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Correspondência entre alvo e saída da prótese auditiva segundo as regras prescritivas NAL-NL1 e NAL-NL2

Fit to target of hearing aids according to NAL-NL1 and NAL-NL2 prescription rules

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ABSTRACT

Purpose: To compare the targets prescribed by the non-linear NAL with the real ear aided response - REAR obtained through probe microphone in the setting of effective use according to the degree of hearing loss. **Methods**:67 experienced hearing aid users participated in the study. All were reassessed when attending follow-up sessions. At that moment, they were asked whether they had any complaints with respect to the amplification. An audiological evaluation was performed, the hours of use of the device were recorded and the new probe microphone measurement was taken. **Results**: The percentage of ears with REAR within ± 10dB of the prescriptive target was verified. It was observed that 80% of the hearing aids of all groups reached the analyzed range, with the exception of the moderate hearing loss group. We also performed the analysis of the percentage of ears whose hearing aid response was within ± 5 dB for the low frequencies and ± 8 dB for the high frequencies, and it was observed that less than 80% of the adjustments reached this range. Confidence intervals were constructed to verify the preference fit to target of experienced users. **Conclusion**: The range of ±10dB proves to be the users' preference. For experienced users, it is suggested that the adaptation phase be found in the range of ±3 in the low and medium frequencies and ±7 in the high frequency region

Keywords: Adult; Hearing loss; Hearing aids; Speech perception; Outcome assessment

RESUMO

Objetivo: analisar comparativamente os alvos prescritos pelas regras NAL (*National Acoustic Laboratories*) não lineares com a resposta da prótese auditiva obtida por meio das mensurações com microfone-sonda no ajuste de uso efetivo, de acordo com o grau da perda auditiva. **Método:** participaram do estudo 67 usuários experientes de próteses auditivas. Todos foram reavaliados quando compareceram às sessões de acompanhamento periódico. Nesse momento, realizou-se avaliação audiológica, registrando-se as horas de uso do dispositivo e realizando-se a resposta com prótese auditiva (REAR - *Real Ear Aided Response*). **Resultado:** observou-se que 80% das próteses auditivas de todos os grupos atingiram a faixa analisada, com exceção do grupo de perda moderada. Também foi realizada a análise da porcentagem de orelhas cuja resposta com prótese auditiva estivesse em ±5 dB para as frequências baixas e ±8 dB nas altas frequências e observou-se que menos de 80% dos ajustes atingiram esta faixa. Intervalos de confiança foram construídos para verificar a faixa de adaptação de preferência dos usuários experientes. **Conclusão:** A faixa de ±10 dB demonstra ser a de preferência dos usuários. Porém, para usuários experientes, sugere-se que a faixa de adaptação encontre-se na faixa de ±3 nas frequências baixas e médias e ±7 na região de altas frequências.

Palavras-chave: Adulto; Perda auditiva; Auxiliares de audição; Percepção da fala; Avaliação de resultados

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INTRODUCTION

Data from the Brazilian Institute of Geography and Statistics (IBGE – abbreviation in Portuguese)[1] indicate that hearing loss is the third most predominant impairment in Brazil. In children, hearing impairment causes important damage to language development, thus requiring some intervention through the use of hearing aids as early as possible for the speech signal audibility to be reestablished. In adults and elderly persons, hearing loss, in addition to damaging communication, has a strong negative impact on life quality. Hearing amplification through hearing aids is recommended to soften the unwanted effects of hearing loss[2].

The process of selection and adaptation of the hearing aids involves verifying their performance to ensure that the amplified speech signal is audible and comfortable to the user. This process determines the most adequate physical, electroacoustic, and technological features to meet the hearing needs of each case. It is also important that the selection of gain per frequency and maximum output required for the hearing amplification of the speech signal is performed through validated prescription methods, such as NAL-NL (National Acoustic Laboratories – Non-Linear)[3] and DSL (Desired Sensation Level)[4]. Such rules have been largely studied in different populations with satisfactory results in providing speech signal audibility and comfort to the hearing amplification user.

