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Dichotic word recognition across ages

Summary

Successful auditory word recognition depends upon acquiring lexical and phonological representations during language acquisition. The intake of information through the auditory system requires an online integration of differing and potentially competing information presented to the two ears. The goal of the present study was to collect developmental data on the auditory-phonetic processing of words in a dichotic listening task with the participation of 320 Hungarian-speaking children between the ages of 3 and 10. Dichotic listening techniques have been used as a sensitive non-invasive procedure to assess language lateralization. Data were scored for each participant as the percentage (and number) of correctly recalled words for the right and left ear input. Results showed a significant increase of the correctly repeated words across ages. As expected, more correctly recalled words were found heard in the children's right ear than in their left ear as an effect of right ear advantage. The dichotic listening method seems to be a good way to detect the auditory-phonetic abilities of typically developing children.

Key words: word recognition, dichotic test, Hungarian children, laterality

1. INTRODUCTION

During language acquisition children have to recognize and remember the sound patterns of words despite their different acoustic manifestations (influenced by speakers, speech rate, contexts, etc.). It is usually assumed that the speaker's lexicon contains a representation of each word in an idealized form which is matched to heard speech (Swingley & Aslin, 2000). Children's representations of familiar words are reported to be phonetically well-specified already around the age of two (Walley, 1993). Successful word recognition seems to depend upon acquiring lexical and phonological representations and developing a matching process that links spoken words to these representations.

Children take part in various types of verbal communication from the beginning of their language acquisition. Typically, they hear words and utterances that pass on identical linguistic information to both of their ears. What happens, however, if the acoustic-phonetic patterns of the words coming to the two ears at the same time are different? Would children be able to differentiate and at the same time integrate the acoustic patterns of the different words? The intake of information through the auditory system requires online integration of differing and potentially competing information presented to the two ears (Litovsky, 2015).

The two hemispheres of the human brain are asymmetric both morphologically and functionally (Halpern, Güntürkün, Hopkins, & Rogers, 2005; Kandel, Schwartz, & Jessel, 2000; Riès, Dronkers, & Knight, 2016; Toga & Thompson, 2003). Hemispheric asymmetry is one of the fundamental principles of neuronal organization that develops during language acquisition (e.g. Hugdahl, 2003; Hugdahl & Westerhausen, 2010). Interaural asymmetry of the auditory system has been well documented, and various kinds of asymmetries have been observed at all levels of the auditory system (Jerger & Martin, 2004). Dichotic listening techniques have been used as a sensitive non-invasive procedure to assess language lateralization under clinical settings and among children with and without learning disabilities (e.g. Fernandes, Smith, Logan, Crawley, & McAndrews, 2006; Helland, Asbjørnsen, Hushovd, & Hugdahl, 2008; Hugdahl, 2011; Obrzut & Mahoney, 2011; Thomsen et al., 2004). Doreen Kimura was the first to describe the physiological background of the phenomenon (1961). Jerger and Martin provide a detailed description of the history of the dichotic method (2004). During a dichotic listening test the participant is to listen to different language stimuli at the same time in the two ears. Test materials range from syllables (of the shape CV) to words, numerals, nonsense sequences, and even sentences yielding different results (e.g. Andrade de, Gil, & Martinelli Iorio, 2015; Bethmann, Tempelmann, De Bleser, Scheich, & Brechmann, 2007; Kimura, 1961; Meyers, Roberts, Bayless, Volkert, & Evitts, 2002; Moncrieff, 2011; Musiek, 1983; Sætrevik, 2012; Willeford, 1977). Linguistic stimuli and the participant's task may vary depending on the nature and aim of the experiment. The application of this method has become widespread in the eighties of the last century (Hugdahl, 2011; Obrzut & Mahoney, 2011). Results of the dichotic listening tests are affected by the instructions used: the task may simply be free recall, but the experimenter may also direct the participant's attention to stimuli coming to one ear or the other. Furthermore, Moncrieff confirmed that the way data is calculated can also be a decisive factor of what the actual results would be (2011).

A large number of papers using various methods (such as PET, fMRI, MEG, electrophysiological measurements, etc.) confirmed the anatomical basis of right-ear-advantage (REA, see Bethmann et al., 2007; Brancucci et al., 2005; Hakvoort et al., 2016; Hugdahl, 2011; Hugdahl et al., 1999; McFadden, 1993; Penna et al., 2007). REA was shown for the great majority of healthy, typically developed participants, more or less irrespective of age (Dawes & Bishop, 2010; Ettinger-Veenstra et al., 2010; Lebel & Beaulieu, 2009; Mildner, Stanković, & Petković, 2005; etc.). Left-ear-advantage (LEA), on the other hand, shows that the individual's right hemisphere is dominant. If no advantage can be found for either ear (NEA: 'no-ear-advantage'), bilateral or mixed dominance can be assumed, or else it can signal left temporal dysfunction. Whenever left or right hemisphere dominance can be established on the basis of dichotic tests, this tallies with the results of Wada tests (Hugdahl, Carlsson, Uvebrant, & Lundervold, 1997). Dichotic tests are eminently suitable for detecting hemispheric dominance, and even for exploring higher cognitive functions (Hugdahl, 2011; Studdert-Kennedy & Shankweiler, 1970). In addition, it is also possible to check the development of the auditory-phonetic processing of words in children (Meyers et al., 2002) since the auditory system is reported to project bilaterally up to the level of the nuclei of the lateral lemniscus (Hugdahl, 1999).

