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Listening effort in patients with sensorineural hearing loss with and without hearing aids

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Abstract

Background: Persons with hearing loss may have difficulty in speech understanding, so they need to shift more resources from other on-going cognitive tasks. This increase in cognitive resources has been referred to as an increase in "listening effort: (LE). Two research questions were addressed: (Q1) Does hearing loss increase LE? (Q2) Can hearing aid (HA) amplification improve LE?

Methods: This study included 55 subjects that were divided into two groups: control group (I), which consisted of 15 adults with normal peripheral hearing, and study group (II), which consisted of 40 patients with bilateral SNHL. They were subdivided into two subgroups: study subgroup (IIa), which consisted of 20 patients did not use (HAs). The study subgroup (IIb) consisted of 20 patients using unilateral or bilateral HAs. LE was measured by subjective (Speech, Spatial and Qualities of Hearing Scale (SSQ), Fatigue Assessment Scale (FAS)) and behavioral measures (dual-task paradigm test (simultaneous primary auditory task (QuickSIN test) and secondary visual task (reaction time and Stroop test)).

Results: Hearing loss patients showed higher fatigue scores and lower scores in SSQ than the normal hearing subjects. They also showed significantly longer reaction times (RTs) in dual conditions. No significant difference was found between patient with SNHL with and without HAs in all tests.

Conclusion: Patients with SNHL with and without HAs showed more LE than the normal hearing subjects (Q1). Hearing aid fitting does not reduce LE (Q2). HA users showed less listening effort in favorable listening situation (higher signal-to-noise ratio) than those who did not use HAs. Increased LE is a consequence of hearing loss which could not be measured by standard audiometric measures, so it should be considered when measuring disability in those with hearing loss.

Keywords: Listening effort (LE), Fatigue assessment scale (FAS), Speech, Spatial qualities of hearing scale (SSQ), Sensorineural hearing loss (SNHL), Reaction time (RT), Dual task paradigm

Background

Listening is the function of hearing with intention and attention and consequently involves cognitive processes beyond the fundamental functions of hearing; therefore, it might require the expenditure of effort [1, 2]. Hearing loss can degrade speech understanding leading to communication difficulties. To maintain optimal understanding in a challenging situation, persons with hearing loss may need to shift more resources from

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other ongoing cognitive tasks (e.g., visual processing or memory rehearsal) than individuals without hearing loss [3–5]. This increase in cognitive resources required to understand degraded speech has been referred to as an increase in "listening effort" [3, 6]. Listening effort can be defined as the mental exertion required attending and understanding an auditory message [7]. Listening for individuals with hearing loss is often reported to be considerably taxing [8]. Those individuals commonly complain of fatigue associated with the higher levels of concentration or effort required to understand speech in everyday listening environments [9].

Listening effort can be quantified using subjective (e.g., SSQ of hearing scale, self-report fatigue scale), physiologic (heart rate, pupillometry), and behavioral techniques (dual-task paradigm test) [10]. Hornsby [11] used self-report and behavioral measures of listening effort and fatigue in a dual task study with hearing-impaired participants. HAs typically restores audibility by amplifying the acoustic signal for reduced hearing sensitivity. However, the HAs benefits vary between individuals, which might be partly explained by individual differences in cognitive capacity [12].

This research addressed two questions: (Q1) Does hearing loss increase listening effort? (Q2) Can hearing aid amplification improve LE?

Subject and method

This study included 55 subjects with age range of 18–45years. It was approved from the ethical committee of Faculty of Medicine, Tanta University, with approval code 31859. Subjects were divided in to two groups: control group (I), which consisted of 15 adults with normal peripheral hearing with hearing threshold level not exceeding 25 dB in the frequency range 250 to 8000 Hz, and study group (II), which consisted of 40 patients with bilateral SNHL from moderate to severe degrees. They were subdivided into two subgroups: study subgroup (IIa), which consisted of 20 patients did not use hearing aids, and study subgroup (IIb), which consisted of 20 patients using unilateral or bilateral hearing aid for not less than 6 months with satisfactory aided response (≤ 30 dB). Subjects used Beltone high power Force Basic, GN Resound, HANSATON base power, and Oticon Dynam sp4. One subject used ITC SIEMENS hearing aid. The exclusion criteria are as follows: unilateral SNHL and patients having neurological or psychological problems. All subjects have Arabic as native language with variation in the educational background at least can read Arabic language.

