Hindawi
Journal of Nanomaterials
Volume 2022, Article ID 9370008, 10 pages
https://doi.org/10.1155/2022/9370008

Research Article

Influence of Methods of Nanomaterial Testing on Product Supply and an IoT-Based Solution for Making a Perfect Choice

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Received 19 April 2022; Accepted 30 May 2022; Published 16 July 2022

Academic Editor: V. Vijayan

Human ear is equivalent to nanomaterials as it has nonporous membrane which decides the hearing ability. The water content and its movements in that tectorial gel membrane are controlled by nanoscale pores. Apart from many disease threats and the age and other issue-related disabling hearing impairment, loss of sensitiveness of nanomaterial, namely, nanopored tectorial gel membrane, is a serious issue. Appropriate supplement must be provided to compensate age-related hearing loss by measuring some innovation methods. The test for hearing loss and cost of hearing aid are another threat. Many studies reported that people do not feel comfortable with their hearing aid and avoided to use it after purchase. The telephonic survey was conducted at Tamil Nadu, India region, which discloses that the hearing aid center is doing continuous motivation over the phone to wear hearing aid after purchase; many people do not turn back for even battery purchase. Very rare people report for free service too. This piece of research is aimed at analysing the root cause of not wearing hearing aid and addressing various possibilities to support them with IoT-based solution requirement to discard this issue. The two kinds of test were conducted for the same patient, and hearing aid was provided to give supplement to compensate sensitiveness loss of tectorial gel membrane. Their effectiveness was measured and analysed scientifically. The Taguchi method was incorporated to formulate the experiments with the natural cases like age, gender, and method of testing the nanomaterial, namely, nanopored tectorial gel membrane sensitiveness (hearing loss/or hearing ability) and existing nature of sensitiveness (severe loss and minor loss) at 2 levels. The observations were analysed with Taguchi analysis and discussed. An integrated solution of IOT-based measuring system was discussed to rid the issues.

1. Introduction

The ability of nanopore tectorial gel membrane (nanomaterial) or loss of hearing is accountable when it exceeds 35 decibels [1]. The World Health Organization (WHO) disclosed some facts that 2.5 billons will be the victims in this case by 2050 and at least 700 million may demand rehabilitation for hearing. Unsafe hearing practice is another issue which will affect 1 billon people (young adults). The statistics further extended that nearly 432 million youth and adults as well as 34 million children require support for their disabling hearing impairment. The pathogenesis of hearing impairment is poorly understood, and no diagnostic tools to distinguish among subgroups are currently available. Patients are generally left with broad therapy alternatives like cochlear implantation, hearing aids, or steroids [2]. Magdy et al. explored localised delivery methods and effective distribution, at ear anatomy, ear obstacles. Also included are the applications of hydrogels and nanocapsules via localised distribution of medicine to the middle ear, as well as middle and inner ear illnesses [3]. Investigate the time necessary to attain equilibrium of kinetics of the adsorption

process or as the molecular sieving by Nano porous membrane, to investigate time of our of equilibrium processes [4]. Loss of hearing ability is a progressive happening in human life; it will become high at old age [5]. Such loss could be generally notable at 40+ age, and loss growth steep will linearly up with respect to age still 80 [6]. Globally, 30% of 60+ aged people are suffered by age-related hearing loss [7] and estimated that in 2030, age-related hearing loss can be among the top 15 leading burden diseases [8]. Apart from common gathering for any family or social occasion, this issue is severely influencing in quality of life especially answering doctors' queries, responding to sound horn at crowd, busy road work place, etc. [9]. Hence, the age-related hearing loss not only affects successful aging by birth [10] but also other aging of human body like productive and healthy aging [1, 10]. In smart cities, people have facility to check their hearing loss and adopt suitable hearing aid. As reported in earlier studies, 23% of hearing aid holders are not using their hearing aid due to behavioral intention [11, 12].