Verification based on measurements using microphone-probe and the use of targets from validated prescription methods is the best practice for the adaptation of hearing aids. However, Mueller[5] highlights that although 78% of the professionals who adapt hearing aids use prescription methods of validated gain, only 44% of them apply measurements using microphone-probe to their clinical routine. This means that many professionals select an adequate and scientifically validated prescription measure, but do not conduct tests to verify whether the desired values of gain and output are reached satisfactorily.

Much has been discussed on the desirable difference between the prescribed targets and the results obtained from the objective verification of the hearing amplification user, whether children or adults. In children, it is fundamental that the amplified signal is as close as possible to the prescribed targets due to their speech development. Therefore, the device of hearing amplification must provide the best audibility possible. It is recommended that the amplified signal reaches a range of ±3 or ±5 dB of the targets prescribed by the DSL to ensure that neither a super nor a sub-hearing amplification occurs[6,7]. As for the adult population, it is believed that the amplified signal should reach the range of ±10 dB of the prescribed targets; however, it is not a consensus[8-13]. There has been evidence demonstrating that the range of usable gain may vary along with the frequencies, suggesting values between 5.8 dB at low frequencies and 8.4 dB at high frequencies[11]. Despite these findings, it is known that adults need and bear lower gains than the pediatric population.

In this sense, it is paramount to learn the ideal adjustment of the hearing aid for the hearing amplification delivered to the patient to be audible, comfortable, and provide the best experience. Thus, the prescribed targets must be comparatively analyzed through non-linear NAL rules with the response of the hearing aid obtained from the measurements using microphone-probe when adjusting its effective use, according to the degree of hearing loss, to verify the preferable adjustment for experienced users adapted to hearing aids.

In this context, this study aimed to comparatively analyze the targets prescribed by the non-linear NAL rules 1 and 2, with the hearing aid response generated through measurements using microphone-probe to adjust the effective use according to the degree of hearing loss, for experienced adults, to establish the ideal range of acoustic gain for this population.

METHODS

This study was approved by the Research Ethics Committee of the Faculty of Medical Sciences of the Santa Casa de São Paulo – FCMSCSP, research protocol 2.483.720. According to the ethical standards for research with human beings. All participants were instructed on the study nature and procedures to which they would be subjected. By agreeing to participate, they signed an Informed Consent Form (TCLE). All steps of the research were conducted at the Speech Therapy Clinic Maria do Carmo Redondo da FCMSCP and the Center of Hearing Disorders Studies – CEDIAU.

All participants are hearing aid users who were invited to participate in the study during the monitoring sections. The candidates were recruited between June 2017 and October 2018. Sixty-six participants were selected according to the following inclusion criteria: adults with hearing loss of any degree and configuration, hearing aids users for at least six months, and self-declared daily use of hearing aid(s) for a period of time equal to or higher than eight hours a day confirmed by the data record in the device. The exclusion criterium considered the presence of any health problems that could hamper participation in any research stage.

At the moment of adaptation, the hearing aids were programmed on a computer equipped with the NOAH 4.0 system to record the individual data and to adjust the electroacoustic features of the hearing aids through a specific interface of each brand/model (iCube, Air Link, Hi-pro*)*, established by the programming software of each manufacturer. The hearing aids selected were adjusted based on the prescription methods NAL-NL1 (National Acoustic Laboratories Non-Linear)[14], for longer users adapted, and NAL-NL2 (National Acoustic Laboratories Non-Linear)[3], for more recent users. Before obtaining the measures using a microphone probe, the initial fine adjustment was performed based on the information provided by the individual regarding sound quality, intensity, and discomfort. The record of hours (data logging) of use was activated in all hearing aids. The participants were reassessed when attending the periodic monitoring sections scheduled at least six months after the adaptation. This step involved observing any complaint regarding the hearing amplification, hearing assessment, verifying the record of use hours of the hearing aid, and a new measurement using microphone-probe equipment. The data obtained were collected and used for further analysis.

The electroacoustic features of the hearing aids were verified in a quiet room equipped with a microphone-probe Verifit by Audioscan using the 'amplified speech mapping' tool. This tool allows assessing the electroacoustic functioning of the hearing aids and verifying whether the values of gain and output generated provide consistent audibility to the speech signal

compared to the targets generated by the prescription rules. The ISTS signal (International Speech Test Signal)[15] at intensities of 55 dB NPS (decibel – level of sound pressure) and 65 dB NPS, respectively, was applied to verify how close the output for different sound inputs was to the targets determined by the prescription rule chosen. The values obtained were recorded by the equipment. Pure tone scanning at the intensity of 90 dB NPS was used to analyze the saturation response of the hearing aid. The tests were immediately interrupted provided that the patient reported any discomfort.