All subjects were subjected to the following:

1. Basic audiological evaluation including pure tone audiometry, speech audiometry using Madsen Astera (GN Otometrics, Madsen, Aurical, ICS) with headphones TDH 39, and acoustic immittance measurements (tympanometry/stapedial reflex) using interacoustics AT235H (using low frequency 226 Hz probe tone). Free field-aided response was done for study subgroup (IIb) using loudspeakers Mixmax.
2. Listening effort was measured by subjective and behavioral tests:

   a. Subjective tests (questionnaires) included:

   – *Speech, Spatial and Qualities of Hearing Scale (SSQ)*: It consisted of 30 questions organized into three sections. In the speech section, questions were asked about difficulties with understanding speech in everyday situations. In the spatial section, questions were asked about difficulties with sound localization and tracking moving sounds. In the qualities section, the patient was asked about difficulties with perceived naturalness of sounds, separating sounds and the amount of effort required to listen. For each question, the scoring was zero when the answer was no, 5 when the answer was sometimes, and 10 when the answer was always. Then, we calculate the scores of each section and the total score for the three sections [13].
   – *Fatigue assessment scale (FAS)*: The FAS is a 10-item general fatigue questionnaire. Five questions reflect physical fatigue and 5 questions (questions 3 and 6–9) reflect mental fatigue. The total FAS score can be calculated by summing the scores on all questions. The total score ranged from 10 to 50. A total FAS score < 22 indicated no fatigue; a score ≥ 22 indicates fatigue [14].

   b. Behavioral tests included:

   – *Dual task paradigm test*: Computer-assisted software program was developed at audio-vestibular unit, Tanta University, by an IT senior consultant [15]. In the sound-treated booth, the subjects perform two tasks simultaneously: the auditory/verbal primary speech recognition task using QuickSIN test and a secondary task (visual/motor secondary task). When performing both tasks simultaneously, listeners were instructed to prioritize the primary task over the secondary task. The test was done at the end of the working day to ensure the fatigue of the subjects.

- *The primary task*: The QuickSIN test was developed to measure the signal-to-noise ratio loss in decibels (dB SNR loss). SNR loss is described as the dB increase in signal-to-noise ratio required by an individual with hearing impairment to understand speech in presence of noise as comparable to normal hearing individual. Lists of QuickSIN test [16] presented through loudspeakers at 70 dB HL for patients with pure tone average of 45 dB HL or less and at 40 dBSL for patients with pure tone average more than 45 dB HL. The list contained 6 sentences with decreasing signal-to-noise ratio (SNR) in 5-dB steps (from +25 to 0) as the list progressed. Participants were instructed to listen to each sentence and repeat it as accurately as possible, even if it required guessing. For subgroup IIb (hearing loss group with hearing aids), the test was done while they were wearing their hearing aids. Five key words are scored in each sentence. One point is given for each key word repeated correctly. The number of correct words for each sentence should be written in the space provided at the end of the sentence and the total correct words for the list were calculated. SNR loss is calculated for each list by using the formula: SNR loss = 25.5 – total correct.
- *The secondary task include easy task (reaction time test) and Stroop test*: In the sound-attenuating booth, participants sat at a desk facing a monitor and a wireless keyboard, and stimuli were presented from laptop positioned external to the sound booth. Using the same visual stimuli, two tasks were created: easy task (simple reaction time task) and hard task (Stroop test). Visual stimuli of Stroop test [17] were displayed on the computer monitor in the sound booth which showed four boxes containing red, blue, green, and yellow. The font color of the words in the virtual button box was black.

In the easy task, which is a simple visual reaction time (RT) test, while listening and repeating the sentence, subjects were instructed to press the space bar on the keyboard as quickly as possible after stimulus four boxes appeared. When the space bar was pressed by the patient, the RT was measured in milliseconds and recorded and then the hard task started.

