TWO DIFFERENT SYSTEMS FOR RHYTHM PROCESSING AND THEIR HIERACHICAL RELATION

Morio Kohno
Kobe City University of Foreign Studies, Kobe, Japan

ABSTRACT

Kohno (1993) already suggested that the mechanism of rhythm processing consists of two neuropsychologically different works, by the examination of rhythm behavior of a patient with an infarction involving the corpus callosum. The present paper is to confirm this hypothesis with additional data. The latter part of this paper will clarify the neuropsychological relation between the two mechanisms of rhythm processing by the study of rhythm behavior of the patient of pure anarthria.

TWO MECHANISMS OF RHYTHM PROCESSING

Split-brain patient's rhythm processing

It is often suggested that, neurolinguistically, the processing of prosody is one thing and the processing of other linguistic elements such as syntactic structure is another. Borden and Harris [1], for example, proposed a model of speaking in which they indicated separate processors for prosody (including rhythm) and for word order. Matsubara et al. [2], proved that prosody, especially F0 control in speaking, is independent of other mechanisms involved in producing recurrent utterances in aphasic patients. But it is not known that rhythm is differently processed from intonation (F0 control). Kashiwagi et al. [3] first discovered that patients with infarction involving the forebrain commissural fibers behave very differently in fitting tempos in time with fast rhythm and slow rhythm. Kohno [3][4] ran a follow-up survey on the patient by requesting him to tap the table fitting various speeds of rhythm and found that the patient's left hand cannot follow any slow rhythms whose inter-beat intervals (IBIs) are more than 450ms, although it can manage to follow the fast rhythms whose IBIs are less than 330ms. His right hand, on the other hand, could properly tap in time to the both rhythms.

Table 1 illustrates this phenomenon.

Table 1. Tapping by a patient with infarction in the corpus callosus (male, 57 years old, right hander).

Hand Used	Target Tempo(IBI)	Observed Inter-beat Intervals				
		N	MEAN	SD	r.v.	r
right	1000	27	1020.1	46.5	4.6	-0.52
	500	46	506.3	31.6	6.2	-0.25
	250	56	261.9	27.1	10.3	+0.19
left	1000	62	673.3	285.7	42.4	+0.96
	500	99	476.4	198.9	41.8	+0.07
	250	51	266.6	36.0	13.6	+0.13

(r.v.=relative variance, r=autocorrelations among the adjacent IBIs)

Table 2 shows the comparative data of a normal adult's behavior on the same task.

Table 2. Tapping by a normal adult(female, 55 years old, right hander).

Hand Used	Target Tempo(IBI)	Observed Inter-beat Intervals				
		N	MEAN	SD	r.v.	r
right	1000	63	1022.7	52.1	5.1	-0.29
	500	55	512.7	22.9	4.5	-0.21
	250	99	257.5	10.6	4.1	+0.45
left	1000	57	1017.7	54.9	5.4	-0.10
	500	71	515.3	22.2	4.3	-0.12
	250	94	257.0	11.0	4.3	+0.04

The fact that the patient's left hand moves very differently not only from both hands of the normal adults, but from his own right hand, and that this feature of movements can be seen when the tempos of stimuli swich from rapid rhythm to slow suggests that the processing of slow and rapid rhythms may be neuropsychologically different from each other. This hypothesis is supported by the fact that negative autocorrelations were detected among the adjacent IBIs in the slow response beats by the right hand of the patient and by both hands of normal adults, but never detected in any responses of the patient's left hand which produced only rapid responses even to slow stimuli and in the normal adult's response beats to the rapid stimuli (See the columns under r in the above tables.) Let us explain the mechanism of keeping time with slow and rapid rhythms.

With slow rhythm, if subjects are normal, they first get a general timing measure listening to the metronome, and then hit their first stroke on the basis of this measure. Their stroke, however, in most cases, misses the target, resulting in a stroke that is too early or too late. If the first stroke is early, they try to lengthen the next beat-interval to correct the timing. This action, however, again misses the target because of the overly-long interval. Subjects then hit their beat earlier in the second stroke by the same psychological reasoning. These reciprocal actions of earlier and later strokes produce negative autocorrelations. Therefore, we might call this processing 'analytic' 'one by one' or 'prediction-testing' processing.

