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EVOKED POTENTIAL P300 IN METRICAL COGNITION – A PILOT STUDY

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Abstract. *In this study we conducted ERP measurement of the P300 evoked potential in three separate tasks. Five musicians and five nonmusicians listened to sequences in which a series of short tones of the same frequency was occasionally interrupted by an octave higher tone. In the first task, with the tempo of one tone in two seconds, the participants counted the higher tones; in the second task, they repeated the procedure, where the only difference was the slower tempo - one tone in three seconds; in the third task, the tempo was significantly faster - four tones in a second, and the participants were asked to ignore pitch changes and internally sequence a 4/4 beat and preserve this patterning until the end of the stimulus (about 4 minutes). Results suggest increased P300 latencies in the second and the third task, especially in the nondominant and dominant temporal areas, respectively. In the third task, P300 and P600 were recorded in all musicians, but in none of the nonmusicians. In addition to the conspicuous difference between musicians and nonmusicians, this suggests that simultaneous perception of a number of factors prolongs EP latencies, which may provide some neurophysiological grounds for constraint-based theories in the cognitive sciences of language and music, such as Optimality Theory. Additionally, pronounced excitation of the left temporal lobe may reveal some common neurological resources for metrical tasks in language and music.*

Key words: *ERP, P300, meter, language, music.*

INTRODUCTION

Regular sequencing of relatively stressed and unstressed beats in temporal perception, usually labeled 'meter', is one of the most widely studied aspects of auditory cognition. It is an abstract capacity of the mind, realized in forms as diverse as music, language, poetry, dance. Theories of meter in psychology, musicology, linguistics and literary theory have been numerous (Lieberman and Prince, 1977; Lerdahl and Jackendoff, 1983; Rothstein, 1989; Palmer and Krumhansl, 1990; Parncutt, 1994; Hayes, 1995; Lerdahl, 2001; Justin, 2004, among many others). An interesting phenomenon in itself, metrical percep-

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tion is also a venue in which aspects of music and language cognition most obviously overlap. For this reason, meter is considered one of the prime subject matters of the expanding interdisciplinary endeavor sometimes called 'musicolinguistics'.

The aim of this study was to test some neurophysiological aspects of human metrical cognition. Ten participants (five musicians and five nonmusicians) volunteered for the neurophysiological measurement of electrical cortical activity during the perception of simple melodic and rhythmical stimuli, in three separate tasks. The study, conducted at the Institute of Neurophysiology of the Clinical Centre Nis, Serbia, tested the neurological reaction using the well known event related potential P300. The latency of brain response was measured in situations in which some features of the perceived stimulus were varied (pitch change, tempo change, inference of metrical patterns). The goal was to determine whether the change of the feature would cause variations in brain response and also whether there would be differences in the results of musicians and nonmusicians. Ultimately, the aim was to test whether cortex areas usually associated with linguistic meter would be found in musical metrical mapping, too.

PREVIOUS STUDIES

Most research of common underlying neurophysiological basis for musical and linguistic cognition has been conducted on healthy subjects. In the literature one usually finds papers with small samples (ten to twenty volunteers), where participants are musically gifted, sometimes musically educated. The method often combines neurophysiological techniques (event-related potentials or brain mapping) and imaging (typically MEG, PET or fMRI scans). Since in Serbia at present there are no devices for real time brain imaging available, the overview that follows will focus mostly on interesting results obtained so far with the use of evoked potentials.

Evoked-potential studies looking into links between musical and linguistic cognition typically attempt to pin down structural or grammatical similarities. Some studies have registered high-latency positive peaks (P100, P300, more recently also P600) in situations in which healthy subjects' structural expectancies were disrupted, in either music or language. While linguistic and musical cues are perceived, expected sequences do not evoke any noticeable reaction, while those structures in which syntactic rules or harmonic progressions are disrupted cause high-latency evoked potentials, sometimes larger than half a second. A typical research containing musical and linguistic stimuli, measuring the P600 potential, was conducted by Patel, Gibson, Ratner, Besson and Holcomb (1998). Fifteen musically educated participants listened to a sequence of randomly distributed acceptable and unacceptable linguistic sentences and musical chord progressions. Results showed that both incongruent linguistic structures and inappropriate chords in harmonic musical structure elicited positive peaks in the dominant hemisphere, approximately 600ms after the onset of the stimulus (the unexpected phrase in the sentence, or chord in the musical cadence). Latency increase following more complicated tasks will be the first assumption behind our study.

In replicated research, authors have suggested that Broca's area remains the main candidate for the localization of this latency, which is however difficult to prove using the ERP method. Working with eighteen musically untrained volunteers, Koelsch, Gunter and Friederici (2000) showed that the antero-temporal region of both hemispheres might be responsible for the perception of tonal and harmonic functions. Further research, utilizing the more advanced MEG technique, showed that Broca's area, once considered the center of linguistic, grammatical localization plays a certain role in musical cognition as well, which some authors a bit awkwardly labeled "musical syntax"[1]. (Maess, Koelsch, Gunter and Friederici, 2001). Broca's antipode in the right hemisphere was found to be active, too. The research of this group continued, in search of the musical correlates of linguistic semantics, where there was also a cautious mention of Wernicke's area, a cortex zone long known to play an important role in linguistic semantics (Koelsch et al, 2002). Tests conducted by the neurophysiological group of the Mediterranean Institute of Cognitive Neurosciences also point to similar tendencies (Besson and Schon, 2001). In the second part of their experiment, musical laypersons of normal intelligence listened to short linguistic and musical phrases interrupted by a pause at an unexpected location. In both cases, high-latency potentials emerged (in linguistic stimuli, 400ms negative, in musical perception 600ms positive), in both hemispheres, ordered as follows: primary auditory areas, temporal and associative areas, followed by a short parietal activation. Once again, the brainwaves differ, but the cortical areas might be the same. There is now some agreement among authors that various kinds of metrical perception are typically processed in the motor areas of the cortex (e.g. Grahn and Brett, 2007).

