Research Article

Auditory Processing Skills in Patients with Multiple Sclerosis

Mahsa Habibi[1*], Saeid Farahani[2], Nematollah Rouhbakhsh[2], Farzaneh Zamiri Abdollahi[2], Ehsan Negin[2], Shohreh Jalaie[3]

[1] *Department of Audiology, School of Rehabilitation, Arak University of Medical Sciences, Arak, Iran*
[2] *Department of Audiology, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran*
[3] *School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran*

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Highlights

- Central auditory processing disorder is common among patients with multiple sclerosis
- The Buffalo model tests can be used to identify CAPD in patients with MS

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ABSTRACT

Background and Aim: Multiple sclerosis (MS) is neurological disease of the central nervous system. Central auditory nervous system can also be affected by MS. The present study aimed to evaluate monaural and binaural auditory processing in patients with MS.

Methods: This cross-sectional study was conducted on 45 patients with MS and 45 normal peers as controls aged 25–45 years. They underwent a central auditory processing test battery including the Persian versions of Buffalo model questionnaire (BMQ), staggered spondee word (SSW) test, quick speech in noise test (QSIN), phonemic synthesis test (PST), and two-pair dichotic digit test (DDT).

Results: The results of SSW test, QSIN test, PST, DDT and BMQ in the MS group were significantly different than in the control group ($p \leq 0.001$). The results showed the poor performance of patients compared to controls in some monaural and binaural auditory processing skills.

Conclusion: Central auditory processing disorder is common among patients with MS. The BMQ is a suitable screening tool for identifying affected people. Dichotic listening skills, phonemic processing and speech perception in noise are impaired in MS patients which can have significant impacts on their quality of life.

Keywords: Auditory processing; multiple sclerosis, central auditory nervous system; adults; speech perception

*** Corresponding Author:**
Department of Audiology, School of Rehabilitation, Arak University of Medical Sciences, Arak, Iran.
mahsahabibi70@yahoo.com

Introduction

Multiple sclerosis (MS) is a chronic autoimmune, inflammatory neurological disease of the central nervous system that was first identified in 1860 by Jean Charcot [1]. This disease affects the myelinated axons in the central nervous system, destroying the myelin and the axons to varying degrees [2]. The gray matter is also affected, leading to motor, sensory, visual, and cognitive impairment. However, these complications depend on the severity of MS course. The course of MS is highly variable and unpredictable [2]. There are various studies that have reported the affected central auditory nervous system (CANS) in subjects with MS [3, 4]. The CANS is the structure responsible for central auditory processing which produces important auditory behaviors such as sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal processing, auditory performance with competing signals, and recognition of degraded signals [5]. Therefore, the integrity of CANS is an essential need for accurate and rapid auditory processing. Central auditory processing disorder (CAPD) includes an impairment in one or more of these central auditory behaviors and skills [5]. The most common complaint of patients with CAPD is difficulty in understanding speech in the presence of background noise [6]. Studies have reported that many MS patients with normal pure-tone thresholds complain of difficulty in speech perception in noise [1, 6]. Complexity and diversity of CAPD has led to the use of reductionism approach to enable specialists to assign central auditory processing and CAPD into pre-defined sub-categories. This categorization helps identify the CAPD and paves the way to provide an effective treatment for the affected auditory processing [7].

One of the popular models for auditory processing is the Buffalo model introduced by Katz et al. (1990) and includes four processing sub-categories: decoding, tolerance-fading memory (TFM), integration, and organization [7]. Decoding is related to the rapid and accurate processing of speech at the level of phonemes and anatomically is more related to left posterior middle temporal lobe. TFM is related to speech perception in noise and short-term auditory memory. Its anatomic structure is anterior temporal lobe including hippocampus and amygdala, and is associated with memory and the limbic system [7]. The integration processing is related to integrating auditory information between hemispheres and with other sensory information especially visual. Its anatomic basis is in the corpus callosum and angular gyrus. The organization processing is characterized by sequencing errors and reversals. This is related to the post- and pre-central gyri and areas in the anterior temporal lobe. There are three main tests based on Buffalo model to recognize CAPD categories: Staggered spondaic words (SSW) test, phonemic synthesis test (PST), and speech in noise (SIN) test [7]. For screening, Buffalo Model Questionnaire (BMQ) is used which is a valid and reliable tool for behavioral central auditory processing evaluation [8]. The Persian version of a set of tests based on Buffalo model have been developed by considering specific Persian language properties, including the Persian SSW test [9], the Persian BMQ [10], the Persian PST [11], and the Persian Quick SIN test [12].