With a rapid rhythm, however, there is no time for subjects to process each beat analytically. They get the configuration of the given rhythm in a flash and reproduce it in their tapping. We might call this kind of processing 'holistic' 'all-at-once' or 'Gestaltic' processing. It never produces negative correlations among adjacent IBIs.

To confirm this hypothesis, we carried out the following experiments.

Experiment 1

Subjects, materials and method: The rhythms with 250, 300, 400, 500, 750 1000ms inter-beat intervals were each aurally presented by the metronome, SEIKO Rhythm Trainer SQM-348, to the twenty university students majoring English and they were requested to reproduce those rhythms in the following two modes. Mode 1: After having listened to the stimuli for ten seconds, the subjects were requested to do multiplication of two digit numbers such as 27×48, and then to reproduce each rhythm from memory by saying ta ta ta …. Twenty seconds were allotted for the calculation (If the calculation was finished by the end of the alotted time (signaled by a bell), the subjects had to wait). Sheets of paper were delivered on which numerical formula were described (e.g. $\frac{27}{\times 48}$) to calculate and write the answers. Mode 2: In place of calculation, the subjects drew circles(○) on the paper for twenty seconds, and then to reproduce the given rhythm by saying ta ta ta …. All the subject's responses were tape-recorded and their IBIs were measured by the use of ON-SEIKOBO NTT Advanced Technology.

Results: In order to know how diverse each response is from its target, each response beat interval was dealt with according to the following formula:

(response beat interval − target interval) ÷ target interval × 100 (absolute value).

The results about the means of differences from the targets are shown in Tables 3 and 4.

Table 3. Significance levels for comparison of the means of differences in the case of reproduction after calculation.

Target Intervals (ms)	250	300	400	500	750	1000
x	7.0	11.2	18.0	20.0	18.3	21.6
250 (7.0)		NS	0.05	0.01	0.01	0.1
300 (11.2)			NS	0.05	NS	0.05
400 (18.0)				NS	NS	NS
500 (20.0)					NS	NS
750 (18.3)						NS
1000 (21.6)						

N=20

ANOVA: $F(5,114)=3.377$ $p<0.01$

Table 4. The means of differences in the case of reproduction of rhythms after drawing circles.

Target Intervals (ms)	250	300	400	500	750	1000
x	5.9	7.7	10.1	10.3	8.8	11.0

ANOVA: $F(5,114)=0.959$ N.S.

The results about the SD values are shown in Tables 5 and 6.

Table 5. Significance levels for comparison of SD in the case of reproduction after calculation.

Target Intervals (ms)	250	300	400	500	750	1000
SD	6.81	11.90	23.65	21.99	22.16	28.19
250 (6.81)		0.05	0.01	0.01	0.01	0.01
300 (11.90)			0.01	0.01	0.01	0.01
400 (23.65)				NS	NS	NS
500 (21.99)					NS	NS
750 (22.16)						NS
1000 (28.19)						

N=20

Cochran's test: $F=0.316$ $p<0.05$

Table 6. SD values in the case of reproduction of rhythms after drawing circles.

Target Intervals (ms)	250	300	400	500	750	1000
SD	5.83	9.05	12.36	13.33	15.15	13.05

Cochran's test: $F=0.265$ N.S.

Tables 7 and 8 show the differences of responses between Modes 1 and 2 per each target rhythm.

All the these tables show the rapid rhythms whose IBIs are 250ms and 300ms were well-memorized and little disturbed by the tasks of both drawing circles and calculation but the memory of slow rhythms whose IBIs are more than 400ms was largely disturbed by the task of calculation while the work of drawing circles did not decrease the memory so much.

Table 7. Comparison of the means of differences between the cases of reproduction after drawing circles and after calculation.