There are two lines of models that intend to explain REA. One of them is a structural model that was originally proposed by Kimura (1967). According to her theory, REA is based on static asymmetries of the neural pathways that connect the auditory periphery and central auditory structures resulting in various interacting factors. What is important here is that she supposes a better representation of information in the opposite hemisphere; therefore, right ear linguistic input has a stronger connection to the left hemisphere (see also Hugdahl, 1998, 2003). Sparks and Geschwind (1968) showed also the importance of callosal transfer within this model. The other approach is commonly called the attention model which is based primarily on verbal behavior. Kinsbourne (1970) proposed that auditory asymmetries arise from an attentional or, more broadly, cognitive bias concerning the given cerebral hemisphere (see Hugdahl et al., 2000).

Inconsistent results are reported in the literature with respect to the age at which hemispheric dominance can first be detected. Some authors assume that, in the case of typically developing children, there is a critical period by the end of which dominance has to be formed; this is taken to be 6 or 7 years of age (e.g. Kimura, 1961). In the development of the connection between the two hemispheres, it has been confirmed that at age 6 a crucial period begins in which the physiological and functional development of the corpus callosum has to start (Westerhausen et al., 2011). In testing six- and eight-year-old children, the authors found that information flow between the two hemispheres (as shown by results of dichotic tests) and observed physiological differences exhibit close correlations; development can be shown to exist in just that age range. They confirmed that the correct recognition of syllables administered to the left ear is closely connected to the state of development of the corpus callosum. They also claimed that it is not a matter of chance that phonological awareness is also stabilized at this age, possibly in connection with current physiological and functional changes.

Moncrieff (2011) studied children between five and twelve years of age by dichotic tests where the stimuli were monosyllabic words and numerals. The results showed REA for nearly 60% of five- to seven-year-olds, over 75% of eight- to ten-year-olds, and roughly 70% of eleven- to twelve-year-old subjects. Almost 30% of the youngest participants, over 20% of the eight- to ten-year-olds, and slightly more than 25% of the oldest group exhibited LEA. Dichotic tests involving numerals were carried out with 200 children between 5 and 13 years (Rosenberg, 2011). Average correct responses showed an increase with age; in the two younger age groups it was items heard in the right ear that were repeated correctly in larger numbers, whereas with the oldest group no such difference was found. In studies involving schoolchildren, the dichotic test results in general confirmed left-hemisphere dominance, and no change was documented in lateralization after the age of 6 (Asbjørnsen & Helland, 2006; Bryden, 1970; Bryden & Allard, 1981; Moncrieff, 2011; Obrzut & Mahoney, 2011). In Moncrieff and Musiek's study with eleven-year-olds (2002), correct recall of right ear words occurred in 88%, and that of left ear words in 82% of the cases (p. 432). Results of dichotic tests performed with nine-, thirteen- and seventeen-year-old participants showed that older subjects recognized linguistic stimuli better than younger ones (Piazza, Gordon, & Lehman, 1985). Carlsson and colleagues studied typically developing 9- and 14-year-old children and found that for 20% of them no hemispheric dominance could be confirmed (2011). Bless and colleagues processed data coming from 4408 participants representing 64 different first languages (2015). Their dichotic test was run as a mobile app (*iDichotic*), the test material consisted of 36 pairs of CV syllables, based on the pronunciations of (British) English, Norwegian, German, and Estonian native speakers (Bless et al., 2015). Participants' average age was 33 years; the youngest subjects were 8 years olds. The results confirmed REA for participants involved in all languages.

Studies were also conducted with Hungarian-speaking kindergarten and schoolchildren, both typically developing ones and those exhibiting difficulties in learning to read (e.g. Gósy, Huntley Bahr, Gyarmathy, & Beke, 2018; Reinhardt, 2003). Reinhardt (2003) studied 126 children; she tested the presence of hemispheric dominance in groups of 4-5-, 7-8-, and 9-10-year-olds. Her results showed that dominance was established in 65% of 4-5-year-old kindergarten children, 40% of 7-8-year-old schoolchildren, and 58% of 9-10-year-old pupils (in the youngest group the right hemisphere was dominant more often than with the older participants, while in the two other groups left-hemisphere dominance was typically found). In the group of 9-10-year-olds, the occurrence of right-hemisphere dominance was found in a mere 13% of the cases. In a recent study by Gósy and colleagues (2018), 8-10-year-old, typically developing children recalled 14-16 words of the possible 20, fewer from words presented in their left ears, and more of those they received in their right ears. In the case of children with reading difficulties, the ratio of observed hemispheric dominance was significantly lower, and fewer recalled words were produced than by members of the typical group. A number of studies confirmed that various problems like specific language impairment, delayed language development, difficulties in the acquisition of written language, dyslexia, learning difficulties, or autism, all correlate with a poorer performance on dichotic tests (Billett & Bellis, 2011; Dlouha, Novak, & Vokřál, 2007; Ettinger-Veenstra at al., 2010; Gósy et al., 2018; Moncrieff, 2010; Moncrieff & Musiek, 2002; Obrzut & Mahoney, 2011).

