Research in Developmental Disabilities 59 (2016) 378–386

Contents lists available at ScienceDirect

Research in Developmental Disabilities

Pitch perception deficits in nonverbal learning disability

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A R T I C L E I N F O

Article history:
Received 1 February 2016
Received in revised form
14 September 2016
Accepted 15 September 2016
Available online 3 October 2016
Number of reviews completed is 2

Keywords:
Nonverbal learning disability
Auditory perception
Pitch
Visuospatial ability
Crossmodal correspondences

A B S T R A C T

The nonverbal learning disability (NLD) is a neurological dysfunction that affects cognitive functions predominantly related to the right hemisphere such as spatial and abstract reasoning. Previous evidence in healthy adults suggests that acoustic pitch (i.e., the relative difference in frequency between sounds) is, under certain conditions, encoded in specific areas of the right hemisphere that also encode the spatial elevation of external objects (e.g., high vs. low position). Taking this evidence into account, we explored the perception of pitch in preadolescents and adolescents with NLD and in a group of healthy participants matched by age, gender, musical knowledge and handedness. Participants performed four speeded tests: a stimulus detection test and three perceptual categorization tests based on colour, spatial position and pitch.

Results revealed that both groups were equally fast at detecting visual targets and categorizing visual stimuli according to their colour. In contrast, the NLD group showed slower responses than the control group when categorizing space (direction of a visual object) and pitch (direction of a change in sound frequency). This pattern of results suggests the presence of a subtle deficit at judging pitch in NLD along with the traditionally-described difficulties in spatial processing.

What does this paper add?

Nonverbal learning disability (NLD) is a complex and multisymptomatic disorder characterized by the presence of deficits in visuospatial processing and in other cognitive abilities such as numerical processing, prosody. However, despite the wide range of cognitive processes affected, auditory perception has been historically discarded as part of the diagnosis criteria for NLD. In the current study, we report a possible deficit in pitch perception in NLD. Our results indicate that children with NLD show significant difficulties at judging the direction of a change in the frequency of sounds. This lower level of pitch perception performance could be associated with structural anomalies previously observed in children with NLD (e.g. white matter alterations in the right hemisphere). The right hemisphere has generally been related to the processing of speech

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http://dx.doi.org/10.1016/j.ridd.2016.09.011
0891-4222/

prosody. Keeping in mind that the key mechanism to decode speech prosody is based on deciphering the variations in pitch that are available in the speech signal, our results may perhaps explain the difficulties in understanding speech prosody previously found in NLD.

1. Introduction

Nonverbal learning disability (NLD) is a neurological learning disorder mostly related to the right hemisphere (see Semrud-Clikeman & Hynd, 1990) whose prevalence is estimated to be around 5–10% of all learning disabilities (Davis & Broitman, 2011). This disability was first described by Myklebust (1975) as a subtype of learning disorders that affect non-linguistic abilities.

Although researchers in the field do not question the need of a diagnostic label for NLD, there is some disagreement regarding the criteria used in its differential diagnosis. In an attempt to reduce this ambiguity in the diagnosis of NLD, Mammarella and Cornoldi (2014) (see also Fine, Semrud-Clikeman, Bledsoe, & Musielak, 2013) proposed several criteria based on a review of the last 30 years of research in the field NLD is characterized by (1) poor visuospatial and good verbal intelligence, (2) the presence of difficulties in visuoconstructive and fine-motor abilities, (3) poor mathematical and good reading decoding achievement at school, (4) spatial working memory deficits, and (5) emotional and social difficulties. The authors of this comprehensive study also suggested that the first criterion should always be present in the diagnosis of NLD and at least two of the other four criteria should be met.