The exploration has continued in recent years. Suggestive ERP studies include the comprehensive meta analysis in Koelsch and Siebel (2005), new syntactic evidence for overlapping neurophysiological integration in language and music provided by Koelsch, Gunter, Witthfold and Sammler (2005) and alleged neurological correlates of problems with understanding both musical and linguistic structures in children suffering from specific language impairment (SLI) (Koelsch, Sallat and Friederici, 2008). In terms of localization, the following areas have been found to be active in the perception of musical and linguistic tasks: primary auditory zones respond equally to musical and linguistic stimuli; secondary auditory zones react to meaningful words and simple grammatical musical phrases, such as full scales; they seem to also contain the center of melodic representation. Gyrus supramarginalis might have a role in the understanding of linguistic symbolism and musical scores; Broca's area is always linked to the motoric (rhythmic) activity in both symbolical forms, and sometimes it responds to purely tonal ungrammatical stimuli, along with its parallel area in the nondominant hemisphere. This last finding encourages us to anticipate a strong activation of the temporal lobe, in both hemispheres, in the perception of metrical and melodic cues. This will serve as the basis for the second assumption of our research.

The third important dilemma in metrical studies is whether there are any differences in the accomplishment of musicians and nonmusicians. On the one hand, Koelsch et al (2000) reported no difference between previous studies, done with musical professionals, and their own, which tested only the musically uneducated. Hence the title of the paper, claiming that "nonmusicians are musical", at least neurophysiologically. Jongsma, Quiroga and van Rijn (2004) are a bit more neutral. They studied omission related potentials in the rhythmic perception of 12 musicians and 12 nonmusicians. Although musi-

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[1] In standard musicolinguistics, ever since Lerdahl and Jackendoff (1983), music and language have been typically compared on phonological or (more rarely) semantic levels. Linguists and music theorists usually agree that the term 'musical syntax', though commonly used, is either an oversimplification or a metaphor. Cognitive neuroscientists, however, tend to use the term to denote chord progressions in music, which is a simplified view, not fully acceptable for musicolinguists.

cians' latencies were a bit smaller, no differences were found in the wave amplitudes during the registration of unexpectedly omitted metrical beats. On the other end of the spectrum, we find studies insisting on differences. Van Zuijen et al (2004) tested the phenomenon of melodic grouping, based on the Generative Theory of Tonal Music (Lerdahl and Jackendoff, 1983) in musicians and nonmusicians. Significant differences were found in instances in which the sequence was separated by a harmonically deviant tone (the onset of the evoked potential). Hence, these authors claimed that, neurologically, the thesis of relative equality of musical grouping in musicians and nonmusicians (raised first by Deliege, 1987, but see also Antovic, 2007, experiment 1) was questionable. Similarly, Magne, Schon and Besson (2006) made a preliminary claim that there were differences between musically educated and uneducated children in terms of detecting unexpected changes in pitch. The third question for our study is, therefore, the possible difference between musicians and nonmusicians while perceiving meter.

What would then be open issues in terms of the neurophysiological basis of metrical perception? First of all, there is the problem of localization. If in metrical tasks we encounter the reaction of some portions of the temporal lobe in the dominant hemisphere (parts of Broca, Wernicke, planum temporale), we may get some additional evidence on the possible deep neurological connection between segments of musical and linguistic functions.[2] If progressively complicated tasks increase response latencies, there will be some neurological support for the thesis that more complex metrical cognitive patterns, in language, music or any other symbolical form, require additional neurological effort. Finally, if differences are registered between musicians and nonmusicians, this will provide some neural grounds for the psychological differences noted in previous research.

The goal of the present study is similar to the papers reported above. However, although high-latency potentials have been standard in neurophysiology for over a decade now, due to the availability of equipment, we have adhered to the classic evoked potential P300 and the research technique known as oddball paradigm, which we slightly modified for the purposes of metrical exploration. This potential was first described very early, by Sutton, Braren, Zubin and John (1965), while it first proved useful as an instrument for perceiving incongruities in temporally ordered structures by McCarthy and Donchin (1981). When studying metrical competence, the method is today used rarely. Yet, we note some quite recent papers utilizing P300 in the study of music. While Schon, Gordon and Besson (2005) in their review mentioned this potential in the perception of harmonic relations, other researchers (Brochard et al, 2003; Abecasis et al, 2005) studied subjective stress imposed on auditory impulses where occasional unexpected strong tones were used to disrupt the subjects' metrical expectancies. As a result, there was a significant increase of P300 amplitude, especially in the left parietal area, typically in musicians.

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[2] How important Broca and parts of the temporal lobe known as Brodman 44, 45 are for the language function should not be particulalry stressed: the loss of grammatical abilities as a result of lesions in that part of the dominant hemisphere has been known since 1861. On the other hand, semantic incongruities are mainly related to Wernicke's area, also located in the left temporal lobe. Some recent papers further substantiating this well-known thesis of neurolinguistics may include: Friederici et al. (1999), Marcus et al. (2003), Musso et al. (2003), Muller and Basho (2004), Grodzinsky (2006). However, all these studies remain cautious in terms of the idea that Broca's area is solely dedicated to linguistic tasks. In doing so, they seem to tacitly criticize the strict position still advocated by Chomsky that linguistic competence is fully specific and separated from other psychological processes. With regard to the musical function, the more integrative position is particularly emphasized in Patel (2003).