Two basic questions arise concerning the processes underlying the recognition of dichotically presented words: 1. Does processing of two different words coming from the two ears at the same time show age-specific changes? and 2. What is the connection with laterality, again, across ages? The goal of the present study was (i) to collect developmental data on the auditory-phonetic processing of words in a dichotic listening task with the participation of Hungarian-speaking children between the ages of 3 and 10, (ii) to see if we can confirm the existence of development in the sense that the ratio of correctly recalled words increases with age, and (iii) to detect the distribution of ear advantage in the various age groups using different calculations. We hypothesized that children would show (i) gradual increase across ages in the number of dichotically presented words they recalled correctly, (ii) a more intensive increase in the number of correctly recalled words presented in their left ear than in their right ear, and (iii) more frequent REA than LEA and NEA in all ages.

2. METHODOLOGY

320 right-handed children aged between 3 and 10 years participated in the study. Children were divided into eight age groups; each group included 40 children (half of them were girls in each group). All of them had normal hearing in both ears (screened at 20 dB HL at octave frequencies from 0.25 to 8 kHz) at the time of testing, no known history of delayed onset of language acquisition, of speech or language difficulties (examined prior to enrollment into the study on language production and perception proficiency, as well as handedness using standardized test batteries), and were native monolingual speakers of Hungarian. The children in this study all had a similar socio-economic status and were recruited from various kindergartens and schools in a large city.

A dichotic listening task was used with 15 pairs of frequently occurring disyllabic Hungarian words (e.g. *alma*/*sapka* 'apple/cap', *csiga*/*béka* 'snail/frog'). Words were used in this study because (i) preliminary data had been successfully collected using words (e.g. Reinhardt, 2003), and (ii) single word presentation makes the test capable of being administered to young children (from the age of 3) (see Moncrieff, 2011). All items of the word list are common, young nursery level Hungarian words. The words were selected so that the list was balanced for phonemic content. Duration of both initial and final syllables were controlled in all word pairs. (Word frequency effects in word repetition tasks for preschoolers and elementary-school children were reported to be minimal, see Garlock, Walley, & Metsala, 2001.)

The first part of the test contained five pairs of disyllabic words (ten words); the second part consisted of five times two pairs of disyllabic words on each trial (twenty different words). This means that in the latter case the pause occurred after the two pair trials. The order of the words and the pairs in the word list was held constant throughout the experiments. The words were read by a male voice without any frequency modulation. Recording of the words was processed according to general demands of dichotic listening test materials. Word pairs were matched for time of onset and time of offset resulting in the total duration of each word in a pair being identical. Average root mean square (RMS) amplitude was equalized for each word so that all stimuli were presented at the same RMS amplitude across the entire test. In the first part of the test there was a silent pause of 500 ms between the pairs while there was a silent pause of 600 ms between two pairs in the second part of the test.

The words were presented through earphones to both ears of each child at a volume allowing comfortable listening (55 dB, on average). The participants were asked to repeat as many of the words they heard as they could after each trial, that is, one or two words in the first part of the test and 1 to 4 words in the second part of the test (non-forced or free-report condition, see Hugdahl, 2003). Since this was a free-report (free recall) condition experiment, the children could differentially and freely attend to the right and left ear input. The headphones were not reversed between subjects. Individual testing was performed by both of the authors. Participants' answers were recorded directly onto a computer.

Data were scored for each participant resulting in three index scores: (i) the left ear score index is the total number of correctly recalled words for the left ear input, (ii) the right ear score index is the total number of correctly recalled words for the right ear input, (iii) the both ears score index is the total number of correctly repeated words heard in both ears. Data were processed in four different ways: (i) analysis of the number and ratio of correctly recalled words, (ii) the calculation of simple subtraction (e.g. Moncrieff, 2011), (iii) the method of double word pairs (see Bever, 1971), and (iv) calculation of lateralization indices (cf. Studdert-Kennedy & Shankweiler, 1970).

(i) We determined for each child the number of correctly repeated words heard in the right and in the left ear, respectively, and we calculated the sum of correctly recalled words. On the basis of this, we determined the age-specific levels of performance. (ii) Next, we subtracted the number of correctly recalled words heard in the left ear from that of correctly recalled words administered to the right ear. (iii) In the method of double word pairs, we analysed the correct recall of 5x2 pairs of words, a total of 20 words, child by child, then in age groups (cf. Bever, 1971). In the first pairs of double word pairs, we noted the words first repeated by the children. The criterion of ear preference was that at least four (or five) words were correctly repeated from the first members of pairs of words heard in one ear. (iv) We determined lateralization indices (LI, cf. Fernandes & Smith, 2000; Hakvoort et al., 2016; Hugdahl, 2003; Studdert-Kennedy & Shankweiler, 1970; etc.). Lateralization indices are calculated from correctly recalled words (or other linguistic stimuli) in dichotic tests, with the following formula: (right ear - left ear) / (right ear + left ear)*100. In this formula, 'right ear' stands for the number of words heard in the right ear and recalled correctly, and 'left ear' stands for the number of words heard in the left ear and repeated correctly. Negative LI shows right-hemisphere dominance, while positive LI shows dominance of the left hemisphere.

