf children. The pattern of LIS use of these hearing participants was occasional, as it was used mostly in the school and with friends, but not with their hearing parents. Moreover, reports of self-confidence in LIS ability might not be an accurate proxy for actual measurement of LIS skill. A better comparison group of hearing LIS/Italian bimodal bilinguals would have been hearing children raised by deaf parents and native users of LIS (i.e., Child Of Deaf Adults, CODAs). The ability in sign-language in CODAs and deaf children would likely be more evenly matched, compared to the current comparison group presented the paper. Consequently, we cannot rule out a potential role for sign-language in the increased GCE for deaf children. Moreover, it remains an empirical question whether other tasks – more difficult and/or reliant on non-social cues – could reveal between group differences related to the unimodal vs. bimodal bilingual experience.

In conclusion, the study of deaf children offered a unique opportunity to assess the contribution of environmental factors in gaze following. Because neuroplastic changes in this group are induced by deafness and are not the result of atypical brain structure at birth, the observed enhanced eye-gaze cueing in young deaf observers is compatible with the environmental learning perspective. Importantly, this does not imply that this mechanism is not ultimately based on innate modules. The observed enhancement observed in young deaf children might be a combination of a predisposition to attend to faces, and learned associations between social cues and attention orienting responses that for the individual proved rewarding and adaptive (Corkum & Moore, 1998; Gregory et al., 2016; Triesch et al., 2006). Critically, given that this enhancement appears to dissipate in deaf adults (Heimler et al., 2015), it can be hypothesised that certain associations change during development.

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Table captions

Table 1. Characteristics of the groups and average performance in the Raven Coloured Progressive Matrices (CPM) and Corsi test. The Raven CPM scores are clustered in the following way: Class I (score equal or above the 95th centile of his/her age range), Class II (score equal or above the 75th centile; if equal or above 90, then Class II+), Class III (score between the 25th and 75th centile; if equal or above 50, then Class III+; if below 50 then III-), Class IV (score equal or below 25th centile); Class V (score below 5th centile). Average Raven CPM scores are also provided. The Corsi Forward scores were corrected according to Orsini et al. (1987). However, no such correction was available for Corsi Backwards hence raw scores are reported.

Figure captions

Figure 1. Sequence of the experimental trial.

Figure 2. (a) Response time in milliseconds and (b) percent of correct responses to valid and invalid central gaze-cue cues. The gaze-cue effect is calculated as the difference in performance between valid and invalid trials, for (c) RTs and (d) accuracy. Circles indicate single participants. Filled circles indicate those deaf participants who were native signers.

Table 1.

	N	Gender	Age (Years; Months)			Raven Progressive Matrices Score		Raven Progressive Matrices (Class)						Corsi test * Forward		Corsi test * Backward	
			Mean	SD	Range	Mean	SD	I	II+	II	III+	III	III-	Mean	SD	Mean	SD
Deaf bilingual	16	8 F / 8 M	10;0	1;9	(7-14)	82,3	18,0	6	5	1	2	2	0	4,3	1,1	4,2	1,2
Hearing bilingual (bimodal)	19	11 F / 8 M	9;8	1;4	(8-12)	87,6	11,5	8	6	1	3	0	1	4,5	0,7	5,0	1,0
Hearing bilingual (unimodal)	17	8 F / 9 M	9;3	1;0	(8-11)	66,8	24,6	2	3	3	6	0	3	4,1	0,8	4,4	0,9
Hearing monolingual	14	7 F / 7 M	9;7	1;1	(8-10)	70,7	29,1	4	4	0	3	0	3	4,5	1,1	5,0	1,0

Figure 1.