In our research we have chosen to approach the problem from the opposite direction: in the final task, we used isochronous sequences in which we asked our participants to *deliberately, consciously* construct a metrical structure and internalize sequencing in a 4/4 beat. In effect, we introduced three separate, simultaneous tasks: pitch discrimination, tempo change and metrical inference, where one would interfere with the other. This technique is not unknown in neurophysiology – such increased workload on the brain has been shown to prolong latencies, but also, somewhat unexpectedly, reduce the P300 amplitudes (originally: "dual resource allocation", Donchin, 1981). Accordingly, in our study, too, we hoped that there would be differences between musicians and nonmusicians, that the temporal lobe, active in linguistic metrical tasks, would become activated, and that latency would increase with the metrical task becoming more complicated. This gave rise to our hypotheses, as described below.

HYPOTHESES

(1) While participants listen to repetitive tones of the same pitch, occasionally replaced by pitches one octave higher, with tempo variations, the latency of the P300 component will increase with the task gaining in complexity.
(2) The latencies will be most pronounced in the temporal regions in both hemispheres.
(3) There will be a significant difference in the achievement of musicians and nonmusicians.

METHODOLOGY

The study was conducted at the Institute of Clinical Neurophysiology of the Clinical Centre, Nis. While electrodes on their scalp were connected to the device, participants listened to three sound sequences: (1) the classic oddball paradigm, where repeated computer-generated tones of 1kHz were played, only to be occasionally, randomly and unexpectedly interrupted by tones one octave higher (2kHz); (2) the oddball paradigm slowed-down three times, with identical pitch progressions and identical task (for the subject to register and count the rarer, higher pitches); (3) the modified oddball paradigm, accelerated four times, where the task of the subject was to ignore any pitch changes and internally construct and follow the 4/4 metrical structure out of the tones he or she was listening to.

Electrophysiological methodology

We used the device for clinical evoked potential studies (Medelec Sapphire II). There were four recording sites on the scalp: C3 (left parietal), C4 (right parietal), T3 (left temporal), T4 (right temporal), referenced to Cz (vertex), according to the international 10-20 system. The following recording parameters were used: high pass filter – 0.1Hz, low pass filter – 50Hz, sweep time 1000ms. We presented the classical oddball paradigm, which consists of the repetition of monotonous, low-pitched stimuli occasionally interrupted by a pitch one octave higher. In each of the tasks, there were 32 targeted (high pitch) stimuli (15% of all stimuli). The rare and frequent stimuli were independently averaged. We focused on the latency of the most positive wave peak between 250ms and 500ms, which is generally taken to be P300.

Participants

The sample in this pilot study gathered ten right-handed volunteers (six men and four women), whose average age was 28.9 years (range 25-31, STD 2.28). All participants had normal intelligence and denied neurological disorders. Five of them did not have any formal musical education, while five were highly musically educated (held the degrees of college of music or academy of musical arts).

Tasks

There were three separate tasks in the study. In the first sequence, the task was only to register the higher (infrequent) tones and calculate how many there were. This was the standard P300, which is otherwise used in clinical practice (the tempo was one tone in two seconds). The second sequence introduced the same task, the only difference being deceleration (one third slower, the tempo was one tone in three seconds). Here, too, the task of the participant was to count the higher tones. In the third sequence, we introduced a dual task paradigm: we played the tones at the highest speed the device allowed us to (eight times faster than standard, or 4 tones per second) and induced the subjects to choose any tone they liked as the first in the sequence and start constructing internal 4/4 beats from that point on. In other words, they were asked to internally perceive one beat out of four as stressed, pattern the tones in such a way that from then on every fourth beat was accented, retain this internal patterning throughout the sequence, and not allow themselves to be "confused" by occasional changes in pitch.

The first part of the research acted as control. The second one represented a partly changed oddball paradigm where we wished to test what would happen if we confronted the tempo change with the perception of different pitches. In the third part we introduced another factor adding to the difficulty of the task: during auditory perception, we confronted pitch change and internalized metrical structuring with background tempo that was significantly accelerated. This was the simultaneous work of three distinct cognitive factors, or constraints, which resulted in effects that we describe below.

Data analysis

The data were analyzed based on latencies. After the resulting waves were obtained, we used the ERP device to allocate their peaks – moments in which the desired neurophysiological reaction was the strongest (representing the time in milliseconds that elapsed since the stimulus onset). Along with this, the shape of the wave was also a relevant factor. We illustrate this description with graphs obtained from individual participants.

