International Journal of Pediatric Otorhinolaryngology 85 (2016) 158–165

Contents lists available at ScienceDirect

International Journal of Pediatric Otorhinolaryngology

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

An exploratory study of visual sequential processing in children with cochlear implants

Sneha V. Bharadwaj [a,*], Jyutika A. Mehta [b,1]

[a] Department of Communication Sciences and Disorders Texas Woman's University, P.O. Box 425737, Denton, TX 76204, USA
[b] Department of Communication Sciences and Disorders, Texas Woman's University, USA

ARTICLE INFO

Article history:
Received 3 November 2015
Received in revised form 26 January 2016
Accepted 24 March 2016
Available online 11 April 2016

Keywords:
Cochlear implants
Visual sequencing
Children
ERP
Electrophysiology
Motor sequencing

ABSTRACT

Objective: The objective of the study was to compare visual sequential processing in school-age children with cochlear implants (CIs) and their normal-hearing (NH) peers. Visual sequential processing was examined using both behavioral and an event-related potential (ERP) measures.
Methods: Eighteen children with CIs and nineteen children who had hearing within normal limits (NH) participated in the behavioral study. Subtests from the Test of Visual Perceptual Skills and the Sensory Integration and Praxis Test were administered to all children. ERP measures were collected from five children with CI and five age-matched peers. Peak latencies (N200 and P300) and reaction times for visual sequential processing were compared in these two groups.
Results: The findings of the study revealed significant group differences in visual sequential memory and visuo-motor sequencing tasks suggesting that children with severe-profound hearing loss may have difficulties in visual sequential tasks. The study also revealed longer P300 latencies and longer reaction times for a visual sequential matching task in children with CI when compared to their NH peers suggesting slower or delayed processing of visual sequential stimuli.
Conclusions: This exploratory study involving behavioral and ERP measures showed that as a group, children with prelingual, severe-profound hearing loss who use CIs have difficulties with visual sequential processing. These findings may have implications for rehabilitation for children with hearing loss in the light of recent evidence that accurate and efficient processing of sequentially presented visual stimuli is important for language and reading outcomes.

Published by Elsevier Ireland Ltd.

1. Introduction

Sequential (or temporal) processing refers to processing two or more stimuli that are presented non-simultaneously [1]. Sequential processing is thought to consist of four components: (a) detection of stimuli; (b) determination of the presence of more than one stimulus (i.e. stimulus individuation); (c) determination of temporal order of non-simultaneously presented stimuli, and (d) accurate sequence matching or sequence discrimination (see Farmer and Klein, 1995 for a discussion on this topic). The fourth component is a complex task given that sequential patterns of stimuli must be processed correctly, stored and then retrieved (memory component) for matching or discrimination. Deficit in any one or more of the four components may lead to problems in sequential processing of sensory signals.

Most of the activities concerning our daily lives involve sequential processing in various modalities. Listening to speech (auditory modality), reading a newspaper (visual modality), walking or writing (motor sequencing), reading braille (tactile modality) or cooking (visual, tactile, motor) all require us to process or perform sequential acts. It is suggested that the auditory modality has an advantage in sequential processing while the visual modality is better suited for the processing of simultaneous or "big picture" information such spatial configurations [2–4]. Regardless of the modality, the ability to accurately process sequential stimuli is important for learning. Difficulties in sequential processing are correlated with deficits in reading and language skills [5–7].

1.1. Sequential (temporal) processing in individuals with hearing loss

According to the *Auditory Scaffolding Hypothesis*, deafness affects cognitive abilities such as learning, recalling and processing

* Corresponding author. Tel.: +1 940 898 4034; fax: +1 940 898 2070.
E-mail addresses: sbharadwaj@twu.edu (S.V. Bharadwaj), jmehta@twu.edu (J.A. Mehta).
[1] Tel.: +1 940 898 2029; fax: +1 940 898 2070.

http://dx.doi.org/10.1016/j.ijporl.2016.03.036
0165-5876/Published by Elsevier Ireland Ltd.

sequential information [8]. Sound is considered as a carrier of temporal events since it is intimately tied to timing information [7]. Sound is considered to be the primary gateway (i.e. it provides scaffolding) for processing temporal information and the loss of auditory information due to hearing loss may result in limited or lack of exposure to sequential input [8]. Consequently, early-onset hearing loss may have a negative impact on encoding, representing and reproducing sequential patterns of stimuli not only in the auditory domain but also in the non-auditory modalities [8].