The aim of all auditory processing models and tests was to evaluate the important central auditory processing areas (e.g. dichotic listening, monaural low-redundancy, and temporal processing) and address the affected processing for having an efficient treatment. Dichotic listening is one of the important auditory functions which is common among all central auditory processing models. In dichotic listening tasks, different auditory stimuli are directed into the ears, simultaneously [13]. These tasks are sensitive to auditory brainstem, auditory cortex, and corpus callosum. The most important clinical dichotic tests are competing sentence test (CST), dichotic consonant-vowel (DCV) test and dichotic digit test (DDT) [14]. The DDT has one, two and three pairs of digit series presented simultaneously into the two ears. The two-pair DDT is the most common type for identifying dichotic listening problems or maturation. Its difficulty is less than that of three-pair DDT (needs more memory) and DCV (with more linguistic demand), and is more difficult than one-pair DDT which is more suitable for young children [15].

Some studies have shown that CANS is affected in patients with MS [3, 4]. It seems that CAPD is also more common in these patients, and is highly dependent on the place of demyelination in the brain. If CAPD is present and left untreated, can potentially affect the speech perception in noisy environments and can have adverse effects on social interactions and quality of life [14]. It seems that CAPD has been neglected in patients with MS. Therefore, the present study aims to evaluate some of monaural/binaural auditory processing by using a test battery including the Persian versions of BMQ, SSW test, PST, Quick SIN test, and two-pair DDT [16] in patients with MS compared to controls.

Methods

Participants

This is a cross-sectional study conducted on 45 patients (25 females and 20 males) with MS and 45 healthy people as controls (25 females and 20 males) aged 25–45 years. Patients were selected from among those referred to the Iranian MS Society. Their disease was diagnosed based on neurologic assessments including electrophysiology and magnetic resonance imaging (MRI), and they had the disease for 4–10 years. Controls were recruited from among the personnel of Tehran University of Medical Sciences in Tehran, Iran. The peripheral auditory system of both groups was evaluated by using an otoscope (Riester, Germany), a conventional audiometer (Harp, Inventis Co., Italy), and an impedance audiometer (AZ26, Interacoustic, Denmark). Only subjects with normal otoscopy and tympanogram, air-conduction and bone-conduction pure-tone thresholds ≤25 dB HL at octave frequencies of 250–8000 HZ without a significant air-bone gap (≤10 dB), and with word recognition score (WRS) ≥90% at the most comfortable level (MCL) were selected [7]. Other inclusion criteria were: No history of hearing loss, seizures, and head trauma; Persian-native speakers (monolingual), right-handedness based on Edinburgh Handedness Inventory score (A score between +40 and +100) [17]. If the disease problems increased in a patient or s/he had no willingness to participate in the study, s/he was replaced by another person. All subjects signed an informed consent form.

Measures

After ensuring that the peripheral auditory system of participants is healthy and they met the inclusion criteria, they underwent a series of central auditory processing tests including the Persian BMQ, SSW test, PST, Quick SIN test (test List no.3), and two-pair DDT (free-recall condition). Tests were conducted using a laptop (HP Pavilion DM4) and presented through a headphone (Philips SHL5605PP). The output of laptop-headphone was calibrated using sound level meter (SLM DSM8930, General tools, USA) by a professional audiologist. The presentation level was set at MCL for all central tests. All tests were performed and scored based on standard protocols.

The Persian version of BMQ has been developed by Khamisabadi et al. [10]. The BMQ consists of 48 items related to behavioral problems and six types of therapy in different categories including decoding (DEC), various TFM items (noise, memory, various), integration (INT), organization (ORG), auditory processing disorder (APD), and general. The items are answered by "Yes" or "No" [10]. Katz (2006) showed high correlation between the score of BMQ and diagnostic tests for CAPD. The questionnaire addresses issues associated with articulation, spelling, oral reading, speech perception in noise, distraction, attention deficit hyperactivity disorder, coordination, sequencing, short-term memory, and other auditory-based tasks [18]. The total APD and total BMQ scores were calculated and interpreted based on the main study protocol [18]. According to studies, there is no normative data for the population aged >12, and we used the normal counterparts for high accuracy and possibility of comparison.