RESULTS

Looking at participants individually, some tendencies were obvious: increase of latency from the first toward the third task and pronounced latency in the temporal zones in the second, and particularly third task. The most conclusive finding, however, remains the fact that in the third task, the P300 wave was not detectable at all in nonmusicians, while it was possible to locate in all musicians. Some typical graphs follow:

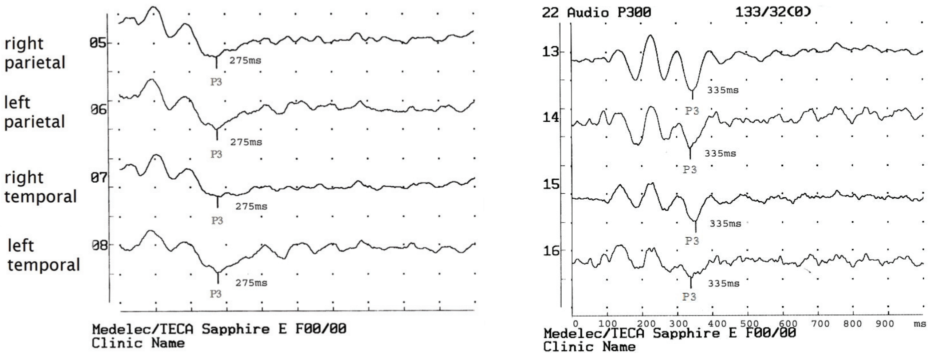

Image 1. P300 graph in the standard oddball paradigm (task 1) in one musician and one nonmusician.

In the nonmusician (right) the latency is a bit higher (335ms as opposed to 275ms), and a bit stronger excitation can be detected on the left temporal electrode (the fourth row) (Image 1). Both findings are normal, however, and they do not suggest any significant differences in perception.

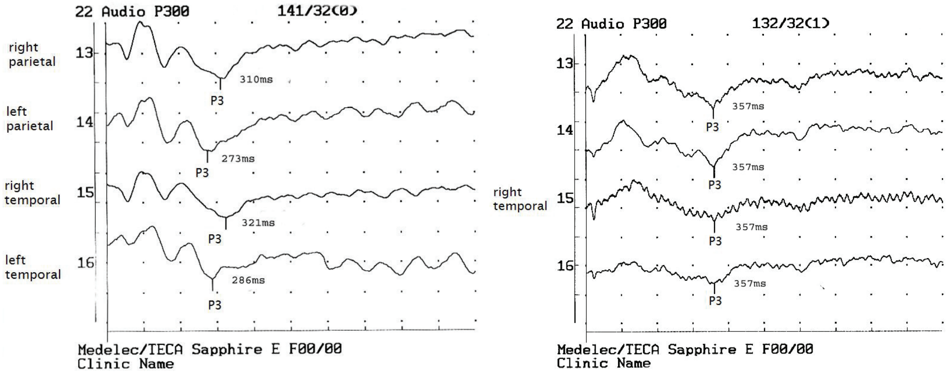

Image 2. P300 graph in the oddball paradigm decelerated three times (task 2) in one musician and one nonmusician.

In the musician (left) we find additional latency in the right hemisphere, especially on the right temporal electrode (third row, 321ms). In the nonmusician (right) all latencies are identical (357ms), but we also note the pronounced sawtooth wave in the right hemisphere, especially on the temporal electrode (Image 2 right, row 3). Therefore, the latency is slightly increased in the musician, and the waveform also suggests stronger beta activity in the right temporal area in the nonmusician.

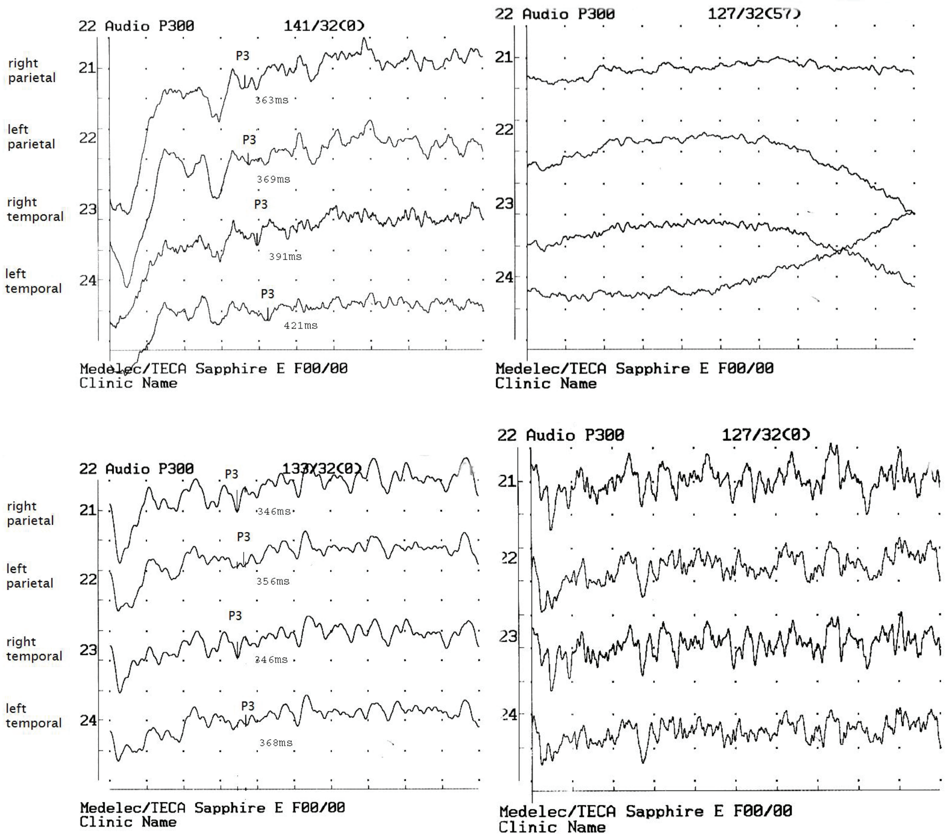

Image 3. EP graph during the internalized inference of 4/4 beat against the oddball paradigm accelerated four times (task 3) in two musicians (left) and two nonmusicians (right).

