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The connection of hemispheric activity in the field of audioverbal perception and the progressive lateralization of speech and motor processes

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This article discusses the connection of hemispheric control over audioverbal perception processes and such individual features as "leading hand" (right-handedness and left-handedness). We present a literature review and description of our research to provide evidence of the complexity and ambiguity of this connection. The method of dichotic listening was used for diagnosing audioverbal perception lateralization. This method allows estimation of the right-ear coefficient (REC), the efficiency coefficient (EC), and the effectiveness ratio (ER) of different aspects of audioverbal perception. Our research involved 47 persons with a leading right hand (mean age, 29.04±9.97 years) and 32 persons with a leading left hand (mean age, 29.41±10.34 years). Different hypotheses about the mechanisms of hemispheric control over audioverbal and motor processes were assessed. The research showed that both the left- and right-handers' audioverbal perception characteristics depended mainly on right-hemisphere activity. The most dynamic and sensitive index of the functioning of the two hemispheres during dichotic listening was the efficiency coefficient of stimuli reproduction through the left ear (EC of the left ear). It turns out that this index depends on the coincidence/noncoincidence of the leading hemispheres in speech and motor processes. The highest efficiency of audioverbal perception revealed itself in the left-handers with a leading left ear (the hemispheric-control coincidence), and the lowest efficiency was in the left-handers with a leading right ear (the hemispheric-control divergence). The right-handers were characterized by less variation in values, although the influence of the coincidence/noncoincidence of the leading hemispheres in speech and motor processes also revealed itself as a tendency. This consistent pattern points out the necessity for further research on asymmetries of the

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different modalities that takes into account their probable interaction. The results of our study comport with scientific data showing genotypic left-handers with subzero right-ear coefficient (REC) values to be more efficient than left-handed persons who display high REC values.

Keywords: left-handers, right-handers, dichotic listening, right-ear coefficient (REC), efficiency coefficient (EC), leading hemisphere in the process of audioverbal perception

The beginning of the study of the cerebral organization of the mental functions of left-handed people dates back to the mid-19th century, when Paul Broca formulated the rule that the hemisphere that controls speech is at the opposite side of a leading hand. In 1899 Bramwell described aphasia as a "cross" in a 36-year-old left-handed person with right-sided hemiparesis (Bramwell, 1899). Later on, it was discovered that there is no direct connection between handedness and hemispheric dominance in speech.

The Wada test and dichotic listening are considered to be the two main methods for differentiation of a dominant-in-speech hemisphere. Wexler and Halwes (1983) proved the high test-retest reliability of the dichotic listening method. Zatorre (1989) carried out dichotic listening on a sample of right- and left-handed patients who also took the Wada test. The finding about speech laterality according to the results of dichotic listening coincided with Wada test values in 36 of the 38 individuals (95%). These empirical data give grounds for judging the dichotic listening test to be highly accurate as an instrument for differentiating a dominant-in-speech hemisphere.

Until now, many contradictory facts have been gathered from the results of dichotic listening with left-handers. For instance, according to the findings of Kimura (1983) 50 percent of left-handers have left-hemispheric dominance in speech, and the remaining 50 percent have right-hemispheric dominance. According to the findings of Warrington and Pratt (1973) this proportion is 75% and 25%, correspondingly. On analyzing the findings of Hécaen and Sauguet (1971), Kinsbourne (1988) reported that 70 percent of left-handers have bilateral representation of speech, and most of the remaining 30 percent have left-hemispheric dominance. Moffat, Hampson, and Lee (1998) reported that, according to their research, 54 percent of left-handers have left-hemispheric dominance in speech, and 46 percent have right-hemispheric dominance. Dos Santos Sequeira and colleagues (2006) showed exactly opposite results (left-hemispheric dominance in speech in 46.4% of left-handers, and right-hemispheric dominance in the remaining 53.6%of left-handers). For their part, 64% of right-handers have left-sided speech control, and 36% have right-sided speech control according to this research.