In the hard task, while still listening and repeating sentence, subjects were asked to respond to the font color, instead of the word, by pressing a keyboard button assigned to a given color as quickly as possible (i.e., the incongruent condition of the Stroop test). The keyboard buttons R, B, G, and Y were assigned to font color red, blue, green, and yellow, respectively. To assist the participants in determining which keyboard button to press during the testing, the keyboard buttons were labeled by the same color. When a given button was pressed, the corresponding virtual button on the screen was highlighted to indicate the response, and the correct answer was calculated. Because the participants needed to inhibit the semantic meaning of the stimulus word and determine which button to push in the hard task, this task was more demanding and would interfere more with the speech recognition task than the easy task. For each list of QuickSIN test, six reaction times and six color answers were recorded.

Statistical analysis

The data was analyzed using version 20 of the Statistical Program for Social Science (SPSS). Statistical presentation and analysis of the present study was conducted, using the mean, standard deviation, *t*-test, ANOVA test, post hoc, and Pearson correlation test.

Results

Fifty five adults were enrolled in this work. The control group (I) consisted of the following: their mean age was 27.80 ± 6.13 years. All subjects had bilateral normal peripheral hearing, and their mean PTA threshold in both ears was 9.79 ± 4.25 dBHL in the frequency range of 250–8000Hz.

The study group (II) consisted of the following: subgroup IIa (their mean age was 30.25 ± 10.45 years, and their mean PTA thresholds were 58.63 ± 8.70 dB), and subgroup IIb (their mean age was 24.40 ± 9.06 years, and their mean unaided PTA thresholds were 61.63 ± 10.52dB). Nineteen subjects used BTE hearing aids.

A. Subjective measures

- *Speech, Spatial and Quality of Hearing Scale (SSQ) results*: ANOVA test and post hoc test showed statistically significant lower scores for the study subgroups than the control group at all sections of the questionnaire, but there was no statistical significant difference between patients with hearing loss with and without HA (Table 1).
- *Fatigue Assessment Scale (FAS) results*: ANOVA test and post hoc test showed statistically significant higher scores for both the study subgroups than the control group, while there no statistical

Table 1 ANOVA test for comparison of Speech, Spatial and Quality of Hearing Scale (SSQ) and Fatigue Assessment Scale (FAS) scores between the control group and study subgroups

	Mean ± SD	*F* test	*P* value	Post hoc test	
Speech					
Control(G1)	71.60 ± 23.54	13.242	0.000*	P1	0.001*
HL (GIIa)	34.40 ± 23.52			P2	0.001*
HA (GIIb)	38.95 ± 17.55			P3	0.479
Spatial					
Control (GI)	80.33 ± 14.45	19.052	0.000*	P1	0.001*
HL (GIIa)	39.75 ± 23.65			P2	0.001*
HA (GIIb)	39.75 ± 20.74			P3	1.0
Quality					
Control (GI)	85.33 ± 12.02	26.247	0.000*	P1	0.001*
HL (GIIa)	42.25 ± 21.43			P2	0.001*
HA (GIIb)	47.50 ± 18.10			P3	0.349
SSQ Total					
Control (GI)	237.27 ± 39.40	27.073	0.000*	P1	0.001*
HL (GIIa)	116.40 ± 59.04			P2	0.001*
HA (GIIb)	126.20 ± 46.73			P3	0.518
FAS					
Control (GI)	21.40 ± 3.44	3.330	0.025*	P1	0.025*
HL (GIIa)	26.68 ± 8.53			P2	0.012*
HA (GIIb)	27.35 ± 6.64			P3	0.752

P1: Comparison between the control group and HL study subgroup (IIa)

P2: Comparison between the control group and HA study subgroup (IIb)

P3: Comparison between the HL study subgroup (IIa) and HA subgroup (IIb)

SSQ Speech, Spatial and Quality of Hearing Scale, *FAS* Fatigue Assessment Scale, *HL* hearing loss, *HA* hearing aid

*Significant $P < 0.05$

significant difference between patients with hearing loss with and without HA (Table 1).

