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Temporal constraints in processing of nonverbal rhythmic patterns

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Abstract. This study investigates the effect of a mental content of presented stimuli, normal aging and individual differences in cognitive abilities on temporal limits of an integration mechanism. Younger and older subjects grouped together the beats generated by a metronome. Subjects were asked to listen to the beats of a metronome and to accentuate mentally every second, third, fourth...etc. beat, to create a subjective rhythm. This rhythm exists, in fact, only in subjects' mind and not objectively. Subjects reported verbally how many clicks they were able to integrate into a perceptual unit. On this basis, the time interval during which subjects were able to integrate temporally separated stimuli was calculated (number of beats reported as being integrated x time distance between beats) for different metronome frequencies. The results show, firstly, that the length of integration periods significantly depends on the frequency of presented metronome beats. When the frequency of metronome beats is high, the time interval during which the subjects integrate beats into a single perceptual unit is shorter. Secondly, older adults integrate information during a longer time interval than younger ones. Thirdly, the length of an integration period is related to a subjects' level of cognitive ability. These results suggest that the length of an integration period is not a constant, stable feature, but varies across the life span depending on the mental content of the information presented and individual factors.

Key words: temporal integration, metronome, subjective present

INTRODUCTION

Temporal mechanisms in the nervous system play a central role in fundamental aspects of information processing. Temporal integration is one of the mechanisms occurring at the highest level in a hierarchical taxonomy of time perception (e.g. Pöppel 1985). This neuronal mechanism allows us to integrate information over time and to bind successive temporally separated events into a single unit. In a hierarchical taxonomy of time perception the elementary temporal experience that is mediated by this integration process has been referred to as "subjective present" (Pöppel 1978). The temporal extent of this integration of nonlinguistic information is limited to approximately 2-3 s.

The temporal limit for integration of successive nonverbal events into perceptual units is for instance observed in motor behaviour, sensorimotor synchronization, spontaneous reversal rates of ambiguous figures and reproduction of temporal intervals (Pöppel 1978, 1985, Fraisse 1984, Schleidt et al. 1987, Mates 1994). There is some evidence that this mechanism can also play an important role in human speech. Spontaneous speech is characterized by rhythmic organization i.e. alteration between hesitation pauses and fluent speech. The notion of rhythmically programmed speech has for instance been suggested by Lashley (1951), Allen (1975), Pöppel (1978, 1985). In at least several languages (i.e. English, Spanish, German or Chinese) pauses in spontaneous speech occur predominantly after 2 to 3 s. (Kowal et al. 1975, Pöppel 1985).

Moreover, a hypothesis also exists suggesting that differential hemispheric processing is based on temporal factors. It has been suggested that the left hemisphere, rather than specializing in speech *per se*, mediates the underlying temporal information in the speech signal (Lashley 1951, Carmon and Nachson 1971, Lackner and Teuber 1973, Divenyi and Efron 1979). According to this theory, timing provides specific temporal constraints for human speech and mechanisms for temporal analysis, including those of temporal integration, are really the basis for left hemisphere processing (e.g., Efron 1990, Levelt 1993, Liberman 1993). Given the well-established laterality of speech functions (e.g., see Springer and Deutsch 1989, Kolb and Whishaw 1990, Hellige 1993 for a recent review), theoretical models that involve rhythmic organization in speech processing would predict that the hemisphere specialized for speech processing is also the most effective hemisphere for rhythm (Halperin et al.1973, Gordon and Bogen 1974, Mavlov 1980). Robinson and Solomon (1970) suggest additionally that not only rhythmic speech patterns but also those nonverbal ones are processed by the same hemisphere as speech.

Much less attention has been paid, however, to the basic neuropsychological mechanisms underlying the binding process. The question arises whether this mechanism is characterized by a stable, unchangeable temporal limit or varies depending on several factors. If so, what factors are crucial for the limits of such a hypothetical integration mechanism? In particular, (1) can the length of integration periods vary depending on the informational content, i.e. how much information can be processed in a particular time interval? (2) are there any individual differences in the lengths of integration periods? (3) does the length of the integration period alter across life span? That is, do the changes in intellectual and cognitive functions, resulting from normal chronological aging (see Storand 1990, for a recent review), affect the temporal limits of this integration mechanism.