All data were computed and subjected to descriptive and inferential analyses. The descriptive analysis encompassed qualitative variables, such as age, sex, time of adaptation, daily use, and degree of hearing loss. All variables generated absolute (n) and relative (%) values, standard deviation, and median. The analysis of the differences between target and response in the groups adopted the significance level of $p \leq 0.05$ based on the Pearson Qui-square test. Confidence intervals were generated for the differences between prescription target and hearing aid response. All statistical analyses were performed on the SPSS software (13.0).

RESULTS

The study sample was composed of 66 adults – 35 male and 31 female –, all aged over 18 years old, predominantly formed by elderly persons (more than 60 years). Most ears were classified as having moderate loss (55%), as shown in Table 1. As for the wear time, the sampled individuals had been adapted to their hearing aids for at least 6 months, with an average period of 5 years.

We considered the effective use of the hearing aids when used for a period higher than or equal to 8 hours a day. The daily wear time was indicated as a marker of the user's satisfaction with the hearing amplification. Subsequently, we performed an analysis of the targets generated by the prescription rules by calculating the variation between target and response with the hearing aid (REAR – Real Ear Aided Response). We verified the percentages of ears with a hearing aid response ranging ±10 dB of the prescription target and ears with a response between ±5 dB and ±8 dB, according to the frequency obtained from the microphone-probe verification for weak (55 dB) and moderate (65 dB) input signals to establish an ideal range of hearing amplification for experienced users. Table 2 shows the descriptive analysis of the ranges analyzed, according to the input signal intensity.

In addition, confidence intervals for weak speech signal (55 dB), moderate (65 dB), and maximum output (MPO) were built from the differences between hearing aid response and prescription targets, considering the degree of hearing loss, to verify the range of acoustic gain and maximum output used for the prescription rules NAL-NL1 and NAL-NL2 by experienced users of hearing amplification. It is worth highlighting that all hearing aids were adjusted seeking to reach the targets proposed by the prescription rules and respecting the individual sensation of each patient. Tables 3, 4, and 5 show the descriptive results of the difference between target and response for the prescription rules NAL-NL1 and NAL-NL2 and confidence intervals.

Table 1. Sample characterization

	N= 114	%
PRESCRIPTION RULE		
NAL-NL1	66	57,9
NAL-NL2	48	42,1
DEGREE OF LOSS		
Mild	25	21,9
Moderate	62	54,4
Moderately Severe	16	14,0
Severe or Profound	11	9,6
	N (n= 66)	**%**
TYPE OF AID		
Receptor in the channel	51	45
Retro auricular with a fine tube	2	2
Conventional retro auricular	7	6
Microchannel/Intrachannel	6	5
SEX		
MALE	35	53
FEMALE	31	47
AGE (YEARS)		
18 - 59	7	11
Above 60	59	89
MEAN AGE:	76,9	
ADAPTATION		
Unilateral	18	27
Bilateral	48	73

Subtitle: N= total of ears analyzed; % = percentage; NAL-NL = National Acoustic Laboratories Non-Linear

DISCUSSION

The study sample is composed of 66 adults who had been adapted to the hearing aids for at least six months and minimum daily use of eight hours. The participants are aged on average 76.9 years old, that is, the elderly population represented almost 90% of the sample. All participants have been effectively using their hearing aids for a period varying between eight and 17 hours, with an average of ten daily hours. Based on the wear time, all individuals were considered well adapted to the hearing amplification since it would reflect the benefit and user's satisfaction with the devices, thus corroborating other studies[16,17].