The data were subjected to statistical analyses (GLMM method) using SPSS 19 software. The random factor was 'speaker' in all statistical analyses. Significance was set at the 95% confidence level.

3. RESULTS

The data we collected from the dichotic tests will be presented in subsections corresponding to the four manners of calculation.

3.1. Analysis of the number and ratio of correctly recalled words

Participants were able to repeat 20 words on average (67%) out of the total 30 words presented to them, all age groups considered together. The mean of correctly recalled left-ear administered words was 57% in the population tested, and that of right-ear administered words was 76%. Adding the data from both ears to one another, as well as taking the correct recognition of the words administered to each ear separately, the number of correctly recalled words increases from 3-year-olds' performance to that of 10-year-olds. The results are presented in absolute numbers and in ratios, too (Table 1).

Table 1. The numbers and percentages of correctly recalled words in speakers' age groups (total number of words for the two ears together = 30) (N = number, y. = year, min. = minimum, max. = maximum)

Tablica 1. Broj točnih riječi i postotak dobiven prisjećanjem s obzirom na dobnu skupinu ispitanika (ukupan broj riječi za oba uha = 30) (N = broj, y. = godina, min. = minimum, max. = maksimum)

Age (y.) / Dob (god.)	Number of correctly recalled words / Broj točnih riječi dobiven prisjećanjem				
	Two ears added up / Oba uha			Left ear / Lijevo uho	Right ear / Desno uho
	Mean / Prosjek (N/%)	Min. (N/%)	Max. (N/%)	Mean / Prosjek (N/%)	Mean (N/%)
3	14/46	10/13	18/87	6/38	8/53
4	16/52	10/13	20/87	6/39	9/64
5	17/58	13/13	24/93	7/43	11/72
6	20/64	13/33	25/100	8/52	11/77
7	21/68	15/13	28/93	9/56	12/80
8	23/80	15/7	30/100	10/72	12/87
9	24/81	19/53	28/100	11/74	12/88
10	25/85	21/67	29/100	12/81	13/90

The total number of correct recalls in the individual age groups confirms the claim that the number of appropriately repeated words keeps growing with age. In the youngest group we tested, that of three-year-olds, our subjects accurately repeated less then half of the words they heard (7 words on average per ear). The improvement of performance can be said to be even until age 6, yearly 6% on average: four-year-olds were able to correctly repeat 52% of the words, five-year-olds 58%, and six-year-olds 64%. Between ages 6 and 7, that increase became somewhat more moderate, the older children's performance improved by merely 4%. After age 7, the increments between neighboring age groups showed larger differences. Between 7 and 8, the increase is 12%, whereas between 8 and 9, the increase practically stops. The difference between 9- and 10-year-olds was 4%.

Of the words presented in their left ears, children correctly repeated two and a half words fewer than of the words arriving in their right ears (9 words on average, 60%, 11.5 words on average, 76%; respectively). Right-ear-advantage was confirmed for all age groups (at the group level). The largest difference between the two ears showed up with five-year-old children; they correctly recalled 4.5 words more on average from the right ear than from the left ear. The smallest difference occurred in the two oldest groups: here, the difference was a single word on average.

Generalized linear mixed model for the number of correctly repeated words with 'age' (3–10), 'ear' (left, right) and 'gender' as fixed factors was tested. Statistical results confirmed the development of performance on dichotic tests between ages 3 and 10 with significant differences across age groups in the number of correctly repeated words [$F(7, 473) = 37.595$; $p < 0.001$] and between right and left ear performance [$F(1, 478) = 107.248$, $p < 0.001$], as well as for the interaction between 'age' and 'ear' [$F(7, 478) = 24.214$; $p = 0.001$]. There was no significant difference between boys and girls within groups as far as the number of correctly repeated words was concerned. Figure 1 shows the percentages of the correctly repeated words individually for each ear.

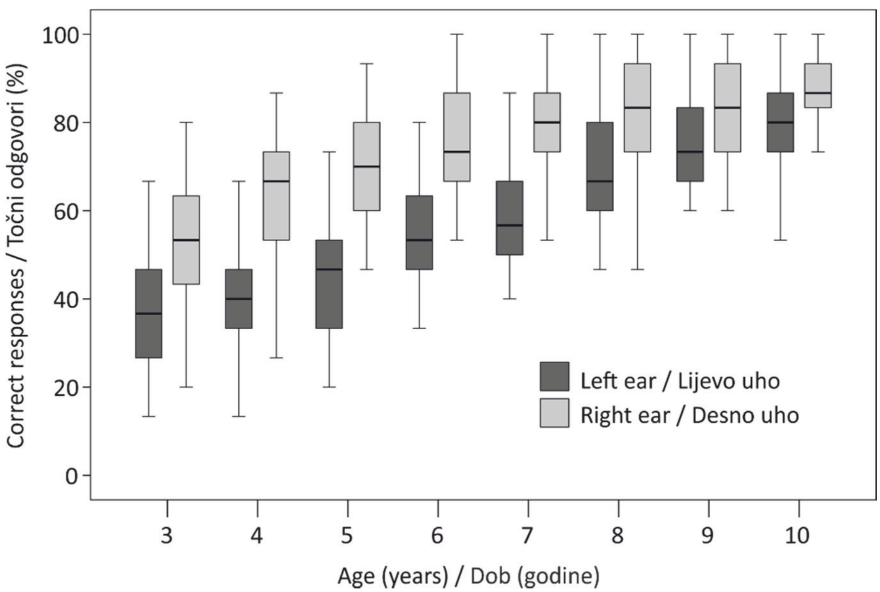

Figure 1. Correct responses of dichotically presented words across ages (median and standard deviations)