Kimura explains her findings in the following way. When two diverse stimuli are introduced in different auditory canals, the difference in the capacity of the ducts increases so much that transmission in the ipsilateral canal is suppressed (Kimura, 1961). This supposition explains the right ear's advantage. In his study Kotik (1975) comes to the following conclusion: both the left and the right hemispheres of the brain take part in audioverbal processes, particularly in the process of perception and reproduction of dichotic verbal stimuli. Thus, both the hemispheres are capable of coding audioverbal information. However, tracking in a subdominant hemisphere has its own particular features; in the case of dichotic perception, verbal stimuli form "the track"—that is, the "acoustic iconic figure" in the right hemisphere. When transmitting to the left hemisphere this track is subject to linguistic encoding, and it can be reproduced. At the same time, stimuli coming into the right ear and transmitted immediately to the left hemisphere have a shorter transmission path and, probably, this path is shorter on one link of encoding. Thus, one can suppose that stimuli perception is equally efficient in both auditory canals, but the hemispheres are not equal in the process of reproduction. This phenomenon creates an advantage for the right ear (Kotik, 1974).

When the results of dichotic listening in left-handers who do not have any left-handedness in their family were analyzed, the advantage of the right ear appeared, but there was no distinction in stimuli perception by the right and left ears within hereditary left-handers. Left-handers with left-handed relatives have a pronounced right-sided asymmetry, and left-handers who have no left-handed relatives show signs of bilateral and right-hemispheric control of speech function (Kinsbourne, 1988). Some other researches point out the absence of differences in asymmetry between hereditary and nonhereditary left-handers (Springer & Deutsch, 1989). According to the finding of Jäncke and colleagues right-handers and ambidexters reproduce the stimuli more rapidly and often as they are delivered into the right ear during dichotic listening, while left-handers respond more rapidly to the stimuli addressed to the left ear (Jäncke & Shah, 2002; Jäncke, Wüstenberg, Scheich, & Heinze, 2002).

In this article in discussing the empirical data we avoid the phrase "dominant-in-speech hemisphere." In our opinion, the procedures of the different variants of the dichotic listening test (verbal, syllabic, musical, etc.) are aimed not so much at the full composite of the processes of speech functioning, which is complex in its morphofunctional organization of the structure, but at its particular processes—namely, at audioverbal perception and audioverbal memory.

Method

In our experiment, the dichotic listening test was administered to two groups of individuals. Both groups consisted of healthy individuals from 18 to 51 years old with specialized secondary education, incomplete higher education, or higher education. None of them had a craniocerebral injury or organic brain lesion; none had sought medical help from a psychiatrist. The group of right-handers consisted of individuals with a leading right hand (47 persons aged 29.04±9.97) who did not have any left-handed close relatives. In the group of left-handers (32 persons aged 29.41±10.34) were individuals with a leading left hand who had at least one left-handed close relative (a father, mother, brother, sister, grandmother, grandfather, uncle, aunt) and who did not have any injuries or other organic brain diseases.

In this research the dichotic listening test used was by Kimura (1961) and was adapted to the Russian language by Kotik (1974). The experimental procedure consisted of 13 presentations of verbal-stimulus material. In the first series four dichotic pairs of words were presented to each individual. Before each following presentation the individual was to pronounce all the heard words. Then the earphones were reversed (the phones on the left ear were placed on the right ear), and the procedure was repeated (the second experimental series). Only the first-series results were used for analysis (Kovyazina & Roshchina, 2014). The subjects were given the following instruction: "You will be presented simultaneously with different words through both earphones, some words into one ear, other words into the other. The words are produced in series. There are long pauses in between the series. Your task is to name all the heard words during the pauses."

The following coefficients were determined on the basis of the test results:

- The right-ear coefficient (REC) was determined according to this formula:

REC = *(∑D-∑S) / (∑D+∑S)*100%*, where *∑D* is the total quantity of correctly reproduced words presented to the right ear and *∑S* is the total of correctly reproduced words presented to the left ear.

- The effectiveness ratio (ER), proposed by Kotik (1988), was determined according to this formula:

ER = *(∑r-∑w) / (∑r+∑w)*100%*, where *∑r* is the total number of right answers and *∑w* is the total number of mistakes.

- The efficiency coefficient (EC): EC total, EC of the right ear, EC of the left ear:

EC total = *A / taw * 100%,* where *A* is the number of correctly reproduced words and *taw* is the total number of test words for all the reproduced words; *taw* = 104 words.

