Neuroscience Letters 584 (2015) 71–76

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

Informational masking of complex tones in dyslexic children

Axelle Calcus[a,b,c,*], Cécile Colin[b,c], Paul Deltenre[c], Régine Kolinsky[a,b]

[a] Fonds de la Recherche Scientifique (FRS-FNRS), Brussels, Belgium
[b] Unité de Recherche en Neurosciences Cognitives (UNESCOG), Center for Research in Cognition and Neurosciences (CRCN), Université Libre de Bruxelles (ULB), Brussels, Belgium
[c] Laboratoire de Neurophysiologie Sensorielle et Cognitive, Hôpital Brugmann, Brussels, Belgium

HIGHLIGHTS

- Noise typically includes both energetic (EM) and informational masking (IM).
- Dyslexic children are thought to be impaired in situations inducing mainly EM.
- Here, we evidence a core difficulty in complex sequences inducing pure IM.
- Such a difficulty is not caused by general auditory inattention to the task.

ARTICLE INFO

Article history:
Received 24 June 2014
Received in revised form 6 September 2014
Accepted 13 October 2014
Available online 24 October 2014

Keywords:
Developmental dyslexia
Auditory perception
Informational masking

ABSTRACT

In complex auditory scenes, perceiving a given target signal is often complicated by the presence of competing maskers. In addition to energetic masking (EM), which arises because of peripheral interferences between target and maskers at the cochlear level, informational masking (IM), which takes place at a more central level, is also responsible for the difficulties encountered in typical ecological auditory environments. While recent research has led to mixed results regarding a potential speech-perception-in-noise deficit in dyslexic children, most of them actually investigated EM situations. The current study aimed at evaluating dyslexic children's sensitivity to pure IM in complex auditory sequences. Performance of the control normally-reading children increased throughout the experiment, reaching a significantly better level than dyslexics' in the last blocks. Our results provide evidence for a general auditory deficit in noise in dyslexic children. Although due to central mechanisms, this deficit does not seem to stem from a mere auditory attention impairment. Further research is needed to examine the precise nature of the auditory difficulty, and its link with reading acquisition in dyslexic children.

1. Introduction

Developmental dyslexia is a neurodevelopmental disorder characterized by severe and long-lasting reading and/or spelling difficulties, despite adequate intelligence and educational opportunities [26]. Most recent research on dyslexia points to a deficit in the representation of and/or access to phonological information [5,6], which might in turn lead to difficulties in acquiring phoneme to grapheme conversion, hence impeding reading acquisition [27]. A broad range of auditory impairments has been suggested to contribute to the phonological difficulties associated to dyslexia (for a review, see [4]). Yet, evidence remains inconsistent, and it is now acknowledged that only a subset of the dyslexic population experience auditory deficits. Moreover, there is no clear correlation between auditory and reading skills in dyslexics (for a discussion of these arguments, see [23]). In addition, as psychoacoustic performance is correlated with general cognitive ability [17], some authors have suggested that difficulties in basic auditory processing might in fact be due to differences in cognitive abilities such as attention, memory, or learning [2].

However, subtle auditory difficulties might remain unnoticed in quiet conditions. Indeed, the optimal listening conditions used in most laboratory situations offer a highly redundant signal that allow listeners to compensate for poor representations of and/or deficient access to certain acoustic cues [24]. Yet, in most real-life auditory environments, listeners have to perform the challenging task of extracting behaviourally relevant signals from noisy backgrounds. Noise typically induces two kinds of masking: energetic

---

* Corresponding author at: Université Libre de Bruxelles (ULB), Center for Research in Cognition and Neurosciences (CRCN), Unité de Recherche en Neurosciences Cognitives (UNESCOG), 1050 Brussels, Belgium. Tel.: +32 26504812.
E-mail addresses: Axelle.Calcus@ulb.ac.be, acalcus@ulb.ac.be (A. Calcus).

http://dx.doi.org/10.1016/j.neulet.2014.10.026

and informational. Energetic masking (EM) arises when both signal and masker fall within the same frequency band, and is thought to reflect the limits of cochlear frequency selectivity [21]. Informational masking (IM) has commonly been equated to nonenergetic masking [13]. It has initially been evidenced in situations where pure tone target and maskers were well separated in frequency [18], being attributed to uncertainty and/or timbral similarity between the target and maskers [18]. More recently, IM was also demonstrated using broadband speech streams overlapping in frequency [7], being defined in this case as the excess of masking that cannot be explained by spectral interference between the target and masker. Whereas the mechanisms underlying IM in speech and nonspeech situations are likely to differ, they share a common characteristic: they cannot be accounted for by interactions in the auditory periphery. Rather, factors influencing a listener's susceptibility to IM are mostly cognitive, ranging from selective attention to familiarity or uncertainty regarding the target signal (for a review, see [13]).