Everybody is aware of the fact that our experience of passing time is influenced by what we are doing. More then 50 years ago Axel (1925) and Swift and McGleoch (1925) theorized that "the level of behavioural activity" determines the experience of time. If one is engaged in a higher level of behavioural activity, time appears to pass rapidly, whereas a low level of behavioural activity, when one is bored, for instance, results in an impression of a time drag. This notion gathers support from recent research showing that informational content plays an important role in the reproduction of temporal intervals. A period devoid of interesting events is retrospectively estimated to be of a shorter duration than an empty period (Michon 1970, Vroon 1970, Pöppel 1978, Fraisse 1984).

In connection with the above, this study was designed to investigate whether the capacity of temporal integration depends on the information content of the presentaed stimuli. Although several studies (cited above) have investigated the effect of mental content of presented stimuli on the estimation of temporal intervals, the influence of such information content on integration process has not been studied before. As there exists considerable evidence concerning large individual differences among human beings in their cognitive abilities such as memory span, rate of information processing, duration of "the present", intelligence quotient - one can assume that the underlying mechanisms of temporal processing are related to differences in such abilities.

Another problem often discussed in the recent literature and well documented by clinical and experimental investigations is a later-life impairment of memory (both verbal and nonverbal), intelligence, verbal fluency, capacity for new learning, spatial ability, reasoning and problem-solving (e.g. Schaie 1979, Huff 1990, Gabrieli 1991, Huppert 1991). The cause of such declines are still not known (Storand 1990). One possible explanation is that such declines are part of the normal aging process.

On the other hand, in the existing literature there is some controversy about which of two competing points of view provides a better characterization of the neuropsychological basis underlying the normal aging process (see Hellige 1993 for a review). According to one point of view, aging involves greater loss of right- than left-hemisphere functions and therefore the right hemisphere ages more rapidly (e.g., Schaie and Schaie 1977, Klisz 1978, Albert and Kaplan 1979). As a consequence, an alteration occurs in the "normal" patterns of cerebral functional asymmetry in elderly subjects. According to the other point of view, the two hemispheres decline in the same extent with advancing age (e.g. Goldstein and Shelly 1981, Ellis and Oscar-Berman 1989, Mittenberg et al. 1989).

The hypothesis of "right-hemisphere aging" is based on the observation that psychometrically measured nonverbal, visuo-spatial functions, tend to decline more rapidly than verbal functions with old age (Wechsler 1958, Horn 1988). Elderly people are more likely to show decrements in a variety of nonverbal tasks (e.g., solving block-design problems) than in verbal tasks (e.g., vocabulary). Moreover, Horn and Cattell (1972) suggested that "impaired Performance IQ" and "spared Verbal IQ" are more typical for neurological patients with right-hemisphere injury than with left hemisphere injury. Based on this observation, it has been concluded that decreased intellectual functioning, in the elderly individuals, might be the result of the accumulation of minor insults to the brain. On the other hand, the results of recent studies of age-related changes in specific cognitive abilities do not support the conclusion that normal aging has a differential effect on the two hemispheres. For example, Goldstein and Shelly (1981) found that performance in tests from Halstead-Reitan neuropsychological battery associated with each hemisphere decreased linearly across the age range tested and there was no hemisphere-by-age interaction. Similarly, there is no evidence for reduced performance in tests associated with right- rather than left--hemisphere functions, as reported by Mittenberg (et al. 1989), or shown in studies investigating perceptual asymmetries using dichotic-listening (Ellis and Oscar-Bermann 1984) or the visual-half--field method (Byrd and Moscovitch 1984, Obler et al. 1984). As it can be assumed that temporal integration mechanisms are a basis of left hemisphere processing or general inter-hemispheric processing, age-related changes in basic measures of integration periods might reflect declines in left hemisphere functioning or a more general inter-hemispheric functional impairment.

Given all these points, the aim of the present study was to investigate: (1) whether the temporal limit of the hypothetical integration mechanism depends on the number of events within a particular time interval, (2) whether there are individual differences as well as age-related changes to the length of the period during which temporal information can be integrated in the central nervous system. The experimental task used to investigate temporal processing in the present experiment was the integration of auditory information contained in metronome continuous beats.