EC (right ear) = *A(r) / taw(r) * 100%,* where *A(r)* is the number of correctly reproduced words by means of the right ear and *taw(r)* is the number of test words by means of the right ear; *taw(r)* = 52 words.

EC (left ear) = *A(l) / taw(l) * 100%,* where *A(l)* is the number of correctly reproduced words by means of the left ear and *taw(l)* is the number of test words by means of the left ear; *taw(l)* = 52 words.

In the opinion of A. R. Luria, when rating the reproduction of dichotic stimuli one needs to employ all three indices (REC, ER, and EC), which in aggregate define "a dichotic syndrome" (Kotik, 1988).

Results

All the individuals in the research were divided into six groups depending on the leading hand and REC values. The extraction method of the extreme groups according to the quartile values of the REC (median, 11.76; 25th percentile, 0; 75th percentile, 28.2) was applied to divide the individuals into six groups: the group with a leading right hemisphere in audioverbal perception included those individuals whose REC 2qw less than 0%; the group with bihemispheric control of audioverbal perception included those individuals with a REC of 0% through 28.2%; the group with a leading left hemisphere in audioverbal perception included those with a REC of more than 28.2%. Each of these groups was divided into subgroups according to the leading hand. Thus, there were six groups of individuals: the left-handers with a leading right hemisphere in audioverbal perception — that is, with low REC values (8 persons, 10%); the left-handers with a leading left hemisphere in audioverbal perception — that is, with high REC values (9 persons, 11%); the left-handers with bilateral control of audioverbal perception — that is, with medium REC values (15 persons, 19%); the right-handers with low REC values (11 persons, 14%); the right-handers with high REC values (11 persons, 14%), and the right-handers with medium REC values (25 persons, 32%).

Comparison of the values (according to Cramer's V) did not reveal any differences between the groups ($V = 0.065$, $p = 0.845$). The findings conformed to empirical data of the last 15 years, which show that the distribution of right- and left-handers depending on REC values is nearly equal (Dos Santos Sequeira et al., 2006; Moffat, Hampson, & Lee, 1998; and others).

Comparison of the REC values in the left-handers and the right-handers by means of the Mann-Whitney U test did not reveal any significant differences between them (the medium REC value in the right-handers was 10.39 ± 23, 42%, the median was 11.76; in the left-handers it was 12.9 ± 27, 33%, the median is 12.7%; $U = 728.5$, $p = 0.814$).

The research results are shown in Figures 1, 2, 3 and 5 for the following groups: 1, the left-handers with a leading left ear; 2, the right-handers with a leading left ear; 3, the left-handers with a leading right ear; 4, the right-handers with a leading right ear. Figure 4 is a comparison of the groups' high and low REC values only (REC > 28.2% and REC < 0%). The medium group's scores (0% ≤ REC < 28.2%) are presented as additional information.