All participants were adapted using the rules NAL-NL1 or NAL-NL2, depending on their previous experience. It is worth highlighting that the validated prescription methods are the best practice for the adaptation of hearing aids and determining the electroacoustic features of the hearing aids[18]. However, no hearing aid was used without requiring fine adjustments and verifying the prescribed targets. Regardless of the validated method chosen for the adaptation of the hearing aids, it is fundamental to verify the features of gain and maximum output

Table 2. Descriptive statistics of the difference between target and response of the aid by frequency and degree of hearing loss according to the NAL-NL2

Degree of Loss	Input	Range of adapt. (dB)	250 Hz %	500 Hz %	1KHz %		2 KHz %	3 KHz %	4 Hz %
Mild	55 dB	± 10	100	100	88		100	84	92
(n= 25)		± 5	88	68	48	± 8	80	73	64
	65 dB	± 10	100	100	89		100	93	93
		± 5	96	76	60	± 8	84	76	92
	Output	**- 10**	76	100	89		100	96	96
		- 5	12	0	8	**- 8**	35	46	12
Moderate	55 dB	± 10	97	68	66		97	95	74
(n=62)		± 5	77	30	47	± 8	80	87	63
	65 dB	± 10	95	78	70		94	90	84
		± 5	81	42	75	± 8	91	86	75
	Output	**- 10**	31	81	73		97	94	86
		- 5	5	2	8	**- 8**	28	54	13
Mod/Sev.	55 dB	± 10	87	73	88		93	93	77
(n=16)		± 5	50	32	62	± 8	69	81	57
	65 dB	± 10	81	69	81		88	75	63
		± 5	63	44	69	± 8	69	63	77
	Output	**- 10**	27	73	81		94	86	77
		- 5	7	6	13	**- 8**	44	38	6
Sev/Profound	55 dB	± 10	93	100	81		87	83	75
(n=11)		± 5	45	45	73	± 8	55	45	9
	65 dB	± 10	70	91	73		78	57	50
		± 5	40	55	67	± 8	75	57	25
	Output	**- 10**	30	91	73		78	57	50
		- 5	10	18	27	**- 8**	27	57	50

Subtitle: NAL-NL = (National Acoustic Laboratories - Non-Linear); N = number of individuals % = percentage; dB = decibel; Hz = hertz; KHz = kilohertz; adapt. = adaptation; Mod/Sev. = moderate/severe; Sev/Profound = severe/profound

through microphone-probe measures since such features provide the information of audible amplified speech to the user.

In clinical practice, seeking an ideal adjustment for hearing aids can be a challenge, since the ideal range of adaptation for hearing aids users is often unknown. It is known that the best practice to confirm the adjustment of hearing aids is the verification based on measures using a microphone probe that allows visualizing the hearing amplification provided by the hearing aid to the user. Even though such tools are essential, the speech therapist must know how to use the information obtained. For example, according to the different prescription methods, experienced users with hearing amplification prefer the gain more than new users. However, what is the ideal range of acoustic gain for each individual to benefit the most from the hearing amplification? The ideal adjustment of the hearing aid is the one that provides the user with an amplified sound at a comfortable intensity and with good sound quality, allowing the full-time use of hearing amplification and offering the best sound information possible[19].

Fine adjustments must be performed for the features of gain and output of the hearing aids aiming at the targets calculated by the prescription methods – within a certain variation range – and providing audibility of the speech signals of weak and moderate intensities without any discomfort to the user[3].

Our study compared the targets prescribed by the NAL-NL1 and NAL-NL2 with the hearing aid responses (REAR) obtained for weak (55 dB) and moderate (65 dB) wear time to identify the ideal range of adaptation for the experienced user. Several studies[9,10,12,20] mention different criteria for the adaptation of hearing aids, regardless of the prescription rule adopted, with

Table 3. Confidence interval of 95% for the differences between target and response according to the prescription rule NAL-NL1

Degree of Loss	Level of Input (dB NPS)	250 Hz	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz
Mild	55	6,05	5,7	4,5	7,6	7,7	7,7
(n= 25)	65	3,3	10,3	4,1	8,6	8,6	6,1
	Output	2,3	10,3	5,6	8,8	8,8	10,6
Moderate	55	3,2	3,6	4,5	3,3	4,7	4,7
(n=62)	65	2,8	3,1	4,3	3,1	4,6	5,4
	Output	2,1	3,1	4,2	3,1	4,6	6,0
Mod/Severe	55	26,7	11,7	17,3	12,2	8,7	39,8
(n=16)	65	18,3	16,2	14,7	12,1	6,2	44,7
	Output	39,2	24,4	20,5	19,6	10,3	23,4
Profound	55	12,8	9,0	6,8	4,6	28,7	*
(n=11)	65	17,8	8,4	10,5	10,3	24,7	*
	Output	18,9	10,9	21,5	25,9	26,5	35,1

