Brain & Language 129 (2014) 1–6

Contents lists available at ScienceDirect

Brain & Language

journal homepage: www.elsevier.com/locate/b&l

Short Communication

Cerebral lateralization for language in deaf children with cochlear implantation

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ARTICLE INFO

Article history:
Accepted 11 December 2013
Available online 24 January 2014

Keywords:
Cerebral language lateralization
Functional transcranial Doppler ultrasonography
Deaf children
Cochlear implantation
Language outcome

ABSTRACT

Functional Transcranial Doppler ultrasonography (fTCD) was used to investigate the effects of early acoustic deprivation and subsequent reafferentation on cerebral dominance for language in deaf children provided with Cochlear Implantation (CI). Twenty children with CI (13 in right ear and 7 in left ear) and 20 controls matched for age, sex and handedness were administered a fTCD animation description task. Left hemisphere dominance for language with comparable mean Laterality Indexes (LIs) was found in children with CI and controls; right-ear implanted subjects showed cerebral activation controlateral to implanted ear more frequently than left-ear implanted ones. Linguistic proficiency of CI recipients was below age expectation in comparison to controls; language scores did not significantly differ between children with left and right LI, whereas both age and side of implantation were significantly related to language outcome. Theoretical implication and potential clinical application of fTCD in CI management are discussed.

1. Introduction

One of the central issues of developmental neuroscience is the understanding of how highly specialized functions, such as language, are biologically constrained and to which extent they depend on and can be modified by environmental inputs.

In the case of congenital deafness, there is evidence from animal and human studies that early auditory deprivation leads to an atypical organization of auditory nervous system (Gilley, Sharma, & Dorman, 2008; Kral & Sharma, 2012). Profound congenital deafness may also alter the pattern of cerebral asymmetry for language that has been shown to favor the left hemisphere in the first months of life in typically developing infants with normal hearing (Dehaene-Lambertz et al., 2006).

Results of earlier studies aimed at determining whether deaf children develop the same pattern of hemispheric asymmetry for language as hearing children (Kelly & Tomlinson-Keusey, 1981) revealed an inverse laterality pattern in the two groups. In fact, in a visual half-field presentation task of words or letters, deaf subjects showed a left visual field advantage (suggestive of right hemisphere dominance for linguistic stimuli), whereas hearing subjects showed a right visual field advantage (indicative of a left hemisphere dominance). In a study by Marcotte and Morere (1990) cerebral lateralization for speech in right-handed normal hearing and deaf adolescents was assessed using a dual-task paradigm. Subjects with normal hearing at birth and deafness acquired after 3 years of age displayed left hemispheric dominance for speech production, whereas children with both congenital and early acquired deafness (onset 6–36 months) showed an atypical cerebral representation. These results support the hypothesis that exposure to adequate environmental stimulation during a critical developmental period may be needed to activate left hemispheric dominance for speech. Nevertheless, according to D'Hondt and Leybaert (2003), hemifield paradigm studies do not provide clear empirical evidence of left hemisphere advantage for written words by deaf children, because lateralization effects may vary in relation to the semantic or phonological nature of the task.

In the last twenty years with the advent of Cochlear Implant (CI), deaf children can benefit, from those critical sensory inputs that are necessary for developing a 'listening brain'. Restoring auditory input through monoaural cochlear implantation in children who are born profoundly deaf, offers a unique opportunity for investigating the role of stimulus-dependent mechanisms in the asymmetrical organization of neurofunctional circuitries

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0093-934X/$ - see front matter
http://dx.doi.org/10.1016/j.bandl.2013.12.002

sub-serving language and on the variables that influence these processes, such as CI side, age at implantation and language experience before CI. As reported by several authors (Hugdahl, 2005; Kimura, 1967; Langers, van Dijk, & Backes, 2005; Woldorff et al., 1999), although in the normal hearing population, both auditory cortices receive sensory input from both ears, they are excited most strongly by stimulation of the contralateral ear. In the case of deaf children with unilateral auditory reafferentation, the question on the effects of right- or left-sided CI on the hemispheric dominance for language has never been clearly settled.

Direct measures of cerebral language lateralization by means of classical non-invasive methods such as the dichotic listening paradigm and functional Magnetic Resonance Imaging (fMRI) are not feasible in deaf subjects with CI: for the former, since most patients are monaurally fitted with CI, and for the latter, because high MRI magnetic fields ($\geqslant$1.5 T) may interfere with the magnetic components of the implant. In the past decade neuroimaging with Near Infrared Spectroscopy (NIRS) has shown to be a potential complement to the above objective techniques but application in deaf subjects with CI has just started (Sevy et al., 2010). Some indirect evidence on cerebral language lateralization of implanted subjects has been recently provided by Gilley et al. (2008), who used high density EEG recordings to estimate generators of the P1 response.