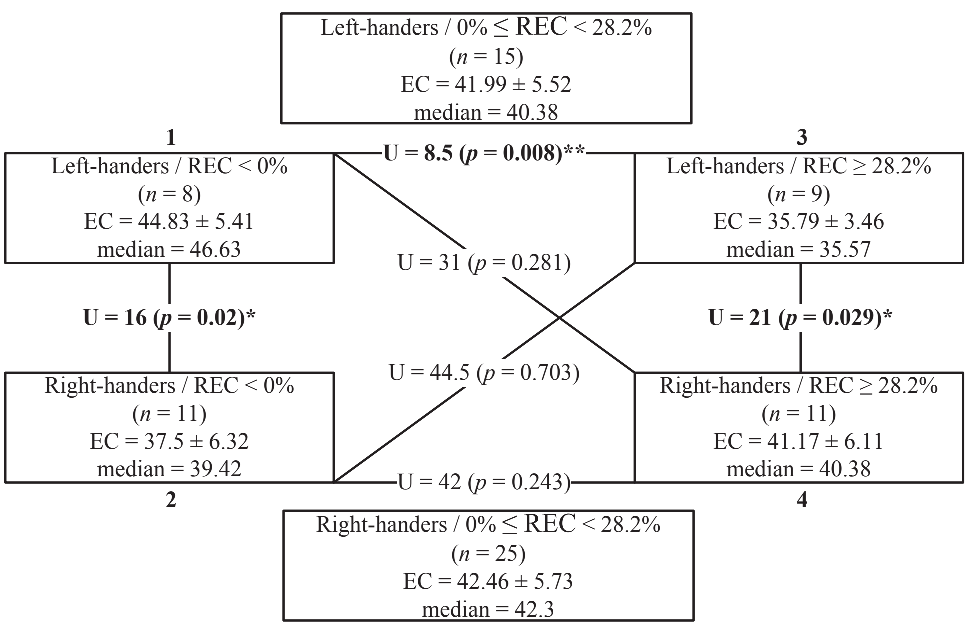

Figure 1. The EC in all the groups and the results of the extreme-group comparison according to REC (1, 2, 3, 4) by means of the Mann-Whitney U test

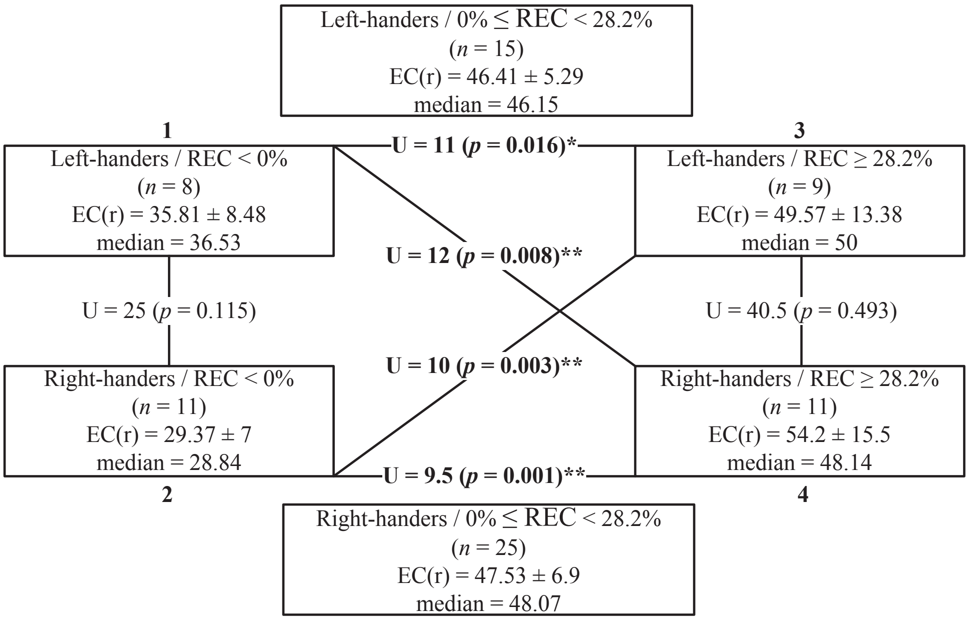

Figure 2. The EC of the right ear in all groups and the results of the extreme-group comparison according to REC (1, 2, 3, 4) by means of the Mann-Whitney U test