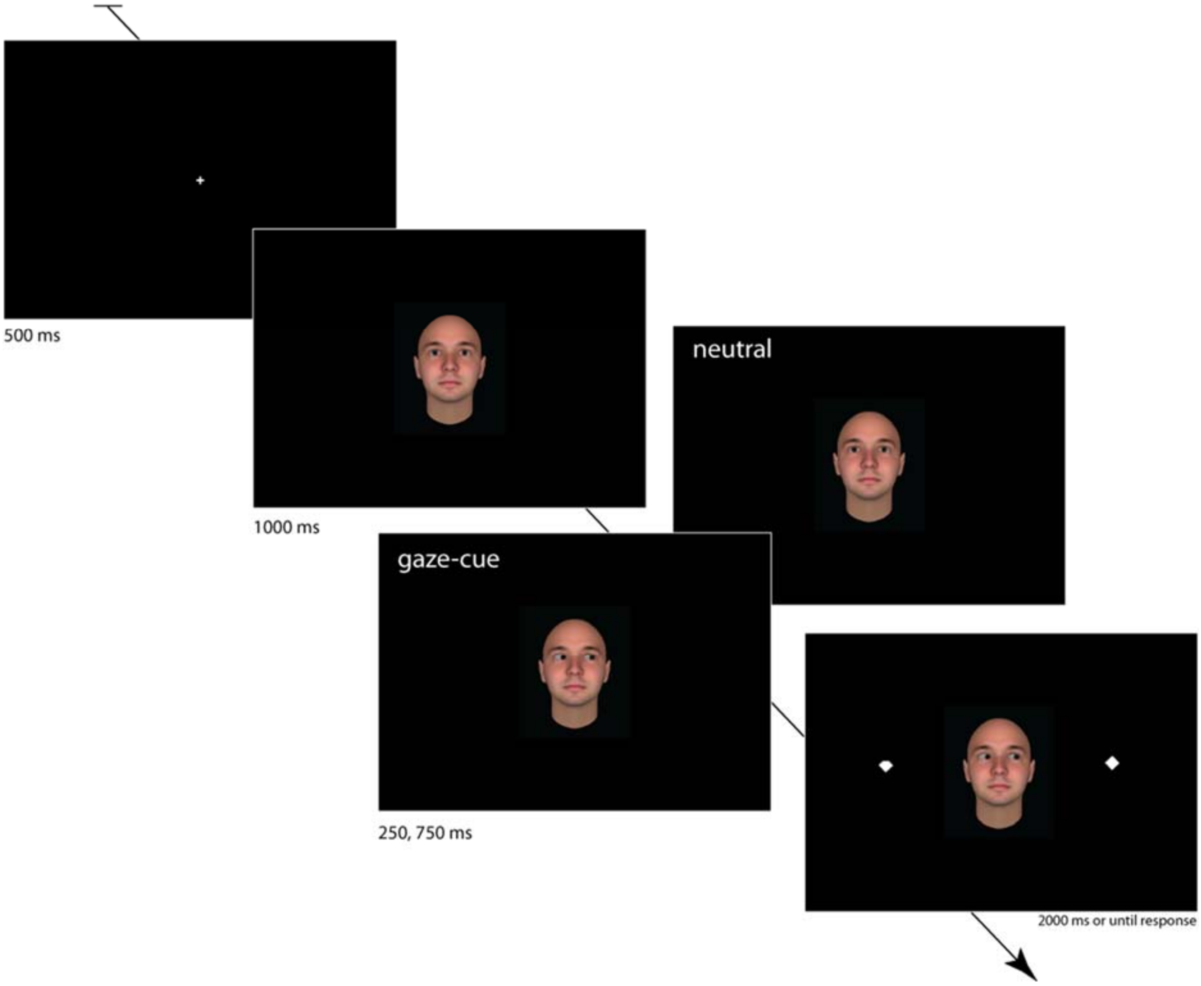
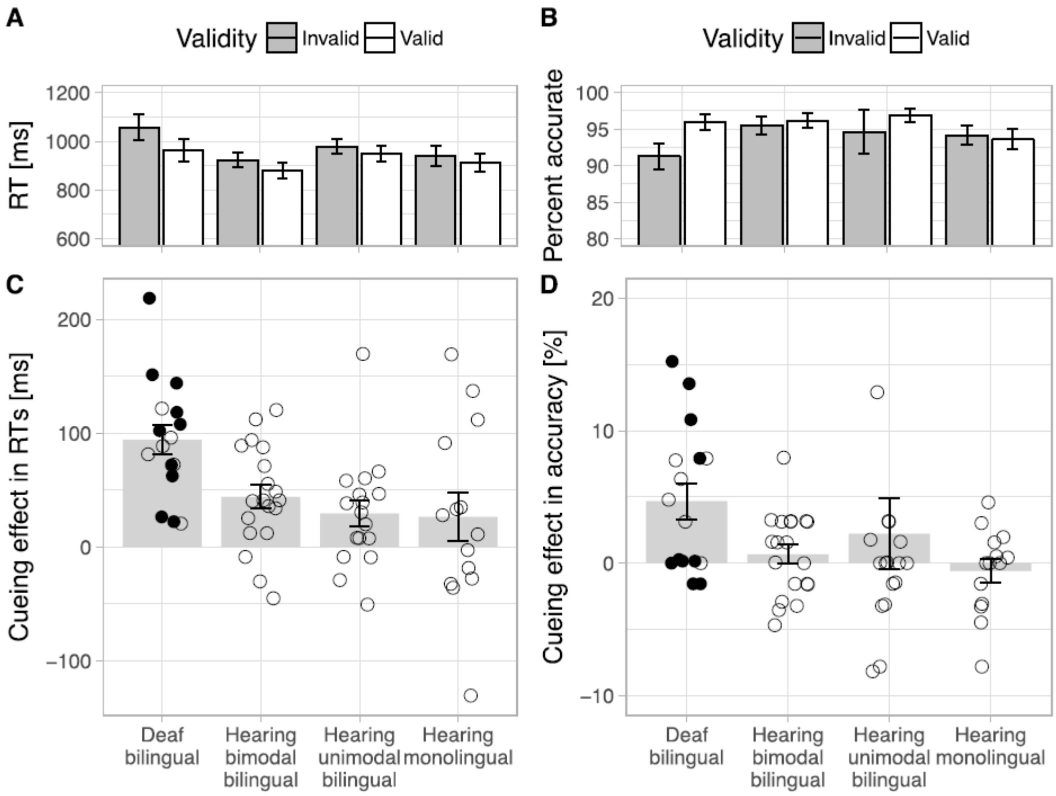

500 ms
1000 ms
neutral
gaze-cue
250, 750 ms
2000 ms or until response

Figure 2.


A
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C
Cueing effect in RTs [ms]
200
100
0
−100
D
Cueing effect in accuracy [%]
20
10
0
−10
Deaf bilingual
Hearing bimodal bilingual
Hearing unimodal bilingual
Hearing monolingual