B. Dual task paradigm

- *ANOVA test and post hoc test* were done for comparison between groups for the primary task using QuickSIN test and showed significant more SNR loss in the study subgroups than the control group, i.e., more LE. However, no statistical significant difference was found between patients with hearing loss with and without HA (Table 2).
- *Reaction time to visual and auditory tasks*: for dual task which represents measuring RTs with auditory stimuli varying in SNR from 25+ to 0+ SNR increasing noise by 5+dB from RT1 to RT6 making the test more difficult. ANOVA test showed significant difference between groups in all RTs. The post hoc test showed significantly longer RTs in the study subgroups than the control group, i.e., more LE (Fig. 1). Although there was no significant difference between subgroup IIa (hearing loss group without HA) and subgroup IIb (hearing loss group with HA), the reaction time was shorter in the hearing aid group (IIb) than in the hearing loss group (IIa) at higher SNR (+25, +20, +15), while, in more challenging situations, in lower SNR, no difference was found (Fig. 1).
- *The Stroop test results* showed no significant difference between control and study subgroups and no statistically significant differences between group (IIa) and group (IIb) using ANOVA test (Table 3).

Table 2 ANOVA test for comparison of SNR loss of primary task (QuickSIN test) results in dual conditions between the control and study subgroups

	Mean ± SD	*F* test	*P* value	Post hoc test	
SNR loss					
Control (GI)	− 0.70 ± 2.11	58.486	0.001*	P1	0.001*
HL (GIIa)	10.40 ± 5.26			P2	0.001*
HA (GIIb)	12.20 ± 4.96			P3	0.184

P1: Comparison between the control group and HL study subgroup (IIa)

P2: Comparison between the control group and HA study subgroup (IIb)

P3: Comparison between the HL study subgroup (IIa) and HA subgroup (IIb)

SNR signal-to-noise ratio, *HL* hearing loss, *HA* hearing aid

*Significant $P < 0.05$

Comparison between patients using unilateral and bilateral hearing aids showed no statistically significant difference as regards SNR loss, FAS, SSQ, and RTs (Table 4).

In the hearing loss group (IIa), the Pearson correlation test showed statistically significant positive correlations between SNR loss in dual primary tasks and FAS ($r=0.447$, $P=0.048$). While there was a significant negative correlation between SNR loss and the total SSQ questionnaire score ($r=-0.489$, $P=0.029$). In the hearing aid group (IIb), there was no significant correlation between SNR loss and FAS or total SSQ questionnaire.

Discussion

Among different methodologies that can quantify listening effort, the dual-task paradigm is one of the most widely-used behavioral measures [18].

Dawes et al. [19] constructed a listening effort subscale from the effort-related questions in the Speech, Spatial and Qualities of Hearing Scale (SSQ) questionnaire in order to examine changes in listening effort subsequent to acclimatization to hearing aids.