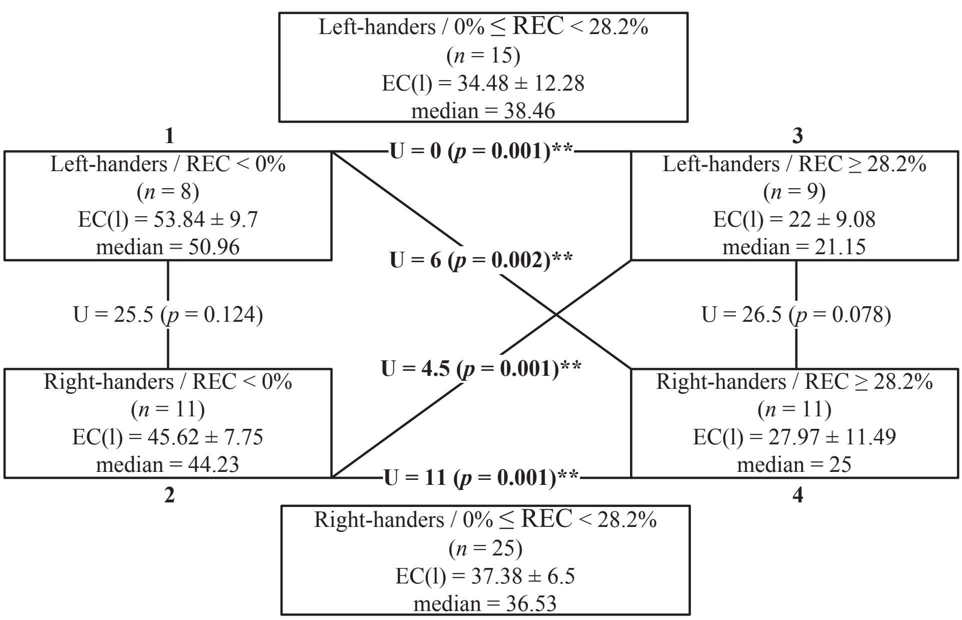

Figure 3. The EC of the left ear in all groups and the results of the extreme-group comparison according to REC (1, 2, 3, 4) by means of the Mann-Whitney U test

Discussion

Let us begin analyzing the results with presumption 1 (existent in the scientific literature): there is tight interaction of the hemispheres and their reciprocal interference in right-handers but not in left-handers. Left-handers are characterized by "a relative autonomy of the brain hemispheres" (Semenovich, 1991, pp. 83–84) and a considerable elimination of the reciprocal inhibitory influence of the cerebral hemispheres (Corballis, 1983; Dobrokhotova & Bragina, 1994; and others). "Because of this, the right hemisphere should be 'freer,' which enables it to take part in various forms of mental activity flow more actively" (Semenovich, 1991, pp. 83–84).

Let us consider the values of dichotic listening of the left- and right-handers with high REC values (groups 3 and 4 in Figures 2 and 3). Analysis of the EC of the right ear and the EC of the left ear provides evidence that the contribution of the left hemisphere to audioverbal perception processes in both groups is equal (in these groups there are no statistically significant differences between the EC values of the right ear, U = 40.5; p = 0.493). And the right-hemisphere contribution is seemingly not equal (the EC values of the left ear of the left-handers are lower than those of the right-handers' reflecting tendency, U = 26.5; p = 0.078). The right hemisphere in the individuals in the 3rd group is less "active" than in those in the 4th group. Thus, presumption 1 is disproved both when accepting the empirical data as statistically insignificant (left-handers have no advantage) and when taking into account the differences in reflecting tendency (according to the EC of the left ear the advantage is with the right-handers, not the left-handers).

According to the model proposed by Sparks and Geschwind (1968) the poor reproduction of dichotic verbal stimuli through the left ear (with left-hemisphere dominance in speech) is explained by the fact that information obtained through the right ear arrives immediately in the left hemisphere; through the left ear it arrives initially in the right hemisphere, and then, through commissural fibers, it is transmitted to the speech areas located in the left hemisphere of the brain. But why is the EC of the left ear lower in the 3rd-group left-handers than in the 4th-group right-handers if the mechanism of the efficiency reduction of dichotic-stimuli reproduction through the left ear is the same?

Let us make presumption 2: that the presence of differences between the right- and left-handers is hidden in a different hemispheric control of motor and verbal processes. If motor and verbal processes are under the control of oppositional hemispheres, the EC values of a nonleading ear are lower than are similar values when hemispheric control of motor and speech processes is nonoppositional. One needs to compare groups 1 and 2 in Figure 2 and groups 3 and 4 in Figure 3 in order to verify this presumption.

Let us check presumption 2 by analyzing the EC of the right ear in groups 1 and 2 — the left- and right-handers with low REC values, correspondingly, in Figure 2. Our presumption is not verified as there are no statistically significant differences between the EC values of the right ear in groups 1 and 2 (U = 25; p = 0.115). However, the left hemisphere's contribution is somewhat higher within the left-handers (group 1) than within the right-handers (group 2). The EC total value rises to statistical significance in the left-handers of group 1 but not in the right-handers of group 2 (Figure 1; U = 16; p = 0.02). The comparison of groups 3 and 4 is provided in our discussion above of presumption 1. In addition, the higher EC values of the left ear in groups 1 and 2 in comparison with the EC values of the left ear in groups 3 and 4, correspondingly, in Figure 3, can be explained by the fact that the left ear is leading in groups 1 and 2. Thus, in the presence of right-hemisphere dominance in audioverbal perception both hemispheres are more "active" in the left-handers than in the right-handers in the absence of statistically significant differences between the EC values of the left and right ear in these groups (1 and 2; 3 and 4).