Slika 1. Točni odgovori u testu dihotičkog slušanja s obzirom na dob (medijan i SD)

78.5% of the children (251 subjects) repeated more of the words coming to their right ears, and 14% (45 subjects) were more successful with the words coming to their left ears; in the case of 7.5% (24 subjects), no ear advantage was found in the groups we tested. With increasing age, the following trend can be observed: until age 5, the difference between the two ears gradually grows, while between 5 and 10 it gradually decreases; i.e. in these older groups, the performances of the two ears converge (Figure 2). However, we have to be careful in interpreting this result, given that the present study is cross-sectional (that is, not longitudinal).

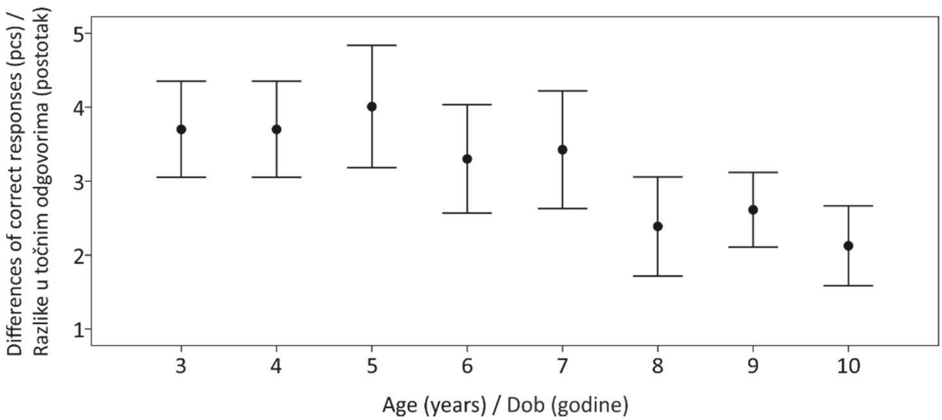

Figure 2. Differences of correct responses for words presented in right and left ear (means and standard deviations)

Slika 2. Razlike u točnim odgovorima ovisno o desnom i lijevom uhu (aritmetička sredina i SD)

3.2. Applying the method of simple subtraction

In this calculation, we subtract the number of correctly repeated words heard in the left ear from that of correctly repeated words heard in the right ear (cf. Moncrieff, 2011). Statistical analyses confirmed a significant difference in those subtraction results (as dependent factors) according to age (as independent factor) [$F(1, 640) = 9.734$; $p < 0.001$]. Whenever correct repetition of right-ear words surpasses that of left-ear words, the result is a positive integer, when left-ear words fare better, the result is negative. Positive results suggest REA, while negative results suggest LEA (Figure 3). Observed dominance characterized 95.7% of the children. Most children (82% of the subjects) revealed REA; the ratio of participants with LEA was a mere 13.7%, while 4.3% of the subjects did not exhibit any ear advantage. Looking at the data group by group, we can observe differences across ages. LEA was shown by 17.5% of three-year-olds, 12.5% of the four-year-olds, 10% of the five-year-olds, 2.5% of the six-year-olds, 7.5% of the seven-year-olds, 15% of the eight-year-olds, 32.5% of the nine-year-olds, and 15% of the ten-year-olds. The largest REA was found with six- and seven-year-olds. Three children in the five- and six-year-old groups (each), two children in the four-, seven- and eight-year-old groups (each), as well as one child in the nine-year-old group, and one in the ten-year-old group exhibited NEA. This situation did not occur at all in the youngest group of children.

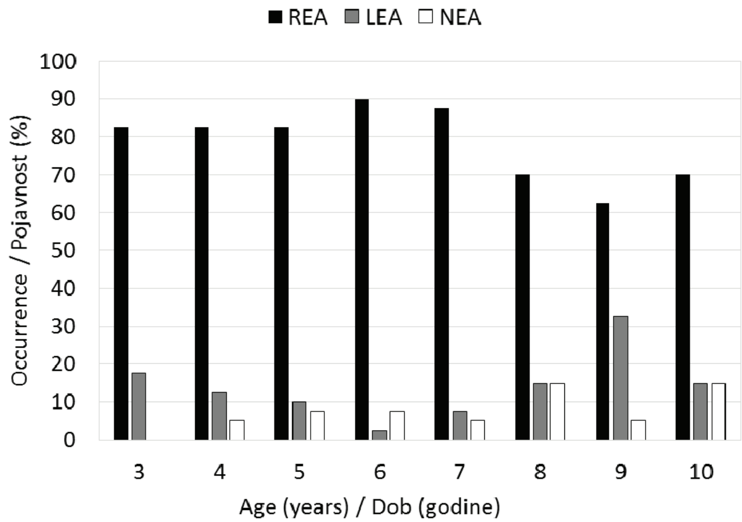

Figure 3. The occurrence of REA, LEA, and NEA in the age groups studied, based on the application of simple subtraction