The SSW test is one of the most sensitive tests for identifying CAPD [19]. It consisted of 40 items each with two spondees where the first monosyllable of the first spondee is presented to one ear without competition (Right non-competing; RNC) and the first monosyllable of the second spondee is presented to other ear simultaneously in dichotic condition (Right competing/left competing; RC/LC). The second monosyllable of the second spondee is directed into the other ear (Left non-competing; LNC) at 50 dB SL (with pure-tone averages of 500, 1000, and 2000 Hz). Odd items are first presented to the right ear (Right ear first; REF) and even items to the left one (Left ear first; LEF). The test scoring has quantitative and qualitative indices and qualifiers. Quantitative index includes errors for RNC, RC/LC, LNC and their total errors. Response bias index includes ear effect (ratio of the total REF error to the total LEF error) and order effect (ratio of the total error at the beginning to that at the end of the items). The higher number in the ratios is called high (H) and the lower one is called low (L). Qualifiers include the behaviors of the subject during responding which is listed in Table 1 along with the categories involved [9]. It should be noted that the test scoring was done according to the main article (by Katz J) [19].

The PST targets phonemic blending and consists of 25 recorded test items. There are one-second silent intervals among phonemes of each word. The subject is asked to blend phonemes and utter the word (consisting of 2-4 phonemes) after hearing a beep. The PST is presented to both ears at 50 dB SL (with pure-tone averages of 500, 1000, and 2000 Hz). They receive one point for each correctly repeated word. In case of a mistake, their responses are written in the corresponding response column. A single hyphen is used to indicate the omitted word. The quantitative score is obtained by summing up the total number of correctly repeated items minus one point for each of the items that had qualifiers. It ranges from 0 to 25. The qualifiers included delay (X), excessive delay (XX), quick response (Q) before hearing the beep after the item 11, non-fused items (NF), quiet rehearsal (QR), reversal error (REV), perseveration (P), and 1st phoneme omission. The total qualitative score is obtained by subtracting one point for each of the items that were correctly answered but with a delay, an excessive delay, a quick response, or a quiet rehearsal. The qualitative scores were equal to or less than the quantitative scores in a range of 0–25 [11].

Quick SIN test is one of the most commonly used tests for evaluation of perception of speech (sentences) in noisy situations (four-talker babble) [12, 20]. In this test, signal-to-noise ratio (SNR) loss is reported. It is calculated by subtracting the patients' SNR-50 score (ability to recognize 50% of the presented stimuli) from the average SNR-50 score of normal subjects. For this test, there are five identical lists, each with 6 sentences (5 keywords in each sentence) presented at SNRs of 0, +5, +10, +15, +20, and +25 dB. In this study, we selected the list number 3 [12]. SNR-50 score for each list is calculated by subtracting 27.5 from the total number of words that are recognized correctly. The scores of this test are calculated based on the expression of keywords in sentences between 0 and 30. In order to investigate the effects of binaural processing on speech perception in noise, this test was performed in binaural mode.

The Persian version of two-pair DDT includes presenting 20 two paired series of different monosyllabic digits (from 1 to 10 except for 4 in Persian language) to ears simultaneously at the MCL and the subject is asked to repeat all the digits regardless of their order (free-recall condition). The list includes 80 digits (40 for the right ear and 40 for the left ear) and the score for each digit is 2.5%. The scores of the right and left ears are reported in percentage and numerically between 0 and 100. We calculated the total score for the right ear and left ears. The ear advantage was determined by subtracting the left ear score from that of the right ear which reported numerically between 0 and 1. The positive ear advantage is an indicative of right ear advantage (REA) while the negative advantage is an indicative of left ear advantage (LEA) [16].