2. Need for This Research

Nanosensitive human ear test for hearing deficient could not complete with physical alone successfully, and it needs psychological aspect too. A sample survey released by WHO is that in the populated China, 65+ aged people population was 9.5% (123 million) at the year of 2000, at 2015, it was 16.5% (214 million), and based on the growth rate, such population will be 25.6% (332 million) in the year of 2050 [1]. Internet-based healthcare assistance must be improved to compensate healthcare of such aged people to ensure their life's quality [13]. Apart from other care, hearing loss affects their basic life and it is classified as one of the top prevalent age-related chronic diseases [14]. But it can be compensated by adopting appropriate hearing aid [15]. Hearing aid supports them to compensate the deficiency at acceptable level [16]. But after adopting hearing aid, the patient is not using that hearing aid due to his dissatisfaction. This investigation addresses the solution for complete test of ear material for making his appropriate choice of hearing aid to compensate by a hearing aid with complete satisfaction.

3. IoT Technology

IoT technological support extends to connect hearing device to the online healthcare services [17]. The IoT technology helps the hearing aid user to fix appointment with doctors, booking their periodical or special checkup. IoT devices are internet-based, and they are utilized for collecting the required data, monitoring specific thing, and also utilizing for control purpose too [18]. IoT is highly supported for developing the smart grids [19], smart cities [20, 21], smart weathers [22], smart transportation [23], smart healthcare [24], in particular E-Health [25], M-health [26, 27], and S-health [28]. IoT is a technology to help to people share and communicate at real time including audio, video, text, doc, files, and simulation with online signals [29]. Hence, IoT is a promising solution to many human-related disability issues. The nanopore human ear gel membrane (nanomaterial) sensitiveness could be measured more accurately with IoT technological-based test setup.

4. Nonuse of Hearing Aid

Most of the hearing-deficient patients adopt hearing aid, and they did not use. The technological advancements improve the clarity of hearings but may not fulfil in test methodology which was used to measure hearing supplement needed. Psychological barriers for nonuse of hearing aid are demonstrated in Figure 1. People behaviors are some of the applicable behaviors which are discussed below.

(i) Planned behavior is one of the highlighted reasons at this stage that human in the state of lack of control perceived feelings while interacting with new persons [30, 31]. This usually overcome by availing the facility to meet such situation [32] and manage such situation by self-efficacy [33]

(ii) Lack of acceptance to adopt new hearing aid is another thing by which the people hesitate to it [34]. This can be overcome by perceived usefulness and attitude. The perceived usefulness means the human must have strong belief that new hearing aid will strongly help, useful, and supports at all situation to execute their doings [35]. And attitude is one by which human has intention to try new things to do or update himself periodically or adopt new hearing aid by considering fashion, etc. [35–38]

(iii) According to first version of unified theory of acceptance, the people seeks facilitating conditions, effort, and performance expectancy as well as social influence [39]

(iv) According to second version of unified theory, the people adapt and accept new hearing aid based on degree of playfulness, price factor [40], own habit, age, gender and experience [38], and intention [41]. They need people's rating, reviews, comments, advertisements, etc., about the usefulness particular hearing aid [19, 42–44]

(v) As per the senior technology acceptance model, the elder people decide new thing or hearing aid based on the usefulness and usage of the same [45]

(vi) Based on the self-determination theory, people adapt hearing aid by intrinsic (just for enjoyment or fun) or extrinsic (realizing its purpose) motivation [46]

(vii) The theory of reasoned action said that the people adopt the hearing aid based on the subjective norms and attitude. The people adopt hearing aid with trust on results of audiology [47]