TABLE I

Correlation between the level of cognitive ability (KAI-test) and age group (Spearman's one-tailed test)

Cognitive abilities	Age group
Intelligence quotient	-0.476*
Memory span	-0.491*
Rate of information processing	-0.590*
Duration of "the present"	0.016

*$P<.05$

METHOD

Subjects

Sixteen volunteers were studied and divided into two age groups. One group consisted of six individuals aged from 25 to 49 years (mean age=36.3 years, SD = 9.2) and the other consisted of ten individuals ranging in age from 50 to 66 years (mean age = 57.7 years, SD = 5.3). Subjects were divided into the above age groups based both on results of longitudinal studies (Schaie 1983, Siegler 1983, Schock et al. 1984) indicating a pervasive decline in cognitive functions after 50, and on results of the KAI-test (Kurztest für allgemeine Basisgrössen der Informationsverarbeitung) employed in the present study. This test constitutes a commonly used psychometrical tool, standardized for the German population, for assessing cognitive functions such as: forward memory span, rate of information processing, duration of "the present", intelligence quotient. Each subject was given the KAI test and scored according to the standard instruction. Based on Spearman's correlation coefficient (one-tailed test) between age groups and the level of particular cognitive abilities, measured by the KAI-test, it was proved that older people performed poorer than younger ones on this psychometrical test. The significance levels are listed in Table I. Normal aging adults were defined, according to Ellis and Oscar-Berman (1989, p.129), as those demonstrating "...the absence of such characteristics as history of significant head injury, seizure disorder, stroke, or other serious neurological diseases; significant diabetes, heart disease, or other underlying medical illness; serious psychiatric disturbance such as psychosis or chronic drug (including alcohol) abuse; ongoing psychologic disability such as depression; and ongoing use of psychotropic medications". Moreover, all subjects included in the present study were right-handed as determined by Briggs and Nebes questionnaire (1975), had no cases of left handedness in the family history, had normal hearing (clinical assessment) and IQ over 80 points (RAVEN).

Material

The auditory stimuli were metronome beats (clicks) presented at a frequency of 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5 beats/s. The frequencies were chosen on the basis of a pretesting data. These data show that the majority of tested subjects could not perform the experimental task (for the particular description see Procedure) when the metronome beat rates were above or below those enumerated above. The duration of separate click was 1 ms. The sound generator of the computer was used as the stimulus generator. Beats with different frequencies were produced by a computer program. Stimulus sequences were presented *via* earphones to both ears for 10 s.

Procedure

The experiment was conducted in a soundproof chamber. The subjects were seated in an armchair. They were asked to listen to the equally spaced beats of a metronome and integrate beats into larger units consisting of 2, 3 or more beats. To do this, they were instructed to accentuate mentally every second, third, fourth ...etc. beat and to hear a subjective rhythm. Obviously, this accentuated rhythm exists only in the subject's mind and not objectively. The subjects reported verbally how many clicks they could integrate into one perceptual unit. The time interval in which the subject could integrate the information was evaluated (number of integrated beats x time distance between beats) for different metronome frequencies.

The experiment itself consisted of one session lasting approximately one hour. During the session, nine stimulus frequencies described above were presented 10 times each in random order. The session consisted of 90 trials. The stimuli were presented in six series of 15 sequences which were separated by two-minute rest breaks. The consecutive trials were separated by 30 s breaks.

RESULTS

The experimental data on time intervals during which the metronome beats were integrated as well as the number of beats reported as being integrated were studied separately. Complementary analyses were performed on these two variables. As the relationships found for time intervals were identical to those for number of beats, only results obtained for integrated time intervals are presented here.

To test the significance of main effects and interactions among variables, the experimental data were submitted to a 2-factor analysis of variance (ANOVA) with repeated measures applied to the mean measured integration time for particular metronome frequencies. The factors in the analysis were: age group (younger subjects/older subjects) - as the between-subjects variable and metronome frequency (nine various levels) - as the within-subjects variable.

The analysis of variance indicated age group as a significant main effect (F=12.068; df=1,14; P<0.004) and also a significant metronome frequency main effect (F=14.514; df=8,112; P<0.000). The interaction: age group x metronome frequency was statistically nonsignificant (F=0.090; df=8,112; P<0.999).