The first obvious result in musicians (left) is a pronounced positive wave in the first 100ms. As we were after the P300, we leave the interpretation of this tendency for further research. Otherwise, in musicians (left) the P300 wave may be tentatively discerned, although the latency is conspicuously prolonged, especially on the left temporal electrode, and the amplitude is quite small (Image 3, left, fourth row). In nonmusicians (right) we find asymmetric waves varying in morphology, where no clear-cut P300 can be found.

Finally, we present the graphs of four musicians in the third task (Image 4, inference of 4/4 beat). In all four, there is strong positive activity in the first 100ms. In addition, P300 is discernible, and it occurs later in the left temporal zone as compared with the remaining three electrodes. Typical of this group was the emergence of another similar positive component, with the peak occurring between 500ms and 800ms after the onset of the stimulus, especially on parietal electrodes (rows one and two):

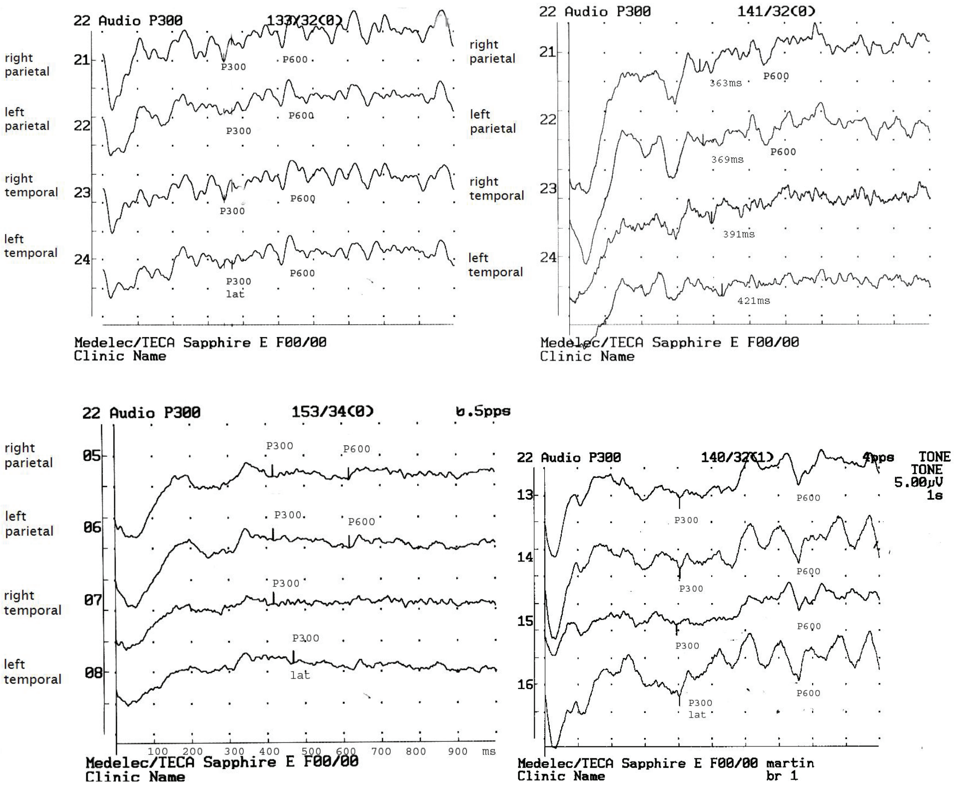

Image 4. EP graphs during metrical inference in 4/4 beat against the oddball paradigm accelerated four times in four musicians.

One should pay attention to the late potential in the graph. Quite possibly, in addition to P300, there emerged the component sometimes labeled P600 in the literature (see discussion).

The results provided so far have used individual latencies and graphs to help us pinpoint tendencies for the entire sample and two groups. To make any regularities clearer, below we report mean latencies and standard deviations.

Table 1. Mean P300 latencies. Entire sample (N=10).

Task	I – oddball 0.5		II – oddball – 0.3		III – 4/4 – 4
Electrode	Mean	SD	Mean	SD	
Parietal (R)	307	22.92	327.4	18.13	No P300 was found in nonmusicians.
Parietal (L)	309.5	20.34	320.9	27.71	
Temporal (R)	307	22.92	330.8	14.62	
Temporal (L)	309.5	20.34	323.9	26.80	

For the entire pilot sample, we have found the following (Table 1):

1. The standard oddball task (tempo: 2 beats per second) provided normal results in all ten participants. Average latencies were quite close to the 300 ms value – they were slightly prolonged in the left hemisphere (2.5ms). Naturally, as we were working with healthy participants, this was fully expected.

2. The slowed down oddball provided generally higher latencies (occurring on average 17.4ms later than in the first task), whereby more prolonged response time was registered in the right hemisphere (less pronounced in the parietal and more pronounced in the temporal lobe – 20.4ms longer on average in the parietal, and 23.8ms in the temporal zone). The preliminary conclusion might be that the right hemisphere, especially the right temporal zone, needs more time to respond when tempo is decelerated.

3. In the third task, there was no point in calculating means as there were no interpretable P300 waves (and, consequently, peaks) in nonmusicians.

Table 2. Average P300 latencies. Musicians (N=5).