The findings enable us to make another presumption — presumption 3: when the left hemisphere is dominant in audioverbal perception processes, then the coincidence/noncoincidence of hemispheric control over motor and speech processes influences the EC values of the nonleading ear (the EC values of a nonleading ear are higher in the case of coincidence than in the case of noncoincidence). When the right hemisphere is dominant in audioverbal perception processes, then the coincidence/noncoincidence of hemispheric control over motor and speech functions influences the EC values of the leading ear (the EC values of a leading ear are higher in the case of coincidence than in the case of noncoincidence).

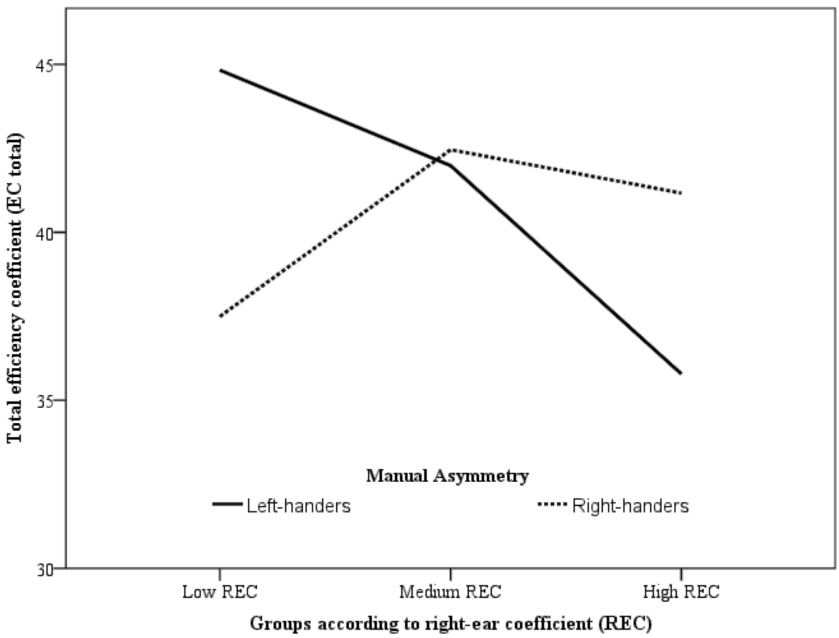

Figure 4. The EC in left- and right-handers with low, medium, and high REC values

Let us compare groups 1–2 and 3–4 in Figure 3 for the purpose of verification. Verification needs to show that the presumption is correct for both the right- and left-handers and needs to confirm the right hemisphere's greater contribution to hemispheric interaction in that, as the presumption states, "influences" on a leading and nonleading ear are always connected with the right hemisphere (the left ear). The comparison reveals that the presumption is not verified, but one may assert its higher probability as EC total values in group pairs 1–2 and 3–4 (Figure 1) have statistically significant differences. Moreover, the most interesting result is the following consistent pattern: the EC is significantly higher in the left-handers with a leading left ear than in the right-handers with a leading left ear; and this index is significantly higher in the right-handers with a leading right ear than in the left-handers with a leading right ear (Figure 4). The following fact deserves attention: the highest efficiency among all the groups is achieved by the left-handers with a leading left ear; the next highest efficiency is achieved by the right-handers with a leading right ear and then by the right-handers with a leading left ear, and the least efficiency is typical of the left-handers with a leading right ear. One cannot but admit that audioverbal perception efficiency is conditioned by an intermodal interaction (the interaction of manual and audioverbal asymmetry). This finding points out the necessity of further research on the asymmetries of the different modalities with due regard for their contingent interaction.

Let us state presumption 4: the left-handers with low REC values and the right-handers with high REC values have similar features in their audioverbal perception processes because manual and verbal processes in both groups are under the control of one hemisphere (groups 1 and 4) (see Figure 4). The same is correct in relation to the right-handers with low REC values and the left-handers with high REC values as manual and verbal processes in the both groups are controlled by different hemispheres (groups 2 and 3). One needs to compare each of the group pairs according to their ECs in order to accept this presumption (Figure 1).