In the present study, we considered IM in its strictest sense, namely masking that occurs in the absence of frequency overlap between target and maskers. Therefore, we used an original paradigm to investigate pure IM with complex tone sequences. Classical IM experiments have focused on situations in which a fixed-frequency regular pure tone target is embedded in a multitone background sequence whose components are excluded from a protected region surrounding the target frequency, hence limiting EM [18]. Yet, in real-life conditions, most simultaneous signals are broadband, preventing the use of this frequency gap technique. An obvious solution is to present signal and masker dichotically. However, dichotic presentation nearly cancels masking [15], due to strong lateralization cues that allow listeners to experience spatial masking release (SMR). Therefore, we recently developed a new paradigm to preserve IM in sequences composed of complex tones [8,9]. In this paradigm, listeners are asked to detect a regularly repeating target tone embedded in a randomly-varying background noise. Target and maskers are presented dichotically, but their lateralization randomly alternates several times throughout sequences. Rapidly switching target and maskers prevents listeners from experiencing SMR, and hence preserves a substantial amount of IM. This paradigm provides a useful methodological tool to isolate IM in sequences composed of complex tones.

Investigating speech intelligibility of dyslexic children in noisy backgrounds, studies provided evidence for a deficit in consonant identification [28] and sentence repetition [10] in noise, but not in either the identification or discrimination of a "bee-pea" synthetic contrast [20]. Interestingly, dyslexic adults were recently evidenced to experience specific difficulties in ecological situations inducing IM [12]. However, as target and maskers always overlapped in frequency, these studies mainly investigated EM. Focusing on IM provides a unique opportunity to evaluate the impact of cognitive mechanisms on auditory perception in noise. Moreover, IM is thought to account for most of the difficulty encountered by listeners in typical complex auditory scenes [7]. Therefore, the present experiment aimed at evaluating pure IM in dyslexic children.

To do so, we investigated IM of complex tone sequences in dyslexic children and in both age- and reading level-matched control children. The latter comparison allowed investigating the influence of reading level on auditory perception. We presented children with conditions inducing respectively strong (i.e., nonswitching sequences) or weak (i.e., rapidly switching sequences) lateralization cues. The nonswitching condition was expected to induce little or no masking at all, unless listeners failed to benefit from the lateralization cues inherent to dichotic listening. Preventing access to these lateralization cues (in the switching condition) preserves important amount of IM [8,9], and was thus hypothesized to worsen the detection performance compared to the nonswitching condition in all groups. A lower performance in dyslexic children, compared to controls, would thus reflect the contribution of central mechanisms involved in their impairment in noisy auditory backgrounds.

In addition, because of the high comorbidity between dyslexia and attention deficit hyperactivity disorder (ADHD), a neurodevelopmental disorder which symptoms are hyperactivity, impulsiveness and inattention [14], we tried to disentangle the respective contributions of general inattention towards the experiment from the specific difficulty induced by IM [13]. We did so in two ways. First, we carefully selected dyslexic children who were free from formal diagnosis of ADHD. However, subtle attentional deficits might entail substantial difficulties in our auditory task, which requires listeners to selectively focus on a specific target tone within each trial and to sustain their attention throughout the whole experiment. Therefore, we also examined the evolution, throughout the experiment, of performance level, response delays and detection time variability as markers of attention to the task [3]. Small variability would indicate a high consistency in response delays across the blocks, suggesting that listeners successfully sustained their attention to the task throughout the experiment. A general increase in performance, associated with a decrease in response delays variability would reflect learning effects throughout the experiment. On the contrary, a decrease in performance, associated with increasing response delays variability would illustrate fatigue and/or inattention.

2. Method

2.1. Subjects

Sixty-eight monolingual French native children were recruited from public elementary schools in Brussels. The study was conducted with the understanding and consent of the participants and their parents. All children had normal audiometric thresholds as measured at octave intervals from 250 to 8000 Hz. Children with phonological dyslexia ($n = 21$, aged 7.4 to 11.9 years) were included in the study if their performance IQ was above 80 on the Weschler Non Verbal scale of ability, if they were free of other developmental disorders (speech language impairment, ADHD, autism, dyspraxia), and if their reading level was at least 2 standard deviations below the norm on MIM and REGUL reading tests (BELEC, [22]) that evaluate reading of regular, irregular and pseudo-words varying in complexity. Phonological processing was assessed by the pseudo-word repetition task and by the phoneme deletion task. As illustrated in Table 1, control children were matched to dyslexics on either age- ($n = 24$) or reading level ($n = 23$), even after exclusion of children who did not understand the task (see Section 3).

2.2. Material

Stimuli used in this experiment were adapted from [9]. Target and maskers were 100 ms complex tones, consisting of the third, fourth and fifth harmonics of a missing fundamental frequency ($F0$). Children heard 81 6.5 s long sequences, 54 of them containing a target tone repeating at 2 Hz. Possible target $F0$ were 244 Hz, 359 Hz, 528 Hz, 776 Hz, 1143 Hz, and 1681 Hz tones. Maskers consisted of a randomly varying background whose components were uniformly distributed over time and log-frequency, ranging from 112 to 3000 Hz. Each of the six target frequencies was presented together with nine differently randomized masker sequences. The remaining 27 sequences did not contain any target. Sequences were presented in random order, with a .5-s inter-stimulus interval (ISI). Targets were repeated 12 times throughout the sequences, with a