Slika 3. Pojavnost REA, LEA i NEA u ispitivanim dobnim skupinama primjenom jednostavnog oduzimanja

3.3. Results based on double word pairs

With this method of counting (taking into consideration the 5 times 2 pairs, a total of 20 words), the results diverge from the above data based on simpler calculations. Here, the correctly recalled words ranged from 6 to 10 in the case of right ear input and 3 to 7 in the case of left ear input across ages. For the analysis of ear advantage, we took into account only the first recalled member of the two pairs of words. It was with 56% of the participants that some ear advantage was observable. The ratio of observed ear advantage increased with age; the smallest ratio (15%) was found with four-year-olds; the largest (85%) with nine-year-olds. The largest increase of observed ear advantage (approx. 30%) was found between five and six years of age. LEA was characteristic of 17% of the children, and REA was observed with 71% (Figure 4). The largest number of right-ear-dominant children was found in the eight-year-old group, and the smallest number with ten-year-olds. Across ages, there were no significant differences in occurrence for children with REA, while with LEA children, there were [$\chi^2 = 7.195$; $p = 0.019$]. No significant difference was found between boys and girls.

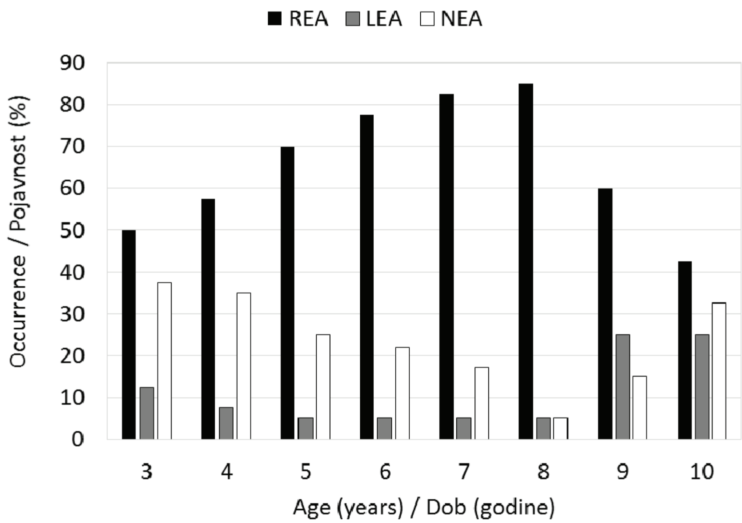

Figure 4. The occurrence of REA, LEA, and NEA in the age groups studied, based on double word pairs

Slika 4. Pojavnost REA, LEA i NEA u ispitivanim dobnim skupinama s obzirom na dvostruke parove riječi

3.4. Calculating lateralization indices

We submitted our raw data to LI calculations (see Figures 5 and 6). Observed dominance characterized 92% of all children. As most of our participants exhibited REA, group-level LI's were obviously positive. Lateralization indices exhibit a significant difference between kindergarten pupils and schoolchildren. Until age 8, lateralization indices are relatively high, while in the three oldest groups we received relatively small values. Statistical analyses revealed a significant difference in LI-values (as dependent factors) according to age (as independent factor) [$F(2, 634) = 11.234$; $p < 0.001$].

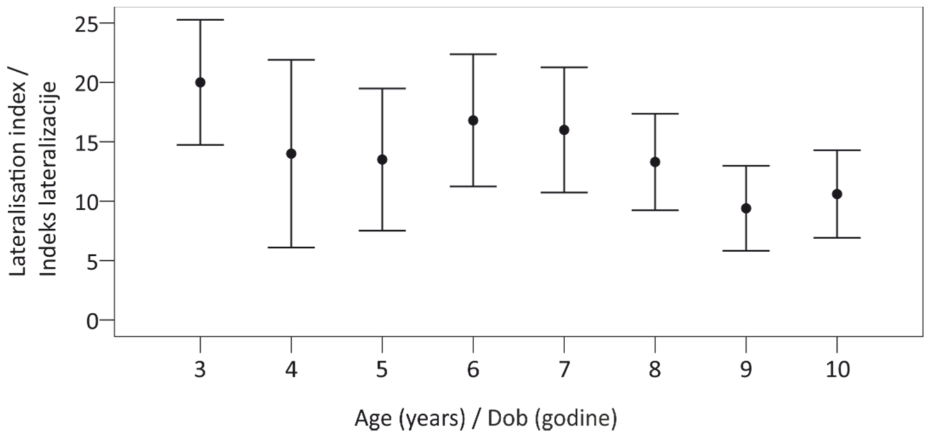

Figure 5. Data of the lateralization index by age group (means and standard deviations)

Slika 5. Indeks lateralizacije s obzirom na dob (aritmetička sredina i SD)

On the basis of LI, we once more found REA to be confirmed in most cases in each age group. The occurrence of LEA is far more modest, except for nine-year-olds, where this value showed a local maximum. LEA occurred the least frequently with six- and seven-year-olds; it was higher for both younger and older groups. Three-year-olds showed no NEA at all. The values of NEA exhibit a slightly increasing tendency with growing age (except for nine-year-olds). Statistical analyses showed that the occurrence of REA, LEA and NEA based on LI-values exhibit significant differences with growing age [$\chi^2 = 11.015$; $p = 0.03$].