Task Electrode	I – oddball 0.5		II – oddball – 0.3		III – 4/4 – 4	
	Mean	SD	Mean	SD	Mean	SD
Parietal (R)	295.6	22.24	314	7.71	371.4	25.01
Parietal (L)	299.4	17.46	299	15.84	375.6	23.24
Temporal (R)	295.6	22.24	320.8	3.49	377.4	26.06
Temporal (L)	299.4	17.46	302.4	13.31	394.6	27.13

With musicians, the following regularities may be reported (Table 2):

1. The classical oddball test has provided normal results (average brain response times are very close to 300 ms – a bit more pronounced in the left hemisphere, however the differences amount to neglectable 4ms or less).

2. The slowed down oddball task resulted in the generally higher latency (11.65ms late on average), where a more conspicuously late response was found in the right hemisphere. Like in the entire sample, in the right temporal lobe the latency is very prominent: on average, additional 25.2ms. We conclude that in musicians in particular, the right hemisphere, first of all its temporal area, is late in response to tempo deceleration.

3. Metrical inference of the 4/4 beat provided strong positive peaks within the 100ms range. In terms of P300, there was a generally higher latency as compared with the first two tasks (on average, the delay amounted to very prominent additional 82.25ms as compared with the first task). The late response is most obvious in the left temporal area (on average, as much as additional 95.2ms).

Table 3. Average P300 latencies. Nonmusicians (N=5).

Task Electrode	I – oddball 0.5		II – oddball – 0.3		III – 4/4 – 4
	Mean	SD	Mean	SD	
Parietal (R)	318.4	19.03	340.8	15.20	No P300 was found in nonmusicians.
Parietal (L)	319.6	19.27	342.8	16.69	
Temporal (R)	318.4	19.03	340.8	14.80	
Temporal (L)	319.6	19.27	345.4	16.83	

With nonmusicians, we report the following results:

1. The standard oddball test provided normal results here, too (average latencies center around the 300ms value – insignificantly prolonged in the left hemisphere, 1.2ms on average). However, here nonmusicians are late as opposed to musicians (on average, about 20ms on all electrodes, no statistical significance).

2. The slowed down oddball task provided a generally higher latency (23.45ms on average), where later response was found in the left hemisphere (less in the parietal – 23.2ms, more in the temporal area – 25.8ms). Therefore, with nonmusicians, the left hemisphere, too, is late when tempo slows down.

3. In the third task there was no point in calculating means since not one of the musicians provided the P300 wave.

Table 4. Statistical significance for the differences in average latencies of evoked potentials. Musicians and nonmusicians.

Task Electrode	I – oddball 0.5	II – oddball – 0.3	III – 4/4 – 4
	T test	T test	T test
Parietal (R)	t=1.741 df=8 Sig=0.120	t=3.515 df=8 Sig=0.08	t=33.211 df=8 Sig=0.00
Parietal (L)	t=1.737 df=8 Sig=0.121	t=4.255 df=8 Sig=0.03	t=36.132 df=8 Sig=0.00
Temporal (R)	t=1.741 df=8 Sig=0.120	t=2940 df=8 Sig=0.19	t=32.378 df=8 Sig=0.00
Temporal (L)	t=1.737 df=8 Sig=0.121	t=7.598 df=8 Sig=0.02	t=32.528 df=8 Sig=0.00

The comparison of average latencies of musicians and nonmusicians, based on t-test, shows there were no statistically significant differences in the first task (Table 4). Therefore, musicians and nonmusicians completed the classical oddball test in pretty much the same way. In the second task, there were significant differences on both left electrodes between the two groups, but not on the right electrodes. In the last test the P300 potential was registered in all musicians and no nonmusicians. As there were only ten participants, statistical calculations should be taken as illustration only. Even so, our study seems to have pointed at some neurophysiological differences in the achievement of musicians and nonmusicians with tempo change and construction of metrical patterns. We discuss this in further text.

DISCUSSION

To date, no one has posed a clear connection between psychological and neurological functions. Latencies, disrupted expectancies or subhemispheric localizations only attempt to register cortical zones active during particular perceptive tasks. Time and again it turns out that cognitive tasks, even if simplified to trivial levels, cause very complex neurological activation. Thus, accurate description of how the brain works is still an impossible task for science. At this point, attempts to link neurophysiological graphs or imaging scans with brain functions seem particularly speculative. In other words, even though we today can provide a real-time estimation "where" in the brain an activity is happening and "how late" it is (and this is itself a huge advance in science in the last ten or so years), many questions cannot be answered even in principle: "why" those areas and not some others, "how" those regions are networked into functional wholes, "what kind" of link there is between their activity and the construction of mental representations, and, finally, "what is the nature of our mental states", since, as much as they are introspectively convincing, they seem to emerge solely based on the activity of the brain as a formal system constrained by laws of physics. Dilemmas are numerous, responses lie far ahead, and they deal with the very essence of human nature.

At the present stage of neuroscience, in local conditions in particular, there are not many instruments to interpret our results with much certainty. Therefore, in order to reach any conclusions, let us start with the facts that, we believe, have been shown in this pilot study:

1. The clinical result of the perception of the standard oddball paradigm is the same in all participants. There are small fluctuations, nonmusicians are on average 20ms late, but with no statistical significance. In this respect, we may conclude that musical education is not a predictive factor for achieving better results in the standard, clinical P300 auditory test. Apart from being good for the test itself, this finding suggests that all participants were healthy, that they did the control task as expected, which allows us to interpret the remaining results with some certainty.