Data analysis

Data analysis was performed in SPSS v.17 software. Data were described as mean±standard deviation (SD). Based on the results of Kolmogorov-Smirnov test that showed an abnormal data distribution, non-parametric tests were selected for the analysis. In this regard, chi-square test was sued to compare the scores of the Ear Effect and Order Effect between the two control and MS groups, and Mann-Whitney U test was used to determine the gender effect in each group. Finally, the independent t-test was used to compare the results of each test between the two groups according to the central limit

Table 1. Qualifiers, description and the signs of the Persian staggered spondaic words test

Qualifiers	Description	Sign	Subtype involved
Tongue twister	Knows the answer but does not say it right. Gets tripped up in own words, repeats/anticipates sounds.	TTW	TFM
Delay	Counted as qualifier only when the answer is correct, but presented with significant delay.	X	DEC
Quick	Counted as qualifier only when the answer is correct, but presented before the beep sound.	Q	TFM
Perseveration	Repeats word from recent item or repeats error that was given before.	P	DEC
Quiet rehearsal	Rehears the words with him/herself so faintly before the beep sound.	QR	DEC
Smush	Smush: combines competing words	Sm	TFM
Extreme delay	The answer presented with extreme delay. Must show no great effort and item should be correct or error on LC item only.	XX	INT/DEC
Smush-2	Combines a spondee word	Sm-2	DEC
Intrusive word	Gives 5th word	IW	DEC
Back to back	Says same word back to back	BTB	DEC

TTW; Tongue twister, TFM; tolerance fading memory, X; delay, DEC; decoding, Q; quick, P; perseveration, QR; quiet rehearsal, Sm; smush, XX; extreme delay, INT; integration, Sm-2; smush-2, IW; intrusive word, BTB; back to back theorem and a sample size more than 30 people in each group. The significance level was set at 0.05.

Results

Participants

Participants were 45 patients with MS including 20 males (Mean age=35.95±5.73 years) and 25 females (Mean age=37.40±6.10 years) and 45 healthy peers as controls including 20 males (Mean age=37.20±6.15 years) and 25 females (Mean age=37.80±6.02 years). The mean scores of BMQ in two control and MS groups are presented in Table 2. Independent t-test results showed a significant difference between the two groups. Patients reported many problems in speech perception in noise which increased their total and APD scores compared to controls. The mean and standard deviation of errors related to CAPD categories in BMQ are presented in Table 3. Independent t-test results showed a significant difference between the two groups regarding errors in all CAPD categories. The effect sizes for DEC, TFM, INT and ORG were 0.85, 0.97, 1.01, and 0.49, respectively. In terms of ear effect, 9 out of 45 patients had high/low (H/L) status and 31 cases had low/high (L/H) status, while 18 out of 45 controls had H/L and one had L/H.

Table 2. Comparison of the Persian Buffalo model questionnaire scores between patients with multiple sclerosis (n=45) and control group (n=45) with independent t-test

	Mean (SD)		p
	Control (n=45)	Multiple sclerosis (n=45)	
Total score P-BMQ	1.53 (1.35)	10.04 (6.55)	<0.001
APD score P-BMQ	0.89 (1.02)	8.29 (5.47)	<0.001

P-BMQ; Persian Buffalo model questionnaire, APD; auditory processing disorder

Table 3. The analysis of Persian-staggered spondaic word scores in different conditions in patients with multiple sclerosis (n=45) and control group (n=45) with independent t-test

		Mean (SD)		p
		Control (n=45)	Multiple sclerosis (n=45)	
Quantitative	RNC	0.00 (0.00)	1.22 (3.35)	<0.001
	RC	0.09 (0.28)	1.62 (4.36)	<0.001
	LC	0.78 (1.04)	4.07 (3.94)	<0.001
	LNC	0.20 (0.50)	1.76 (2.36)	<0.001
	Total	1.07 (1.51)	8.67 (10.55)	<0.001
Qualitative	P	0.42 (0.75)	1.53 (1.35)	<0.001
	Sm2	0.00 (0.00)	0.04 (0.29)	0.310
	BTB	0.33 (0.67)	1.16 (1.31)	<0.001
	Re	1.20 (1.45)	3.02 (5.28)	0.270
Categories	DEC	0.84 (1.38)	6.76 (9.69)	<0.001
	TFM	1.42 (1.87)	5.84 (6.13)	<0.001
	INT	0.60 (1.05)	3.76 (4.26)	<0.001
	ORG	0.87 (1.61)	2.84 (5.36)	<0.001