In recent years, functional transcranial Doppler ultrasound (fTCD) has been proposed as a reliable alternative method for measuring cerebral lateralization during speech in both adults and children. This technique assesses cerebral lateralization by comparing changes in mean blood flow velocity in the middle cerebral arteries (MCAs) during domain-specific tasks. fTCD has been shown to be highly correlated with classic measures of hemispheric lateralization such as the Wada test (Knecht et al., 1998) and fMRI (Deppe et al., 2000; Somers et al., 2011). fTCD has good temporal resolution and provides continuous information about event-related changes in cerebral blood flow associated with functional cortical activation (Deppe et al., 2000); it is non-invasive and is particularly suitable for children (Bishop, Watt, & Papadatou-Pastou, 2009; Haag et al., 2010). Furthermore, Bishop et al. (2009) has created an fTCD animation description task designed to be particularly engaging for children. This paradigm has shown good split-half reliability in children and in adults, and a highly significant correlation with other fTCD tasks, such as word generation and picture description tasks.

From a theoretical point of view, the study on cerebral language organization in deaf children after acoustic reafferentation could provide insights into the plasticity of the auditory system and the neural substrates underlying language processing. From a clinical point of view, fTCD may prove to be a valuable technique in assessing cerebral language processing in deaf children with CI, and could help clinical teams in CI management.

The aim of this study was three-fold:

– to evaluate whether fTCD is suitable for deaf children provided with CI;
– to investigate the effects of early severe acoustic deprivation and subsequent reafferentation on patterns of hemispheric dominance for language in comparison with healthy peers;
– to evaluate whether hemispheric dominance for language varies in relation to CI side, in terms of fTCD activation contra-or ipsilateral to the ear implanted.

In order to avoid any confounding effect related to different communication modes, only children with exclusively audioverbal training participated in the study. Cerebral lateralization was assessed by fTCD using the animation description task developed by Bishop et al. (2009). Participants were 20 deaf children fitted with CI (13 in right ear and 7 in left ear) and 20 controls matched for chronological age, sex and handedness. For each subject a Laterality Index (LI) was computed offline, using AVERAGE software and analyzed on the basis of age at implant, ear implanted and language outcome.

2. Results

2.1. fTCD data

The number of accepted epochs did not differ between subjects with CI (M 22.9, SD 6.2; range 13–30) and controls (M 23.8, SD 6.7; range 14–30).

Fig. 1 plots mean activation values, averaged over all epochs for right and left MCAs in deaf and control subjects. No statistically significant difference was found between CI recipients and controls in the measurements taken by the right (CI M −0.82, SD 2.43; controls M −0.23, SD 3.17; $t = -0.85$, $p = 0.45$) or left probe (CI M 0.14, SD 1.77; controls M 0.30, SD 2.74; $t = -2.19$, $p = 0.83$).

Evaluation of the figure indicates that the control group's average activation for left and right MCAs was comparable to that reported by Bishop et al. (2009) using the same paradigm.

Mean laterality indexes in controls and patients with CI (see Table 1), did not differ significantly ($t = 0.44$, $p = 0.5$), although children with CI showed a slightly higher interindividual variability.

The mean LI significantly differed from 0 in both control ($t = 2.01$, $p = 0.05$) and CI subjects ($t = 2.07$, $p = 0.05$). However, if side of implantation was considered, mean LI values of right-ear implanted children differed significantly from 0 (M 3.32., SD 4.46; $t = 2.68$, $p < 0.005$), whereas left-ear implanted children showed more inconsistent results and the mean LI did not differ significantly from 0 (M 0.02, SD 4.5; $t = 0.02$, $p = 0.99$). Though age at implantation differs between children with right and left-ear CI, the effect of side on LI was statistically significant, when adjusted for age at implantation (ANCOVA, $p = 0.005$).

Odd–even split-half reliabilities were sufficiently high for both control and CI groups ($r = 0.80$ and $r = 0.86$ respectively, $p < 0.001$). Following Haag et al. (2010), we calculated the standard error of the mean (SEM) of the lateralization index of each subject and compared the mean values of CI and control subjects (Table 1). The mean SEM of the two groups did not differ significantly ($t = 0.56$, $p = 0.43$), suggesting a comparable signal quality and performance continuity in both groups.

On a categorical level, 70% of control subjects showed a positive LI, indicative of left hemisphere dominance (LH), 20% had right hemisphere dominance (RH) and 10% were uncertain; these figures were comparable to the values reported in literature for typically developing children (Bishop et al., 2009; Haag et al., 2010; Lohmann, Dragger, Muller-Ehrenberg, Deppe, & Knecht, 2005), confirming the reliability of the results obtained in this study. A similar distribution was observed in children with CI (65% left, 20% right and 15% uncertain) and did not differ significantly from controls (Chi square = 1.47, df = 3, $p = 0.68$). Comparison between age at implantation of deaf subjects with negative and positive LI did not reveal any statistically significant difference (Mann–Whitney $U = 34$, $p = 0.8$).

Hemispheric activation was contralateral to the side of implanted ear (LH with right ear CI, and RH with left ear CI) in 13/20 children, and ipsilateral (LH with left-ear CI and RH with right-ear CI) in 4/20 children; three patients failed to show statistically significant hemispheric superiority. By taking into consideration direction (positive or negative values), and not magnitude of LIs, the frequency of controlateral activation was significantly higher in right- than in left-ear implanted children (Chi square = 3.77, df = 1, $p = 0.05$). About 77% of right-ear implanted children presented contralateral activation in left hemisphere,