Target (ms)	Cir. →	Cal.	p
250	5.9	7.0	NS
300	7.7	11.2	NS
400	10.1	18.0	0.05
500	10.3	20.0	0.01
750	8.8	18.3	0.01
1000	11.0	21.6	0.01

ANOVA: $F(11,228)=4.47$ $p<0.01$

Cir.: the case of reproduction after drawing circles

Cal.: the case of reproduction after calculation

p: significance levels

Table 8. Comparison of SD between the cases of reproduction after drawing circles and after calculation.

Target (ms)	Cir. →	Cal.	p
250	5.83	6.81	NS
300	9.05	11.90	NS
400	12.36	23.65	0.01
500	13.33	21.99	0.05
750	15.15	22.16	NS
1000	13.05	28.19	0.01

Cochran's test: $F=0.235$ $p<0.01$

Discussion: Slow rhythms with more than 500ms IBIs will be analytically processed, as suggested by the study of split-brain patient, and this analytic processing of rhythms may be the same kind of active task as calculation, and therefore the retention of this kind was interfered with by the calculation. The rapid rhythm processing, which may be holistic, however, is neuropsychologically different from the work of multiplication, and therefore, it was never disturbed by it. The work of drawing circles is so simple that it effected nothing on memory, just like immediate recalling after having heard the target rhythms (See [4]).

HIERARCHICAL STRUCTURE OF RHYTHM PROCESSING

The above-mentioned experiment about the split brain patient's rhythm perception shows an important fact that the right hand of the patient can do analytic processing with slow rhythms, and at the same time it can do holistic processing with rapid rhythms, while his left hand can only do holistic one (only follow rapid rhythms). This suggests that the analytic processing can be carried out on the basis of holistic processing, but not vice versa. Kohno [4] explains analytic processing, and says that if some person has no ability to make up a general Gestaltic map of tempo about the given rhythm, it is impossible for the person to fit it, even if the given rhythm is a slow one. Fodor[6] says that, in his model of listening comprehension, the modules, fast and holistic processing device, constitute the preliminary processing stage and the slow and analytic, but accurate processing device, that is, so called Central Processing Mechanism, makes up a primary processing stage. All the above-mentioned investigations suggest that the analytic and holistic processing act by a hierarchical system - the holistic may act as a basic structure, and the analytic as a hyperstructure.

Kohno et al.[5], on the other hand, carried out series of experiments using a patient of pure anarthria, and found that the patient demonstrated too analytic idiosyncrasy, processing the fast rhythms with 250ms IBIs by analytic way. In spite of this expreme analytic tendency, the patient still showed the existence of the productive sense unit (PrSU), couterpart of perceptual sense unit, both of which are manifestations of human being's holistic ability (cf.[4]). The patient demonstrated the PrSU by the pitch rise at the end of each unit, a strange way of utterance which is seldom heard in the normal speech in colloquial Japanese. This abnormal way of utterance, however, automatically disappeared, as his very slow speech rate became faster on acount of rehabilitation. This phenomenon therefore shows that pure anarthria might be caused by the suppression of holistic processing by analytic processing, without destroying the former. This phenomenon also suggests the hierarchical structure of rhythm processing. (Full information of this study will be given by printed paper.)

REFERENCES

[1] Borden, G.J. et al.(1984), Speech Science Primer, Baltimore: Williams & Wilkins, pp.9-12.

[2] Matsubara, J. et al.(1994), "Prosody of Recurrent Utterances in Aphasic Patients", Proceedings of 1994 ICSLP, Vol.3, pp.1211-14.

[3] Kashiwagi, A. et al.(1989), "Hemispheric asymmetry of processing temporal aspects of repetitive movement in two patients with infarction involving the corpus callosum", Neuropsychologia, Vol. 27-6: 799-809.

[4] Kohno, M.(1993), "Perceptual sense unit and echoic memory", International Journal of Psycholinguistics, 9-1: 13-31.

[5] Kohno, M. et al.(1994), "Rhythm processing by a patient of pure anarthria and productive sense unit", G. Mininni & S. Stame (eds), Dynamic Contexts of Language Use, University Press, Bologna, Italy.

[6] Fodor, J.A.(1983), The Modularity of Mind, Boston: MIT Press.