RNC; right none competing, RC; right competing, LC; left competing, LNC: left none competing, P; perservation, Sm2; smush 2, BTB; back to back, Re; reversal, DEC; decoding, TFM; tolerance fading memory, INT; integration, ORG; organisation

Table 4. Comparison of Persian-phonemic synthesis test scores between patients with multiple sclerosis (n=45) and control group (n=45) with independent t-test

	Mean (SD)		p	Effect size
	Multiple sclerosis (n=45)	Control (n=45)		
Quantitative	20.24 (6.64)	24.29 (1.60)	<0.001	0.83
Qualitative	18.84 (6.47)	23.58 (2.06)	<0.001	0.98
DEC	2.62 (2.42)	0.09 (0.59)	<0.001	1.43
TFM	1.22 (2.07)	0.49 (0.96)	0.035	-

DEC; decoding, TFM; tolerance fading memory

In terms of order effect, H/L and L/H were observed in 30 and 10 patients and in 1 and 19 controls, respectively. Chi-square test results showed a significant difference between the two groups regarding ear effect and order effect errors (p<0.001).

In the SSW test, 14 out of 45 patients (28%) had normal scores and the remaining (82%) had abnormal scores. The quantitative and qualitative scores of SSW for both groups are shown in Table 3. Independent t-test results showed a significant difference in quantitative scores and in P and back to back (BTB) related to the qualitative analysis. It should be noted that there was no significant difference between smush (Sm2) and REV qualitative scores. No qualitative errors in X, QR, intrusive word (IW), Q, Sm, and tongue twister (TTW) were observed in any subjects.

In the PST test, patients had lower quantitative and qualitative scores in NF, P, and Q compared to controls and this difference was statistically significant according to independent t-test results presented in Table 4 (p<0.001). No subject showed errors in X, XX, REV, and 1st phoneme omission. In QR error, there was no significant difference between patients (Mean=0.04±0.2) and controls (Mean=0.00±0.00) according to the t-test results (p=0.61). There was a significant difference between two groups only in DEC (p<0.001). No significant difference was found in ORG and TFM. In the Quick SIN test, results showed a significant difference in the mean SNR-50 score between patients (2.61±3.78 dB) and controls (–1.12±1.15 dB) according to the t-test (p<0.001). The effect size was 1.33. In the DDT, the right ear, left ear and REA of patients were significantly different from those of controls (p<0.001). As shown in Table 5, the mean scores of right and left ears in patients were lower, while their REA score was higher compared to controls.

Discussion

The purpose of this study was to compare the monaural and binaural auditory processing in patients with MS and normal peers using a set of tests for CAPD assessment. The results study showed that APD score in BMQ was significantly higher in patients than in controls indicating the likelihood of auditory processing disorder in MS group. To our knowledge, there is no other study that has used BMQ in MS patients. BMQ can be applied on subjects from age 6 to adulthood [10]. There are some studies that have reported the impairment of central auditory processing in patients with MS [3, 4]. Previous studies have also shown a strong correlation between the BMQ score and the results of central auditory processing tests (e.g. SSW test, PST, and SIN test) [8, 21]. This indicates that BMQ covers a wide range of auditory behaviors that can be affected by CAPD from speech perception in

Table 5. Comparison of the dichotic digit test scores between patients with multiple sclerosis (n=45) and control group (n=45) with independent t-test

	Mean (SD) (%)		p	Effect Size
	Multiple sclerosis (n=45)	Control (n=45)		
Right ear	87.35 (8.09)	93.94 (5.18)	<0.001	0.97
Left ear	56.11 (23.29)	87.00 (8.24)	<0.001	1.76
Right ear advantage	0.33 (0.23)	0.07 (0.1)	<0.001	1.46

noise to dichotic listening. Zalewski stated that although the BMQ score has strong correlation with Buffalo model test battery, it cannot be used solely as a diagnostic tool [21]. Kaul et al. showed that the BMQ can show treatment-related changes in different auditory processing areas, and is in agreement with behavioral auditory processing tests [22].