We compared the data we gained from the three methods of calculating ear advantage. Ratios of occurrence of REA and LEA in the age groups studied here practically did not differ between results of simple subtraction and lateralization indices. With the double word pairs method, however, we found a difference: characteristic discrepancies were observable in the age groups of three to five years and at ages of 9 and 10. For six-, seven-, and eight-year-olds, however, occurrences were just slightly different.

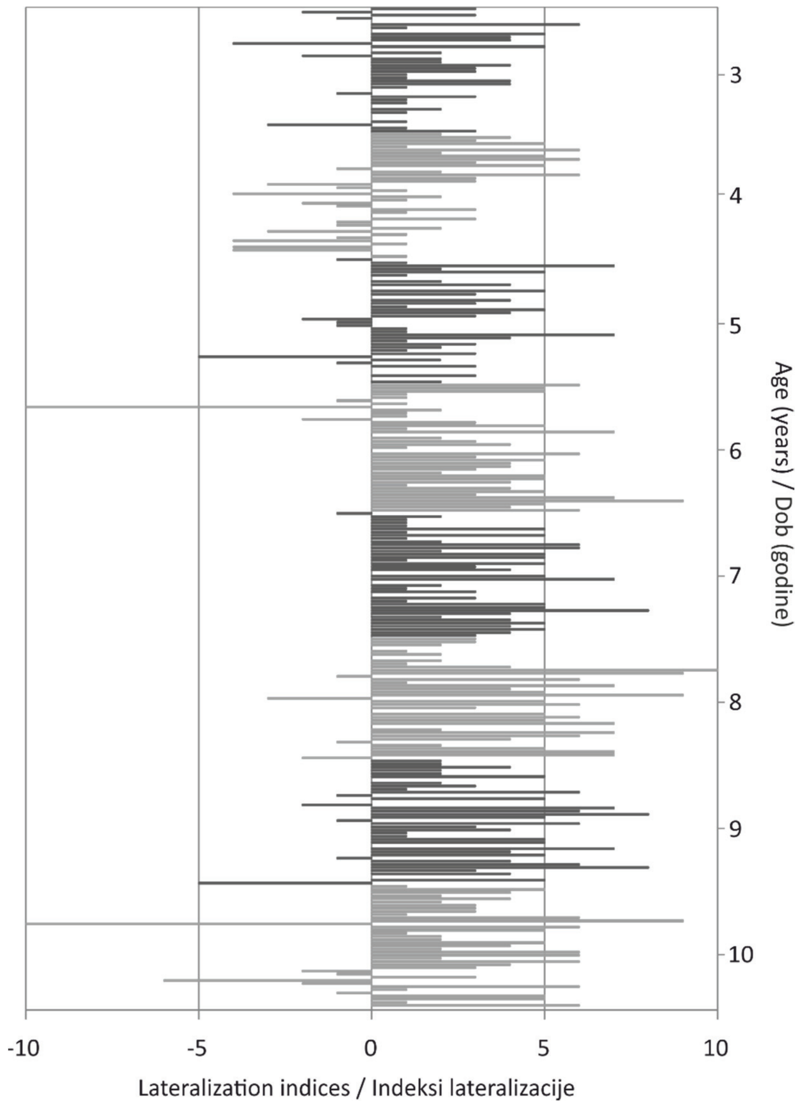

Figure 6. Ear advantage in terms of lateralization indices between 3 and 10 years (the vertical axis illustrates the children, the horizontal axis shows the LI-values)

Slika 6. Prednost uha s obzirom na indeks lateralizacije u dobi od tri do deset godina (okomite linije predstavljaju ispitanike, vodoravne linije pokazuju vrijednosti indeksa lateralizacije)

4. CONCLUSIONS

Previous studies suggested that cerebral asymmetries based on the functional division of labor across various areas of the brain, as well as which cerebral hemisphere is dominant from a linguistic point of view, can be determined from age three on (Best, 1984; Hiscock, 1988). However, the literature contains contradictory claims concerning when exactly ear advantage or hemispheric dominance becomes stabilized. In the present study, we examined 320 typically developing children between three and ten years of age with a dichotic test procedure. The data were processed via a number of calculation methods but the diverse methods yielded rather similar results.

Older children accurately identified more words than the younger ones did, confirming the development of the abilities necessary for word recognition under specific conditions like speech perception control, coordination and integration of the different speech signals. The straightforward explanation may be somewhat speculative, but the fact that a child participates in an increasing number of communicative situations of increasing diversity necessarily contributes to an increasingly better performance in processing incoming linguistic stimuli and this is reflected in the dichotic word recognition task, too. The development of attention with age and its effect on the results of dichotic tests has been offered as an explanatory factor in several studies (e.g. Moncrieff, 2011).

In the present paper, age was found to exert a statistically valid influence on the correct perception of dichotically presented words. Our first hypothesis was thus confirmed. The performance of three- and ten-year-olds differed by 43% (older subjects performed better). The degree of development is higher with younger children than with older ones, but it gradually takes place through all these age groups. The recognition of words administered in the right ear is significantly more accurate at the group level than that of words coming to the left ear. The number of correctly recalled words increases with age; the increase of the correct answers for words coming to the left ear is somewhat more pronounced than the increase of the correct repetition of those heard in the right ear. This suggests that the development of the integration and coordination of the two kinds of linguistic stimuli is larger in the case of words presented to the left ear. The data confirm our hypothesis, and correspond to findings reported in the literature (e.g. Hugdahl, 1999; Moncrieff, 2011).