The prefrontal cortex is proposed to be involved in sequential processing of thought and action. It is postulated that reduced or delayed auditory-frontal connectivity, a result of early-onset hearing loss impacts sequential processing skills across various modalities [7]. Studies have supported this view by revealing that temporal (sequential) processing of visual and tactile information is compromised in adults with prelingual or congenital deafness [9,10]. Hemming and Brown showed that while judging whether tactile stimuli, when applied to the pointer and middle fingers by a mechanical stimulator were simultaneous or not, adults with congenital/prelingual deafness demonstrated higher temporal thresholds (i.e. required a longer separation between the onset of the two tactile stimuli as measured in ms) when compared to their aged-matched controls [10]. These findings suggested that temporal processing of tactile information is compromised in adults with early hearing loss. Similarly, Hemming and Brown also showed that temporal processing of visual information is compromised in adults with prelingual or congenital deafness. In their study, adults with hearing loss judged whether two (LED) illumination onsets were simultaneous or not and their performance was compared to the normal-hearing (NH) controls. Again, adults with hearing loss demonstrated higher temporal thresholds (i.e. required a greater amount of time separating the onset of the two visual stimuli) compared to their aged-matched controls suggesting that early hearing loss might impede the ability to time visual information [10]. The difficulties in temporal processing in these individuals is considered to be due to neural inefficiency as a result of recruiting other brain regions or additional pathways to support temporal processing [10,11].

More recently, Conway and colleagues investigated visual and tactile spatial tasks as well as motor sequencing tasks in 24 children with prelingual, profound hearing loss who use CIs and their 31 age-matched peers between the ages of 5–9 years [7]. Children with hearing loss showed similar performance on visuo-spatial and tactile perception tasks when compared to their peers. However, on the motor sequencing task (sequential finger tapping) they showed significantly poorer scores when compared to the performance of their age-matched peers, as well as to normative data. These findings suggest that there is a disturbance or delay in motor sequencing in children with CIs.

In another study Conway, Pisoni, Anaya, Karpicke and Henning evaluated visual sequential processing in 25 children with CIs and 27 children with NH between the ages of 5–10 years [12]. The task involved memorizing a sequence of four colored squares that appeared sequentially on a computer screen and then tapping on the screen to show the same pattern or sequence. The study showed that while there was individual variability in performance, as a group, children with CIs performed significantly poorer than their NH peers on the visual sequence learning task. Furthermore, the study showed that the sequence learning was negatively correlated with age of implantation and positively correlated with duration of implant use. Overall, the study lent support to the hypothesis that auditory deprivation may impact processing in the non-auditory modalities.

The findings from Conway, Pisoni, Anaya, Karpicke and Henning were supported by Bharadwaj and colleagues who also showed that children with prelingual severe-profound hearing loss who use CIs have difficulties in temporal processing of sensory stimuli [12,13]. In their study Bharadwaj and colleagues investigated performance of children with hearing loss between the ages of 5–8 years 11 months on spatial (visual, tactile and proprioception) and temporal tasks (in tactile and proprioception modalities only). They found that as a group, children with CIs performed in the average or above average range on spatial tasks across all three modalities when compared to the normative data. However, they showed below average performance on temporal (sequential) tasks in the tactile and proprioception modalities. Together these studies suggest possible disturbances in motor sequencing and sequential processing of visual, tactile and proprioception stimuli in pediatric cochlear implant users.

Difficulties in sequential processing of stimuli and sequencing motor movements in children with CIs have been linked to poorer language outcomes. For example, the performance on motor sequencing tasks in children with CIs was shown to be positively correlated with their performance on a standardized test of language skills. Similarly, disturbances in visual sequential processing in children with CIs have also been linked to poorer language abilities [7,12]. While deficits in sequential processing of stimuli have been documented, it is not clear what aspects or components of sequential processing are affected in pediatric users of CIs. Thus it is important to not only examine whether there are disturbances in non-auditory sequential processing in children with hearing loss but also to investigate the nature of this deficit. For this reason, we used ERP (event-related potential) technique to explore the underlying mechanisms that may contribute to the deficit. ERP components highly correlate with various sensory processing parameters and can identify modulations in the latency of responses in the sub-millisecond temporal range. The ERP part of the study was exploratory in nature and was conducted to determine if the ERP components can further inform us about visual sequential processing in children with CI.

The objective of this study was to investigate visual discrimination, visual memory, visual sequential memory and visuo-motor sequencing in children with and without hearing loss using behavioral and ERP measures. Specifically, performance on these visual tasks was evaluated in the context of the sequential processing framework proposed by Farmer and Klein [1]. Compared with behavioral procedures, ERPs provide a continuous measure of processing between the presentation of a stimulus and a response, making it possible to determine stages of processing that are being affected by a specific experimental manipulation. Hence we explore this technique to investigate various components of sequential processing proposed by Farmer and Klein in children with CIs and their NH peers [1].

2. Methods

2.1. Participants

Eighteen children with CIs and nineteen children who had hearing within normal limits (NH) participated in this study. Children with CI (10 girls and 8 boys) were between the ages of 5 years to 10 years, 8 months (mean age: 7 years and 8 months). All children spoke English as their primary language and had prelingual, bilateral, severe-profound hearing loss. Eight children used unilateral CI and ten children used bilateral implants. All children received their first implant prior to age 3 years 10 months except three of whom received their first implant between the ages of 4 and 5.5 years. These three children used hearing aids for amplification prior to implantation. Eight participants used spoken language as their primary mode of communication while the remaining ten used speech with supported signs for communication. Children with reported history of developmental delays,