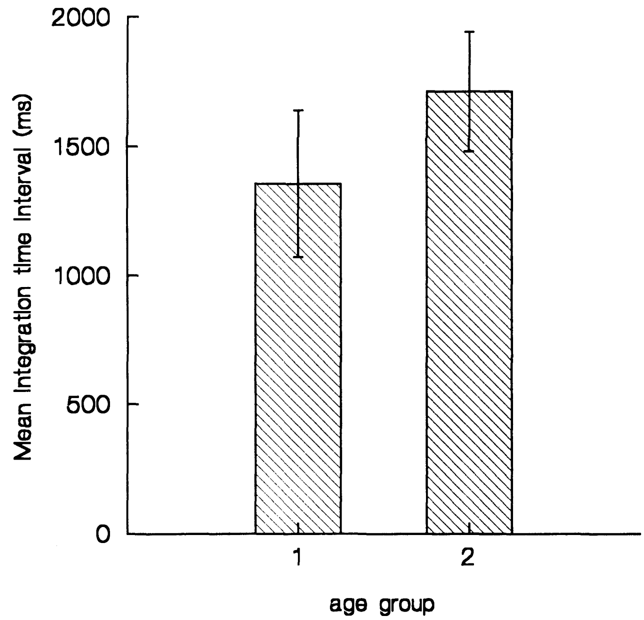

Fig. 1. Mean measured integration time in two age groups: younger (1) and older adults (2).

The mean time interval during which the older subjects were able to integrate temporal information into one perceptual unit (1750.8 ms) was longer than the integration interval observed for younger individuals (1351.5 ms, Fig. 1). Furthermore, the measured integration time was differentiated de-

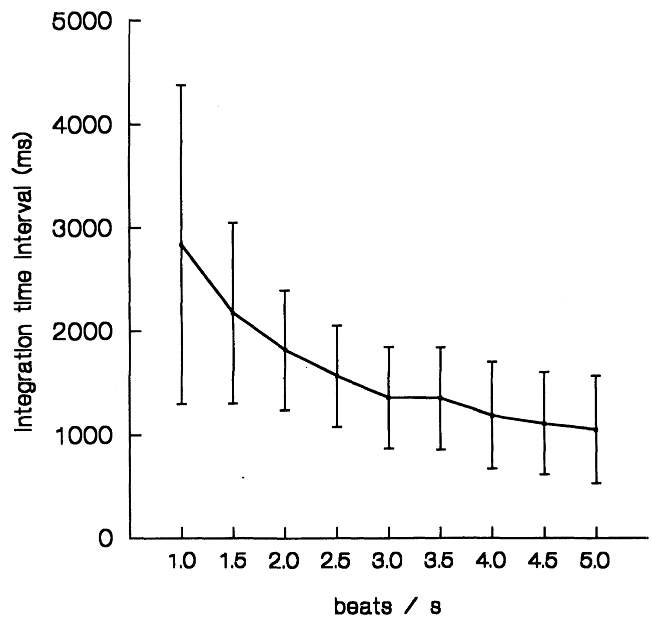

Fig. 2. Measured integration interval length for various metronome frequencies.

TABLE II

Significance levels of means comparisons computed with the Bonferroni post hoc procedure for measured integration time for various metronome frequencies

Frequency (beats/s)	1	1.5	2	2.5	3	3.5	4	4.5	5
1									
1.5	0.014								
2	0.017	0.065							
2.5	0.006	0.006	0.011						
3	0.005	0.004	0.001	0.051					
3.5	0.007	0.008	0.006	0.100	0.455				
4	0.004	0.003	0.001	0.007	0.044	0.001			
4.5	0.005	0.004	0.001	0.010	0.025	0.003	0.210		
5	0.004	0.003	0.001	0.006	0.010	0.001	0.091	0.002	

pendent on the presented metronome frequency (Fig. 2). To determine the significance of differences between integration intervals for particular metronome frequencies, a means comparison test, using the Bonferroni post hoc procedure, was applied. The significance levels obtained from these comparisons are listed in Table II. A general relationship was found - the higher the metronome frequency the shorter the time interval in which the subjects were able to integrate the temporal information into a perceptual unit.

Next, a correlational analysis was undertaken to examine the possibility of various basic integration mechanisms as related to the high and low mental contents of the temporal information. In this order, Spearman correlations (one-tailed test) were computed. Tables III, IV and V show the results of these analyses. Table III displays the correlation scores computed between integration time intervals for a subset of frequencies; within low and high frequencies separately, as compared with the direction of correlation between low and high frequencies,taking into account significance levels. It can be seen that the duration of the integration time interval for the lowest frequency (1 beat/s) correlated positively with the duration of interval for the other lower frequency (1.5 beats/s). Similarly, the duration of integration interval for the highest frequency (5 beats/s.) correlated positively with the duration of integration periods for the other higher frequencies (3, 3.5, 4, and 4.5 beats/s). In contrast, the opposite pattern of relationships was found when the direction of correlation between integrated periods for low and high frequencies was investigated. The integration time interval for the lowest frequency (1 beat/s) correlated negatively with that for the four highest