So far, the visuospatial and mathematical abilities have monopolized most of the research conducted on NLD. In a recent study, Crollen, Vanderclausen, Allaire, Pollaris, and Noël (2015) observed visuospatial and numerical processing deficits in children diagnosed with NLD. More specifically, these authors explored the spatial representation of numbers (see Dehaene, Bossini, & Giroux, 1993) and found that children with NLD were less able to represent numbers spatially than a control group of healthy children. In particular, children with NLD did not show any tendency to associate small numbers to the left side and bigger numbers to the right side of the external space, a phenomenon previously observed in healthy participants and known as the SNARC effect (Spatial Numerical Association of Response Codes; see Dehaene, Bossini, & Giroux, 1993; see also Hubbard, Piazza, Pinel, & Dehaene, 2005, for a review).

Children and adolescents with NLD do not usually show anomalies in basic language skills (e.g. morphology or phonology), reading decoding, or in any other cognitive function such as attention or long-term memory (see Mammarella et al., 2009; Pennington, 2009; Rigau-Ratera, Garcia-Nonell, & Artigas-Pallares, 2004; Rourke & Tsatsanis, 2000). Importantly, previous studies have also discarded the presence of auditory deficits in NLD (see Rourke, 1989, 1995).

Regarding the possible neural bases of NLD, it has been suggested the presence of significant white matter perturbations in the right hemisphere of patients with NLD (Rourke, 1987, 1988, 1995). According to Rourke (1987), white matter alterations in the right hemisphere correlate positively with the presence of symptoms commonly described in NLD such as difficulties in visuospatial processing and speech prosody. Given the prominent participation of the right hemisphere (see Gandour et al., 2004; Ross & Monnot, 2008; Tong et al., 2005; Wong, 2002; for a review) and, specially its posterior (parietal) regions (see Perrone-Bertolotti et al., 2013) in processing prosody of speech, it is not surprising that this linguistic dimension is affected in NLShapiro and Danly (1985) demonstrated, after analysing sentences read by patients with lesions in different areas of the brain, that only patients with post-Rolandic posterior lesions in the right hemisphere produce altered prosodic speech characterized with exaggerated variations in pitch. More recently, in a study conducted with sleeping 3-month-old infants, Homae, Watanabe, Nakano, Asakawa, and Taga (2006) showed that the right temporoparietal regions of the brain are, that the right temporoparietal regions of the brain are more sensitive to normal speech – which includes variations in pitch and loudness- than its left counterparts (see also Arimitsu et al., 2011).

Noteworthy, the key mechanism to decode speech prosody is based on decoding variations in pitch; that is, on discriminating dynamic changes in the frequency of sound (see D. Patel, Peretz, Tramo, & Labreque, 1998). Interestingly, patients with a unilateral cerebrovascular lesion in the right hemisphere show poorer perception of pitch contour than patients with the same lesion in the left hemisphere (see Peretz, 1990). Despite the involvement of pitch perception in the comprehension of speech prosody, and the fact that the right hemisphere contributes to both processes, there are no studies specifically exploring possible deficits in pitch perception in patients with NLD.

Another reason for investigating pitch perception in NLD is based on previous behavioural evidence suggesting that, in a similar way as in the already mentioned SNARC effect, high and low sound frequencies seem to be mapped onto high and low spatial positions, respectively. In fact, there is strong evidence suggesting that the processing of pitch and vertical coordinates in space influence each other in such a way that the responses to one of these dimensions can be modified by manipulating the other (see Melara & O'Brien, 1987; Occelli, Spence, & Zampini, 2009; Rusconi, Kwan, Giordano, Umilta, & Butterworth, 2006). Crucially for the present study, Melara and O'Brien (1987) demonstrated the existence of a crossmodal link between pitch and spatial elevation. In their study, participants had to make an auditory or visual classification task while ignoring any stimulus variation in the other (irrelevant) dimension. When pitch was the relevant dimension, the participants had to press one of two different buttons every time they perceived a high or a low frequency sound. The auditory stimuli were presented together with a dot that could appear in a higher or lower position with respect of the central point of fixation. When the spatial position was the relevant dimension, the same procedure was used but the participants had to respond to the position of the dot instead of responding to sound pitch. These authors observed that a variation in the auditory dimension affected the participants' responses to the visuospatial dimension and vice versa. Moreover, the results revealed