2. In all examples, musicians' average latencies are lower. In the standard paradigm (task one) there was no statistical significance to substantiate this difference, but in the second and third tasks it was noticeabl (at least in the left hemisphere). This suggests that the musically trained mind has less difficulty completing tasks in which segmentation is required based on a musical parameter (pitch discrimination, tempo change, metrical inference). In all these tasks, the musician's brain needed less time, i.e. less attention to register the targeted relation, even when pitch change worked as an expectancy-disrupting factor. Therefore, some neurological dimension may be postulated for the difference between musicians and nonmusicians in perceiving basic metrical relations.

3. When tempo is significantly slowed down, in musicians, the left hemisphere is quite still, but in the right hemisphere there is some additional latency (particularly in the temporal lobe). This suggests that, in musicians, incongruities stemming from the reduced repetition of pitches are predominantly registered in the nondominant hemisphere.

4. The principal result of this study is that, when beat is inferred and tempo accelerated, musicians construct the P300 wave on all electrodes, smaller in amplitude and with quite a long latency, most obvious in the temporal area of the dominant hemisphere. In nonmusicians, this wave is not detectable at all. Musicians seemed to be perfectly aware of what they were doing in this research segment. After the test, we asked them if they managed to register every succession of beats in the common time meter (4/4). The usual response was "of course". On the other hand, after the measurement, nonmusicians explained that, regardless of conscious effort, they usually "got lost" in the inference process, which obviously had an effect on the neurophysiological measurement. If we take this to be a possible consequence of the lack of metrical understanding among nonmusicians, this suggests that certain centers for metrical comprehension are indeed located in the left temporal area, a principal motor center of the brain.

5. In the third task, in musicians, the resulting wave on all electrodes was very suggestive, more complex than we had expected. In all five of them, especially on parietal

electrodes, we isolated a similar wave, positive in direction, less stable in morphology, occurring 500ms to 800ms after the inception of the targeted stimuli. This might be the P600 component. With linguistic stimuli, it was first reported by Hagoort, Brown and Gorthusen (1993). The prevailing opinion today is that P300 is a rather general potential, evoked by any disrupted sequencing of events (oddball), while P600 is considered to be more related to structural, "grammatical" disturbances. In language, the potential was registered when the agreement of the grammatical categories of subject and predicate in English syntax was disrupted (Osterhout, McKinnon, Bersick and Corey, 1996). It is believed to be a "syntactic" potential, although semantic anomalies have been reported recently (Van Herten, Kolk and Chwilla, 2005). In music, Besson and Schon (2001) extracted the P600 component, too – they used disrupted agreement between individual tones in pitch sequences to get this effect. In the present study latencies also varied, and the strong reaction was noted on parietal electrodes. This result, though a bit unexpected, remains as a motivation for further work.

6. In the third task, an early positive component (about 100ms) was very pronounced in musicians. This is also an issue to be studied further.

Our results strongly support the statements above. We now attempt to reach conclusions based on the three hypotheses.

1. The first hypothesis postulated that added complexity of tasks would result in longer latencies. It was fully corroborated. In the entire sample, reaction times ranged from 307 and 309ms on all electrodes in the first task to 320 and 330 ms in the second task. In nonmusicians, the first task provided a response on average 318 to 319ms late, and the second one resulted in 340 to 342 ms latencies. The third task, in which P300 was found only in musicians, provided noticeably large latencies: on average, from 371 to 394ms. From all examples, the lowest latency in an individual participant was found in the first task (268ms) and the highest was located in the third (421ms). Additionally, the highest individual latency in the first task (335ms) was still lower than the lowest latency in the third (346ms). All this suggests that the brain needs more time to process a stimulus if the second, and then the third factor becomes involved in the perception task. The more complex the stimulus (in terms of the simultaneous action of a number of musical elements), the later the brain reaction.

2. The second hypothesis anticipated that there would be more delay in temporal regions in the second and third tasks. This was confirmed, too. In the second task, the right temporal electrode showed the highest latency in the sample and in musicians (330.8ms and 320.8ms on average). In nonmusicians, too, this electrode was conspicuously late (340.8ms). However, with them, the left temporal electrode showed even higher latencies (345.4ms on average). In terms of the third task, the hypothesis holds with musicians (as there were no P300 with nonmusicians): the highest average latency was clearly seen on the left temporal electrode (394.6ms on average, almost 20ms later than the remaining three). This result might suggest that some basic musical relations are indeed registered in temporal regions, whereby metrical patterns are mainly processed in the left temporal area. The more pronounced response of the right temporal region following tempo deceleration is, to our knowledge, a new finding: studies so far have mostly reported this area as the center of melodic and harmonic representation. This might have been the case in our study, too, because the tempo was indeed so slow (one beat in three seconds) that, especially musicians, could have lost any sensation of regular repetition and registered only

the change of pitches. This should be tested in further studies, especially because in this segment differences between musicians and nonmusicians occurred that remain unclear.

3. The third hypothesis proposed there would be a difference in the achievement of musicians and nonmusicians. Studies so far have provided contradictory positions. In the control task, there were no significant differences (although musicians had shorter latencies in all four regions). In the second task, there was a statistically significant difference in brain response times on both left electrodes, but not on the right electrodes. In addition, there was also a difference in the form of waves (with strong, sawtooth right excitation in nonmusicians), and also some difference in the location of the longest latency (left in nonmusicians, right in musicians, mostly in the temporal area). In the third task, nonmusicians did not at all create waveforms that could be measured by our method, while musicians provided a strong early positive component, and also small amplitude waves interpretable as instances of P300. Taken together, all these parameters suggest that musicians and nonmusicians differently perceive our discriminative factors (tempo deceleration, tempo acceleration with metrical segmentation, both followed by occasional pitch change). This thesis should also be tested in further research.