TABLE III

Correlation between the measured integration time for various metronome frequencies (Spearman's one-tailed test)

Frequency (beats/s)	1	1.5	2	2.5	3	3.5	4	4.5	5
1		0.839**	0.382	0.124	-0.364	-0.434*	-0.601**	-0.715**	-0.776**
5	-0.776**	-0.527**	0.074	0.348	0.713**	0.771**	0.887**	0.932**	

*P<0.05; **P<0.01

TABLE IV

Correlation between the level of cognitive ability (KAI-test) and the measured integration time (Spearman's one-tailed test)

Integration time intervals		Cognitive abilities			
		Intelligence quotient	Memory span	Rate of information processing	Duration of "the present"
Frequency	1 beat/s	-0.553*	-0.499*	-0.448*	-0.388
	4.5 beats/s	0.288	0.259	0.098	0.461*
	5 beats/s	0.463*	0.434*	0.324	0.536*

**P*<0.05

presented frequencies (3.5, 4, 4.5 and 5 beats/s). Similarly, the integrated period observed for the highest frequency (5 beats/s) correlated negatively with that for the two lowest frequencies (1 and 1.5 beats/s, Table III). In other words, the longer the integration period for the low frequencies, the shorter the integration period for the high ones.

Table IV summarizes the relation between mean measured integration time for a subset of metronome frequencies and individual cognitive abilities assessed by the KAI-test. The opposite direction of Spearman correlation was found dependently on the frequency of the presented beats. In particular, the duration of an integration interval for the lowest frequency (1 beat/s) correlated negatively with cognitive abilities, whereas, the duration of intervals for the two highest frequencies (4.5 and 5 beats/s) correlated positively with these abilities. It should be stressed that, for any other metronome frequencies, no significant correlation between the level of cognitive functions and the duration of integration periods was found. Moreover, this relationship has the consequence that, as can be seen in Table V, the level of cognitive abilities correlated negatively with the difference in duration between the integration periods for the lowest (1 beat/s) and the highest (5 beats/s) frequencies (see Fig. 2). This means that individuals characterized by a lower level of these abilities displayed a more dramatic decrease in the length of integration periods, depending on the presented metronome frequency in comparison to those with a high level of cognitive abilities.

TABLE V

Correlation between the level of cognitive ability (KAI-test) and the difference in duration between measured integration periods for the lowest (1 beat/s) and the highest (5 beats/s) metronome frequency (Spearman's one-tailed test)

	Cognitive abilities			
	Intelligence quotient	Memory span	Rate of information processing	Duration of "the present"
The difference in duration between integration periods for the lowest and the highest frequency	-0.489*	-0.450*	-0.370	-0.444*

**P*<0.05

DISCUSSION

The results of the present experiment point to an integration process taking place, i.e. temporally separated successive metronome beats were connected mentally with each other into larger perceptual units. Thus, the separate beats in exposed sequences lost their dominance at the perceptual level and were organized into a higher-order structure dominating the serial order.

Moreover, the extent of the hypothetical integration mechanism was found not to be stable but dependent on several factors: the mental content of the presented stimuli, age-related changes and individual differences in cognitive abilities were of most significance.

It turned out that the temporal limitation of the integration mechanism under investigation is strongly related to the number of events within a given time interval (Fig. 2). Accordingly, the upper limit of the measured integration period was 2.864 s and was characteristic for the lowest presented metronome frequency (1 beat/s). It should be stressed that when the beats were separated by intervals longer than 1 s, an accentuated rhythm could no be perceived and only isolated beats were heard. These results support the hypothesis (e.g. Pöppel 1985, Pöppel et al. 1990) that the temporal extent of the integration process is limited to approximately 2-3 s. According to this hypothesis, the integration of information can not exceed this time interval and is possible only if, at least, two successive events fall into one integration interval. Therefore, in the present experiment the accentuation was not possible and, as a consequence, only separate beats could be heard when the distance between successive beats was too long (frequencies slower than 1 beat/s).

On the other hand, the lower limit of this integration mechanism was approximately 1.028 s. (Fig.2) and was characteristic for the highest presented frequency of metronome beats (5 beats/s). Thus, the binding process can also integrate the information in the interval shorter than 2-3 s, if such necessity arises. This relationship was predicted by Pöppel et al. (1991, p. 65): "... the temporal binding process is closed up to approximately 3 s and open for shorter interval...". Moreover, an interesting relationship was found: if the mental content of the presented stimuli was high (beats presented with high frequencies) the duration of the integration periods was found to be shorter; if the mental content was low (beats presented with low frequencies) the duration of these periods appeared to be significantly longer. Thus, the results of our study show that, the temporal limitation of the integration mechanism is related to how much information can be processed in a given time interval.