*Values that were not established due to reduced n for the frequency of 4 kHz in the profound degree group
Subtitle: NAL-NL = National Acoustic Laboratories Non-Linear; n = number of ears dB = decibel; NPS = level of sound pressure; Hz = hertz; Mod = moderate

Table 4. Confidence interval of 95% for the differences between target and response according to the prescription rule NAL-NL2

Degree of Loss	Level of Input (dB NPS)	250 Hz	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz
Mild	55	2,93	-4,6	-3,8	-2,0	-4,4	-7,1
(n= 25)	65	2,1	-2,7	-1,9	-0,2	-1,2	-4,9
	Output	-6,8	-13,9	-14,8	-8,9	-10,6	-15,5
Moderate	55	0,2	-7,6	-4,7	-0,5	-2,9	-6,2
(n= 62)	65	-0,1	-3,8	-1,5	1,1	0,1	-3,8
	Output	-12,0	-17,5	-16,7	-8,4	-9,3	-15,4
Mod/Severe	55	-0,5	-6,7	1,0	2,7	-2,1	-6,3
(n= 16)	65	1,3	-3,2	5,2	3,3	2,1	-4,1
	Output	-13,5	-17,5	-12,0	-7,5	-12,6	-21,6
Profound	55	-3,5	7,0	14,0	11,0	1,0	*
(n= 11)	65	-5,5	11,5	17,0	10,5	*	-2,0
	Output	-18,5	-5,5	-7,0	-3,0	-27,0	-32,0

*Values that were not established due to the reduced n for the frequencies of 3 and 4 kHz in the profound degree group
Subtitle: NAL-NL = National Acoustic Laboratories Non-Linear; n = number of ears; dB = decibel; NPS = level of sound pressure; Hz = hertz; Mod = moderate

the range of ±10 dB being the most recommended. We found that the participants had an acoustic gain between ±3 and ±7 dB from using hearing aids, according to the frequency of sound inputs of weak and moderate intensities. Thus, the ideal adjustment should be conducted and assessed considering not only the hearing thresholds but also individual factors, such as comfort and tolerance to the amplified sound. In addition, the data obtained from the electroacoustic verification of the individuals allowed building confidence intervals for the adaptation ranges to provide the speech therapist with a consistent starting point to adjust the hearing aids[20].

As for the studied groups, we found that the adjustments for both the adaptation range analyzed occurred as expected, thus demonstrating that the technology of the hearing aids reached the prescribed gain. It is worth highlighting the effect of ventilation on the moderate degree group, which included individuals who used open adaptation or major ventilation. Such an effect resulted in only 30% of the adjustments reaching the

Table 5. Descriptive statistics of the mean differences between prescription target and response of the hearing aid by frequency and degree of hearing loss according to the rules NAL-NL1 and NAL-NL2

Degree of Loss	Level of Input (dB NPS)	250 Hz	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz
Mild	55	3,16	-4,7	-5,4	-2,0	-4,7	-7,0
(n= 25)	65	2,0	-2,9	-3,0	0,0	-1,1	-4,7
	Output	-8,5	-13,5	-14,5	-7,3	-9,2	-14,4
Moderate	55	1,4	-8,2	-6,4	-1,7	-3,0	-6,9
(n= 62)	65	1,2	-5,6	-4,0	-0,8	1,0	-2,8
	Output	-10,4	-16,9	-16,3	-9,5	-9,2	-15,8
Mod/Severe	55	-2,9	-6,3	0,8	1,9	-1,2	-6,3
(n= 16)	65	-0,5	-4,1	3,3	2,6	2,4	-4,2
	Output	-15,8	-20,3	-13,1	-7,3	-12,2	-21,9
Profound	55	-2,8	-1,0	1,7	3,9	-3,0	-5,3
(n= 11)	65	0,8	0,2	4,9	5,3	1,3	-4,8
	Output	-16,4	-12,7	-9,0	-5,0	-17,6	-33,4

Subtitle: NAL-NL = National Acoustic Laboratories Non-Linear; n= number of individuals dB = decibel; NPS = level of sound pressure; Hz = Hertz; Mod = moderate

range of ±5 dB at the frequency of 500 Hz and impacting the adjustments at the frequencies of 250 and 1000 Hz.