Analysis of the results shows that there are no significant differences in the EC values both in the pair of groups 1 and 4 and in the pair of groups 2 and 3. However, there are significant differences between groups 1 and 2 (in favor of the left-handers with low REC values) and groups 3 and 4 (in favor of the right-handers with high REC values).

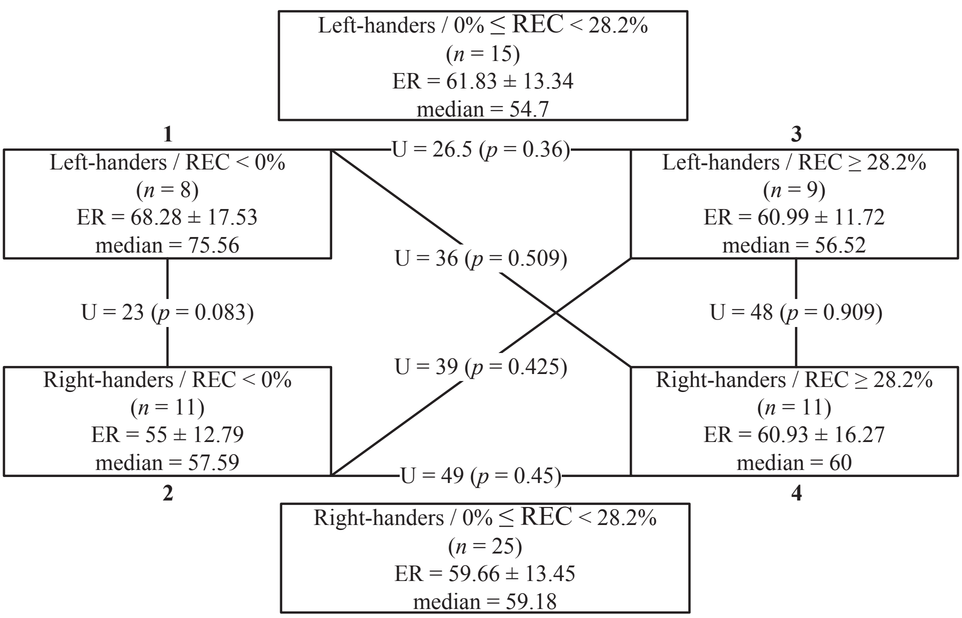

Figure 5. The ER in all groups and results of the extreme-group comparison according to REC (1, 2, 3, 4) by means of the Mann-Whitney U test

To complete our discussion of the results, notice that the EC turns out to be the least informative index for indicating the ratio between the number of correct answers and the number of mistakes when reproducing words during dichotic listening (Figure 5). The groups almost do not differ in this index value. Only between the left-handers with low REC values (group 1) and the right-handers with low REC values (group 2) there is a distinction between reflecting tendency (in favor of group 1). The EC partly conforms to the regularity described above (Figure 4). However, this consistent pattern is not observed in groups 3 and 4. On the one hand, this inconsistency may point to a fundamental distinction between the indices of efficiency and effectiveness. On the other hand, it may point to the necessity for further verification of the empirical data by involving more individuals.

Conclusion

The research results reveal that the peculiarities in the field of audioverbal perception within both the left- and right-handers depend mainly on the right hemisphere's activity. The most dynamic and sensitive index of the two hemispheres functioning during dichotic listening is the efficiency coefficient of stimuli reproduction through the left ear (EC of the left ear). It turns out that this index depends very much on the coincidence/noncoincidence of leading hemispheres in speech and motor processes. The results of this research match the data about genotypic left-handers with low REC values being the more effective than left-handers with high REC values.

Presumption 1 turns out to be the most debatable because of its claim that left-handers' right hemisphere is more active than right-handers' right hemisphere. "All the real left-handers … are placed rather closer to right-handers on the conceptual line whose one extremity is occupied by the right-handers and whose other extremity is represented by an ideal left-hander who is theoretically expected to be antipode to a right-hander in all the functional asymmetries (including psychic asymmetry) but who is, indeed, absent" (Dobrokhotova & Bragina, 1994, pp. 189).

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