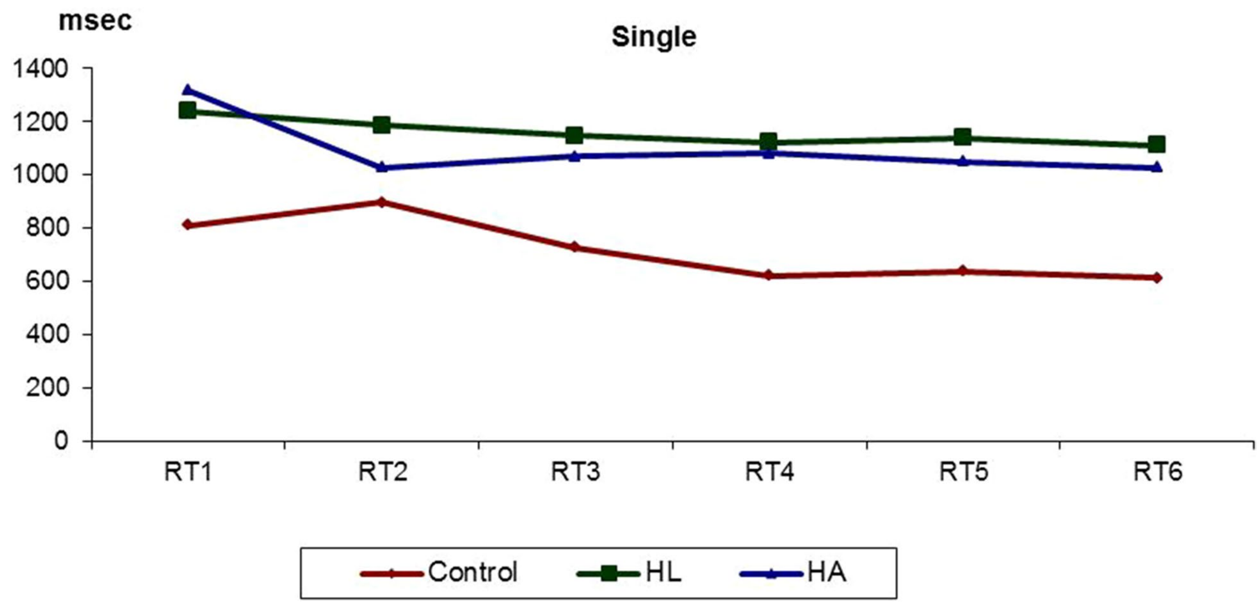

Fig. 1 Comparison of easy task dual condition (reaction times RTs with auditory stimuli) between the control and study subgroups as regards different SNRs

Table 3 Comparison of hard task (Stroop test) answers between the control and study subgroups

	Mean ± SD	*F* test	*P* value
Hard task (Stroop test)			
Control (GI)	5.87 ± 0.35	1.254	0.298
HL (GIIa)	5.40 ± 0.94		
HA (GIIb)	5.65 ± 0.75		

HL hearing loss, *HA* hearing aid

*Significant $P < 0.05$

Table 4 Comparison of results between patients using unilateral and bilateral hearing aids in the study subgroup (IIb)

	Unilateral HA Mean± SD	Bilateral HA Mean ± SD	*t* test	*P* value
QuickSIN (SNR loss)	12.14 ± 4.99	12.28 ± 5.24	0.004	0.951
FAS	27.73 ± 6.97	26.89 ± 6.60	0.075	0.787
SSQ 1	36.82 ± 18.34	41.56 ± 17.23	0.349	0.562
SSQ 2	37.73 ± 17.52	42.22 ± 25.01	0.223	0.642
SSQ 3	45.91 ± 16.86	49.44 ± 20.38	0.181	0.676
Rt 1 dual	1539.00 ± 782.26	1559.11 ± 1050.97	0.002	0.961
Rt 2 dual	1536.64 ± 1037.45	1897.33 ± 1060.47	0.587	0.454
Rt 3 dual	1159.82 ± 640.88	1410.33 ± 1013.37	0.454	0.509
Rt 4 dual	1906.64 ± 1507.33	1800.22 ± 1288.77	0.028	0.869
Rt 5 dual	2384.18 ± 1894.41	1913.11 ± 1406.27	0.382	0.544
Rt 6 dual	1922.45 ± 1089.70	1799.56 ± 1217.98	0.057	0.815

Significant $P < 0.05$

SNR signal-to-noise ratio, *SSQ* Speech, Spatial and Quality of Hearing Scale, *FAS* Fatigue Assessment Scale, *HA* hearing aid, *RT* reaction time

In our study, the SSQ questionnaire results showed highly significantly lower scores for subjects with hearing loss (with and without HAs) than normal hearing subjects in all sections of the questionnaire. Our results agreed with Bess and Hornsby [20], who stated that patients with hearing loss reported increased effort when listening in difficult situations. The hearing-impaired listener might not be able to hear every single word in a sentence. Consequently, more mental effort may be required to identify the relationship between the different items in the sentence, guess misheard words, and the meaning of the sentence. In the current study, all subjects with hearing loss showed significantly higher scores of FAS than normal hearing subjects which agreed with Bess and Hornsby [20] and Hornsby and Kipp [21] who found that through the use of subjective measures of fatigue, individuals with hearing loss experience decrements in their vitality as well as increase in fatigue, likely due to the increased listening effort experienced.

Bentler et al. [22] found no significant difference between unaided and aided conditions in subjective testing which agreed with our results. They also found no significant difference between basic and advanced signal processing features of hearing aids. This could be because benefits from directional and digital noise reduction (DNR) processing in real-world settings are often more subtle than those observed in laboratories.