In the present study, the SSW test results showed abnormal scores in 82% of patients and their quantitative errors in RNC, RC, LC and LNC were significantly higher compared to controls. In qualitative analysis, P and BTB errors were observed. Moreover, ear effect in patient was L/H and order effect was H/L. Patients showed DEC, INT, TFM and ORG errors but their DEC and TFM were normal. This result can be an indicative of lesions in different brain parts of temporal lobe, frontal lobe and corpus callosum in MS patients [8]. Our results showed that errors related to the left ear were significantly higher than in the right ear. This is consistent with the results of Lewis et al. They showed that SSW test had abnormal results in patients with MS and their errors in the left ear were higher than in the right ear. They suggested that the SSW test is inherently a dichotic listening test and corpus callosum seems to be affected in these patients since the left hemisphere of the brain is dominant for language processing [23]. A highly significant reduction of left-ear scores was found in the most of MS patients in our study.

In the present study, the PST score of patients was significantly lower than that of controls. Moreover, there were NF, P and Q errors, and DEC was most the common problem in them. The PST primarily evaluates decoding problems and the results indicate the decoding impairment. Both groups had normal WRS in quiet but in Quick SIN test, patients showed poor performance at each SNR, maybe because they suffer from problems in speech perception in noise. This finding is consistent with the results of Lewis et al. and Ali et al. They showed that patients with MS have poor performance in perception of speech in noise compared to normal subjects, and suggested that these patients have problems in temporal and spatial processing which can lead to speech perception difficulty in challenging acoustic environments and in presence of competition [23, 24]. The SIN test using sentence materials is similar to challenging real-life circumstances.

In the present study, the score of both ears under DDT was lower in the MS group than in the control group, while their REA was higher compared to controls. In patients with MS, left ear score showed more decrease compared to that of controls. The REA is normally seen in adults as the left temporal lobe of the brain is dominant for language processing and the right ear is directly connected to the left temporal lobe. Information from the left ear enter into the right temporal lobe and then is transferred into the left temporal lobe via corpus callosum. It seems that corpus callosum is affected in some of patients with MS resulting in an abnormally higher asymmetry between the two ears. Similar to the present study, Gadea et al. showed abnormally higher REA in patients with MS. They suggested that corpus callosum contains high volume of white matter which is commonly involved in demyelinating process [25]. Against to our results, Berlow et al. showed no significant difference between MS patients and controls in DDT score. The reason may be the difference in the used task. They did not use verbal recognition of presented digits [26]. Rubens et al. used verbal dichotic listening tests using nonsense consonant-vowel stimulus pairs in patients with MS and showed a highly significant reduction of left-ear scores which is consistent with our results. They suggested that the disconnection of the auditory callosal pathway may be responsible for this outcome and that dichotic listening tests may be valuable in detecting the presence of lesions in the deep white matter of the cerebral cortex in MS patients [27].

Some of the limitations of this study were small sample size and not having access to new MRI results of people with MS; as the location of MS plaques changed over time, recent MRI can show the position and severity of the plaques. Further studies with the use of recent MRI results along with the test results are recommended for accurate selection of tests and appropriate rehabilitation.

Conclusion

Central auditory processing disorder is common among patients with Multiple Sclerosis. The Buffalo model questionnaire is a suitable screening tool for identifying affected people. Dichotic listening skills, phonemic processing and speech perception in noise are affected in these patients whose impairments can have negative impact on the quality of life of patients. Since this study examined some of the auditory processing skills in MS patients, it cannot be claimed that they have central auditory processing disorder; therefore, more studies are needed to examine different aspects of central auditory processing in this group of patients.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of Tehran University of Medical Sciences (Code: IR.TUMS. FNM.REC.1397.171).

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Authors' contributions

MH: Study design, acquisition of data, interpretation of the results, statistical analysis, and drafting the manuscript; SF: Study design, interpretation of the results, and drafting the manuscript; NR: Study design, interpretation of the results, and drafting the manuscript; FZA: Study design, interpretation of the results, and drafting the manuscript; EN: Interpretation of the results and drafting the manuscript; SJ: Statistical analysis.

Conflict of interest

The authors declare that they have no conflict of interest.

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