Data taken from the literature are almost impossible to compare with data from other studies (including our own), due to methodological difficulties. With that problem in mind, we compared our data with those of a study in which the ages of the participants were almost identical to those of our subjects but where the dichotic test involved monosyllabic numerals (Rosenberg, 2011). The data, given in percentages, showed a high degree of similarity, both for right and for left ears. Correct repetitions produced by 6-, 8-, 9-, and 10-year-olds were almost identical in the two experiments, with respect to stimuli administered to either ear. Differences between results of the two experiments were found in the case of five-year-olds to a smaller extent, and in the case of seven-year-olds to a larger extent, especially with respect to stimuli presented in the left ear. These results might suggest that the perception of monosyllabic numerals and of disyllabic words may be similar in the given populations.

Participants in the present experiment mostly exhibited REA, but each age group contained subjects with LEA, and NEA also occurred, albeit to an insignificant extent. Our corresponding hypothesis was thus confirmed. Our results are highly reminiscent of the data for the given age range in the literature. We established that, irrespective of the method of calculation, no differences to speak of can be found in the ratios of ear preferences. The occurrence of REA typically diminishes from age eight onwards, and the occurrence of LEA slightly increases (as compared to that observed in younger age groups), as does the ratio of lack of observed preference. We suggest that this finding is in connection primarily with the developmental increases in attention, speech perception, working memory and/or language skills of children that affect ear advantage direction (Moncrieff, 2011).

We cannot explain why nine-year-olds exhibited LEA to an unexpectedly high extent (30% on the basis of data yielded by the simple subtraction method). On the basis of the double word pairs method, it is not only nine-year-olds but also ten-year-olds whose performance suggest diminishing REA and increasing LEA and NEA. This suggests the possibility of a structural reconfiguration of hemispheres and their interconnections as an influencing factor (e.g. Westerhausen et al., 2011).

In an investigation involving a dichotic test with CV-syllables administered to English-speaking young adults, LI-values turned out to be between 2.9 and 30.4 (Penna et al., 2007). In our own material, the LI-values are between 4.3 and 21.0, suggesting that children's results are more homogeneous, although the important difference between the linguistic stimuli used in the two studies (in addition to those of the age ranges) cannot be dismissed, either. The ear-advantage established on the basis of LI-values do not significantly differ from our results based on our previous calculations, confirming the fact that the number of correctly recalled words presented in the given ear is crucial across the board. The difference, nevertheless, between LI results and those gained from double word pairs, is that in the former the significant decrease in the occurrence of REA already begins at age 8.

In this study, we did not find any difference between boys' and girls' performances. Note, however, that in her (similar) dichotic experiment, Moncrieff (2011) found gender differences that even changed across age groups. In her data, 5-7-year-old girls outperformed their male peers. With 8-10-year-olds, she found no difference between boys and girls, either in REA or in LEA. In the 11-12-year-old group, however, she found boys to exhibit larger LEA and smaller REA than in the case of girls.

The present paper reported the results of a cross-sectional study. The dichotic listening method seems to be a good way to detect the auditory-phonetic abilities of typically developing children, and one that can be used from a very young age. If the participants' hearing is normal, ear advantage can be established on the basis of repetition of linguistic stimuli. The amount of words correctly recalled on hearing them in the right or left ear also gives us good indicators on the subject's level of attention and memory (cf. Sætrevik, 2012 on cognitive control over attention). Age-specific data of this study could be used for a better understanding of atypical language development under both educational and clinical circumstances.

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Prepoznavanje riječi dihotičkim slušanjem u različitoj dobi

Sažetak

Slušno prepoznavanje riječi ovisi o usvajanju leksičkih i fonoloških reprezentacija u procesu usvajanja jezika. Ulazne informacije koje se primaju slušanjem različite su za svako uho. One su, stoga, i konkurentske pa se tijekom integracije podražaja međusobno natječu u obradi. Cilj je ovog istraživanja da se prikupe razvojni podaci slušnog (fonetskog) procesiranja riječi primjenom zadatka dihotičkog slušanja. U istraživanju je sudjelovalo 320 ispitanika, govornika mađarskog jezika u dobi od tri do deset godina. Dihotičko se slušanje koristi kao osjetljiva, neinvazivna istraživačka metoda za procjenu lateralizacije jezika. Podaci su obrađeni tako da je za svakog ispitanika, s obzirom na ulazne informacije u svako pojedino uho, izračunat postotak (i broj) točnih riječi po prisjećanju. Rezultati pokazuju značajan porast broja ponovljenih riječi s obzirom na dob. Očekivano, točnije prisjećanje riječi pokazalo se za one podražaje koje su djeca čula u desnom uhu, čime se potvrđuje prednost desnog uha (engl. *right ear advantage* – REA). Dihotičko slušanje je kvalitetna istraživačka metoda za procjenu slušnih, tj. fonetskih sposobnosti djece urednoga govorno-jezičnog razvoja.

Ključne riječi: prepoznavanje riječi, dihotičko slušanje, djeca, mađarski, lateralizacija