It is known that the severity of hearing loss, especially at high frequencies, impacts the gain prescription by the NAL-NL1. This rule considered the presence of possible cochlear dead zones in the region of high frequencies upon high hearing thresholds[4]. The NAL-NL2, in turn, discarded such an assumption[3]. Thereby, we observed a confidence interval for the group of severe/profound loss varying up to -34 dB in the prescription of maximum output (MPO – Maximum Power Output). In addition, the lower percentage of adjustments is probably related to the limitation inherent to the device, associated with the gain per frequency provided by the hearing aids, as found by Baker and Jenstad[13].

In cases where the prescription targets are not generated, the results were analyzed based only on the targets generated. Consequently, there was great variation in the analysis of high frequencies, especially for the severe or profound losses. For example, considering the adaptation range of ±10 dB and the signal of 65 dB, despite the group of severe/profound loss including 11 ears, at the frequency of 4000 Hz, only four prescription targets were generated, that is, two ears represented 50% of the adjustments within the expected range. As for the maximum output, it is worth highlighting that the values of the level of sound pressure recorded in all groups did not exceed the targets determined by the prescription rules.

We also analyzed the adjustment gains for the values of ±5 dB (250, 500, 1000, and 2000 Hz) at ±8 dB (3000 and 4000 Hz), as proposed by Polonenko[11]. For the input signal of 55 dB, the mild degree group obtained 80% of the adjustments in the range of gain at the frequency of 250 Hz. The remaining frequencies had a low percentage of adjustments in the same range. The other groups showed 80% of the adjustments only in the range of 3000 Hz frequency. In addition, the groups of moderately severe and severe/profound degrees presented the lowest percentages of all groups since only 50% of the adjustments reached the range of gain at low frequencies.

Although all individuals who participated in this study were experienced users of hearing aids, it is known that hearing losses cause a reduction in the dynamic area of hearing. Thus, individuals with hearing losses of severe and profound degrees often have a lower tolerance to certain sounds. This could explain that only 33% of the adjustments gained for the group of moderately severe degrees were only 5 dB far from the prescription targets in the region of low frequencies. Baker and Jenstad[13] highlight that reaching values of acoustic gain of ±5 dB at low frequencies and ±8 dB at high frequencies is consistent with the best adaptation of the hearing aids. However, they also highlight that the adjustment gain might need to be farther from the targets for the hearing amplification to be effectively used and tolerated by the user.

For the sound input of 65 dB, the mild degree group obtained 80% of the adjustments only in the range of the 250 Hz frequency. All other groups reached 80% of the adjustments only in the adaptation range of the 3000 Hz frequency. The moderate degree group obtained 42% of the adjustments in the range of gain of the 500 Hz frequency, probably due to the larger number of open adaptations. In addition, once again the severe/profound degree group obtained adjustment only in the range of ±8 dB (4000 Hz), demonstrating the limits of the electronic device to provide the required hearing amplification, especially at high frequencies. According to Baker and Jenstad[13], the novel technology of the commercially available hearing aids can provide a hearing amplification in such a range of gain in 80% of the cases at most frequencies. Our study group demonstrated that it is possible to reach satisfactory moderate gain close to the prescribed targets with the consistent use of hearing amplification.

CONCLUSION

By comparing the targets prescribed by the rules NAL-NL1 and NAL-NL2 with the hearing aid response obtained through the microphone-probe measurements when adjusting the effective use, we found that most users have an acoustic gain in the range of ±10 dB, regardless of their hearing loss degree, indicating it as the preferable range of effective use of hearing aids in adults. As for experienced users, it is suggested that the adaptation range reaches the range of ±3 at low and moderate frequencies, and ±7 in the region of high frequencies, if allowed by the device, always ensuring that aid response compared to the targets is performed through microphone-probe measures.

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