This relationship can be explained referring to the experience of boredom (Pöppel 1978, 1985). According to that hypothesis, people usually become bored during a low level of behavioural activity accompanied by lacking of events. In contrast, a higher level of behavioural activity and time filled by many events results in an impression of a quick passage of time. Accordingly, one of the major findings in our experiment is that this hypothesis is valid not only regarding experience of duration and reproduction of temporal intervals (e.g., Fraisse 1984, Nichelli 1993, see also papers cited in Introduction), but it also applies to the temporal extent of the integration process. More events falling into a given interval are integrated more rapidly and probably, therefore, when a person finds himself in a situation of high informational content (no boredom) time appears, subjectively, to pass more rapidly. The idea of differentiated integration mechanism, depending on the mental content of presented stimuli, might be supported by the results of the correlational analysis undertaken in our study (Table III). It was proved that the integration period for the lowest frequency correlated positively with the duration of integration periods between immediate neighbours i.e. with the other lower frequencies. Similarly, the duration of integration period for the highest frequency correlated positively with that duration for the other higher frequencies. In contrast, a negative correlation was found when investigating the correlation between integration periods for low and high frequencies. The results of the correlational analysis point to a differentiation of integration processes depending on how many events occurred in a particular time interval. We suppose that the various temporal extent of integration processes, depending on informational content may constitute a neurological basis for the experience of boredom.

It is also worth noting that in people showing a high level of cognitive abilities the difference in duration between integration periods observed for the lowest (1 beat/s) and the highest (5 beats/s) metronome frequencies appeared to be significantly smaller than that difference observed in the individuals with low cognitive ability level (Table V). This relationship was probably a consequence of the opposite direction of correlation between the level of cognitive functions and the duration of measured integration periods for low and high metronome frequencies (Table IV). In summary, subjects with high cognitive ability level were able to integrate the information in the longer period when the high frequencies (4.5 and 5 beats/s) were presented, this period being shortened when the lowest frequency (1 beat/s) was presented. It can be assumed, that individuals characterized by the higher level of cognitive abilities can relatively quickly process the sensory information, display shorter reaction times, larger memory span, higher IQ and demonstrate the higher level of behavioural activity. It would follow that as an intellectual consequence they can add more successive events to form a perceptual unit when the mental content of presented stimuli is high. According to this, individual differences in the duration of integration periods could provide information about individual differences in the cognitive domain.

Another interesting finding is that integration periods in the elderly were prolonged as compared with that observed in younger subjects (Fig. 1). This would suggest the hypothetical information process being slowed down in elderly adults. This relationship proved to be valid regardless of the frequency of presented metronome beats i.e. independent of the mental content of the presented stimuli. Similarly a prolonged reproduction of temporal intervals was found in other investigations on mentally ill individuals as compared with the matched normal group. Lhamon and Goldstone (1956) and Fraisse (1984) suggested that schizophrenics overestimate a one-second duration. Moreover, in well-studied populations of learning-impaired individuals, including dyslexics, (Tallal 1978, Tallal and Piercy 1979, Tallal et al. 1985, Shapiro et al. 1990, Merzenich et al. 1993) integration times and stimulus persistence measures were significantly slowed down. The specific temporal processing disorder discovered in our experiment may be a possible neurologic correlate of a decline in perceptual and intellectual functioning associated with normal chronological aging. This conclusion does not support "the right-hemisphere aging hypothesis" but rather points to a deterioration in aging individuals of certain functions typically ascribed not only to the right hemisphere. It remains an open question whether the age-related changes in temporal extent of the integration mechanism are to be considered in terms of the left hemisphere functional decline or a uniform bi-hemispheric deterioration. It is partly caused by the fact that the problem of hemispheric representation of temporal integration mechanisms has not been solved. Though there exists a lot of evidence pointing to left hemisphere specialization in the timing process it can be postulated that temporal integration constitutes a general supra-modal and intra-hemispheric process of a major complexity. It has been well documented that this mechanism is involved in processing of both visual and auditory - verbal and nonverbal information, also in the performance of motor action. Thus, rhythmic temporal organization, temporal integration and "temporal chunking" may also reflect the wide spectrum of human behavioural activities.

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