In the dual task paradigm, our results showed that the SNHL patients without and with hearing aids showed more SNR loss than normal subjects. This can be explained as if the incoming signal is compromised (due to masking noise, or hearing loss for example), the phonological elements may fail to match existing representations [23]. This mismatch will trigger a loop of explicit processing to either restore missing information and retry matching to representations in long-term memory, or if no match can be found, to guess the meaning [24].

Our results also agreed with Picou et al. [25] who reported longer RTs in patients with hearing loss (aided and unaided) than normal hearing subjects. This can be explained by the increased processing required by patients with hearing loss to not only hear the word amidst background noise, recognize and repeat it, but also to comprehend the meaning and the linguistic category it belongs to. This required processing is more increased when speech information input is degraded consuming much of the cognitive capacity and more listening effort needed for the secondary task leading to longer RTs. There was no significant difference between the unaided and aided group which disagreed with Down [26] who found shorter RTs in patients using hearing aids than patients with hearing loss. In the current study, although there was no significant difference between two study subgroups, the reaction times at higher SNR (+25, +20, +15) were shorter in the hearing aid group than in the hearing loss group. However, in more challenging situations with lower SNR (+10, +5, 0), there was no difference between the two groups indicating that RT is better for those wearing HA in higher SNR. So much cognitive capacity and more listening effort is needed for speech processing in challenging situations. High-level background noise may not be sensitive to changes in listening effort with hearing aids [27].

The Stroop test comparison as a measure of listening effort showed no significant difference between the groups. This non-significance could be explained that the Stroop test in our study was at the end of the sentences, so it was easy for subjects to answer it. Our results agreed with Wu YH et al. [28] who found that SNR did not have an effect on the number of correct answers of the Stroop test, suggesting that results did not vary with speech intelligibility.

There was no significant difference in listening effort between patients with unilateral and bilateral hearing aids. Our results disagreed with Schoonhoven et al. [29] who reported that bilateral HAs can provide more reduction in listening effort, better speech reception in noise, and localization than unilateral HAs.

Digital signal processing algorithms in hearing aids enables noise reduction, feedback cancelation, and various dynamic compression settings. However, the benefit of hearing aids varies between individuals, which might partly be explained by individual differences in cognitive capacity. Also, speech reception in noise performance is related to cognitive abilities in individuals using hearing aids [30–32].

Although several studies have shown that hearing aids decrease listening effort [11, 26, 33], others have not demonstrated this benefit [34, 35]. There are many possible reasons for these conflicting findings. It is possible that tests conducted in conditions that are too easy, e.g., quiet, low-level background noise or too difficult, e.g., high-level background noise may not be sensitive to changes in listening effort with hearing aids. Under certain conditions, hearing aids may generate artifacts or distortions or amplify inaudible background noise. These alterations to the target signal may require additional cognitive resources for successful perception [27, 36].

One of the limitations of our study is the small numbers of the group using hearing aids (unilateral and bilateral) and the use of the basic signal processing HAs.

Conclusion

Listening effort in patients with sensorineural hearing loss with or without hearing aids is higher than the normal hearing listeners. No significant difference was found in listening effort between aided and unaided conditions in both subjective and behavioral measures even with satisfactory aided free field. However, these results consider comparison between patients with and without HAs was agreed with some studies and disagreed with others. So, we recommend that more studies are needed to compare listening effort in patients with and without HAs using larger samples and using more advanced HA technologies. Increased LE is a consequence of hearing loss which could not be measured by standard audiometric measures, so it should be considered when measuring disability in those with hearing loss.

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None

Authors' contributions

ABH contributed in clinical examination, collecting the data and revision of the manuscript. RML contributed in clinical examination, collecting the data, writing, preparation and revision of manuscript. AAE collected the data, preparation and revision of manuscript. TE designed of the study, in collecting the data, writing, preparation and revision of manuscript. All Authors of this work contributes in final approval of the version to be published and the agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Availability of data and materials
Data is available on request due to privacy and ethical restrictions.

Declarations

Ethics approval and consent to participate
This work was approved from the ethical committee of Faculty of Medicine, Tanta University, with approval code 31859. Informed consent was obtained from all individual participants included in our study.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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