CONCLUSION

Tendencies discussed above might allow us to speculate more freely about possible effects, relevant to some purely linguistic issues, as well. We propose these with some reservation, as an encouragement for further research.

The first thesis would propose that constraint-based theories, currently widely tested in linguistics (and much of cognitive science), such as Optimality Theory (OT, Prince and Smolensky, 1993), might have some neurophysiological support. If increased latency is a consequence of the need to increase the subject's attention, then the late brain response might come from the conflict of underlying constraints. In the first task, the discrimination boiled down to registering the difference between two pitches. In the second, the significantly decelerated tempo was an additional discriminative factor that the brain had to consider along with the pitch change. In the third task, at least three factors worked at the same time: pitch change, significantly accelerated tempo, and the conscious effort the subjects were putting in in order to internalize the common beat out of the tones they were listening to. Using the vocabulary of Optimality Theory, at play here were one, two, and three simultaneous constraints. As the second, and then the third one was added, with the same expectancy-disrupting factor preserved, the brain response came later and later. The longer latency is probably a reflection of increased task complexity, i.e. the need for the brain to parallelly process more information. Thus, the thesis of an underlying conflict among the constraints, proposed by some connectionist theories in linguistics and musicolinguistics, such as OT, may have some neurophysiological backing.

The second thesis further supports the findings of some musicolinguistic research that brain resources responsible for linguistic and musical functions may partly overlap. More convincingly than other results, the final task registered pronounced left temporal activity in the dominant hemisphere with musicians. This is probably the location to search for the roots of the mental representation of rhythm. Rhythmicity does not seem to depend much on the external symbolical form in which it is presented (language, music, dance, bodily movements…). Rather, what might be registered in this area is cyclic repetition of temporally ordered structures. This would mean that the brain does not parse stimuli based on the symbolical form in which they are embodied in the external world, but rather on grounds of fully abstract structural similarities. Our equipment did not allow more precise localization, or stronger conclusions. In the literature, with respect to this issue, the following areas are mentioned: Broca, Wernicke, Brodman 41, 42, 44, 45, planum temporale, primary auditory zones. All these brain regions are at least partly situated in the temporal lobe. In terms of melodic and harmonic segmentation, the right temporal lobe is also mentioned (in particular Heschl gyrus), and this area was also active in our study when tempo was slowed down. Hence, if there is a neurological common ground for musical and linguistic structure, it should be sought, first of all, in the temporal areas of both hemispheres.

For more conclusive results more research is needed. Our goal in this study was to make a small step toward the neurosciences, having in mind the fact in our country almost no attention is dedicated to the neurological research of higher cognitive functions. On the one hand, this seems strange, since such studies have been quite common in the world in the last decade. On the other, larger samples and more modern equipment require substantial funding, and hence insufficient motivation for neuroscience in our universities. Even so, we believe that some positive changes lie ahead. First of all, today already we have well trained professionals who will be able to handle much more sophisticated equipment with no particular problems. In terms of devices, if magnetoencephalography or positron-emission tomography are indeed an unthinkable investment in local circumstances, a bit more up-to-date EP devices (with more electrodes, linked to modern computers, where stimuli can be freely programmed) and functional brain imaging scans (in concord with the already available classical magnetic resonance imagery) might not be so impossible to acquire in the present conditions. With this regard, we hope that in the near future, university clinical centers of Serbian cities will host modern neurophysiological or imaging devices. This will make a breakthrough not only in clinical practice, but also in neuroscience, where comparisons between language and music will be but a small research segment. Perhaps this preliminary study will serve as a small impetus to such a development in the future.

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EVOCIRANI POTENCIJAL P300 U METRIČKOJ KOGNICIJI – PILOT STUDIJA

Mihailo Antović

U ovom radu merili smo evocirani potencijal P300 u tri odvojena zadatka. Pet muzičara i pet nemuzičara slušalo je sekvence u kojima je niz kratkih tonova iste frekvencije povremeno prekidan za oktavu višim tonom. U prvom zadatku, pri tempu od jednog tona u dve sekunde, učesnici su brojali visoke tonove; u drugom zadatku, ponovili su istu proceduru, osim što je tempo bio sporiji – jedan ton u tri sekunde; u trećem zadatku, tempo je bio značajno brži – četiri tona u sekundi, a učesnici su zamoljeni da ignorišu promene tonskih visina i internalizovano izgrade svest o četvoročetvrtinskom taktu počev od bilo kog tona koji čuju, te da zadrže ovakav metrički sklop do kraja draži (oko četiri minuta). Rezultati sugerišu porast latencije potencijala P300 u drugom i trećem zadatku, naročito, i to redom, u nedominantnim i dominantnim temporalnim zonama. U trećem zadatku, potencijali P300 i P600 registrovani su kod muzičara, ali ne i kod nemuzičara. Uz vrlo primetnu razliku između muzičara i nemuzičara, ovo sugeriše da istovremena aktivnost većeg broja faktora produžava latencije evociranih potencijala, što ukazuje na neurofiziološku osnovu teorija baziranih na ograničenjima u kognitivnim istraživanjima jezika i muzike, poput teorije optimalnosti. Uz to, izražena ekscitacija levog temporalnog režnja sugeriše da postoje neki zajednički neurološki resursi pri metričkim zadacima u jeziku i muzici.

Ključne reči: *potencijali povezani sa događajem, P300, metrika, jezik, muzika*