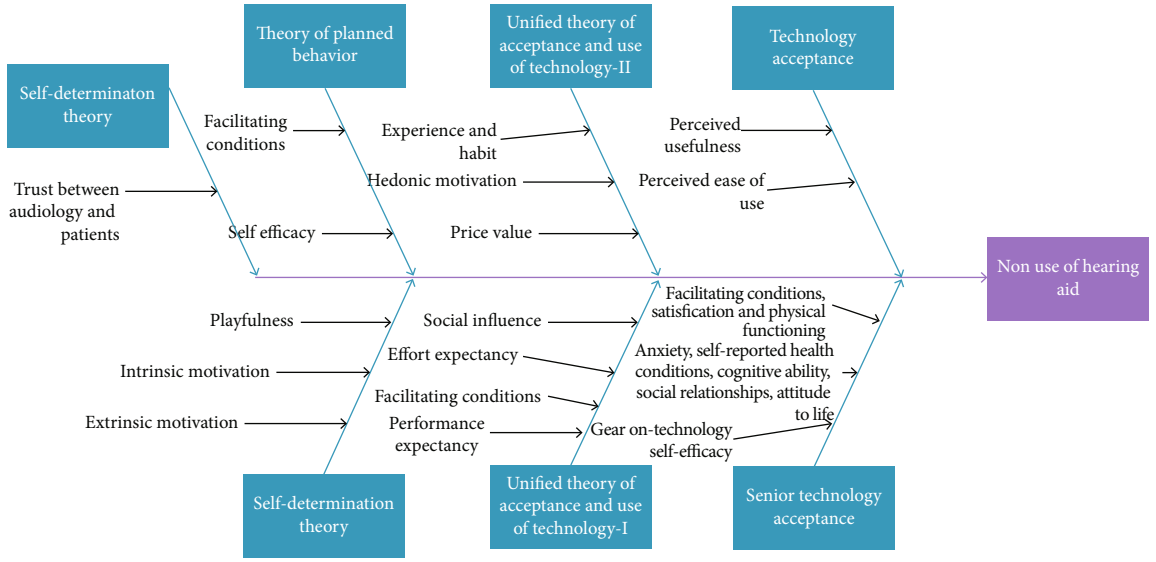

Figure 1: Behavioral theories behind the nonuse of hearing aid.

Table 1: General linear model: factors and their levels.

Factors	Type of factor	Varying level	Level 1	Level 2
Male patient (age in years)	Fixed	2	42	64
Test method (choice of testing)	Fixed	2	App (mobile app)	Audiometry (conventional testing method)
Female patient (age in years)	Fixed	2	48	73
Hearing loss (classification)	Fixed	2	Minor	Major

Method of factor coding (-1, 0, +1).

Table 2: Taguchi experimental design summary.

Taguchi array	L8 (2^4)
Factors	4
Runs	8

5. The Experimental Setup

The experimental design is followed by Taguchi analysis. Age-related hearing loss is a common issue but managing such hearing loss by male and female is not common. The responding to new voice is difficult, and at the same time, female and male voice echoes to responder is common. Impact of selection of hearing aid based on free mobile app and paid audiometric app effects may influence in the selection hearing aid. People adopted reading glass majorly based on the shop level reading test [48–50]. Such trend now spreads on society to adopt hearing aid too. People adopted hearing aid by online market too. Hence, this paper analyses the influence of such practice in the response on human voice [51, 52]. All the samples considered are the self-fitting hearing aid users. The hearing loss category is carefully selected on the range; the 3 male and 3 female samples have almost equal loss 70% and 45% according to the respective class like major loss as well as minor loss patients as well as age group 2 (major and minor loss category) × 2 (male and female) × 2 (age group) × 2 hearing aid; hence, total samples are 24. The test was conducted at test room with 3-feet distance. The hearing air fitted to them was based on two-category adoption of hearing aid by mobile app-based test performance and also hearing aid. According to the design, the variables considered are young female with major hearing loss in the age group 40-50 and 60 to 75 are preferred as a sample with two categories of major and hearing minor loss category; hence, there are 12 samples from female category. Similarly, samples were considered from male side from two age groups and affected by major and minor hearing loss. The consolidated sample details were utilized for creating the Taguchi design of L8 in the Minitab v.18. The general linear model was created to feed the input to the software for experimental designing and analysing responses shown in Table 1. The design summary is presented in Table 2. The numerical 42 and 48 are codes for 40+ age group of male and female samples, respectively, similar to 64 and 73 codes for 60+ age group of male and female samples, respectively. The hearing loss is almost the same for the respective category of male and female. Figure 2 demonstrates the sample selections for investigation.

The LED TV was connected to computer to feed the random questions to the patients. The deployed question is to be asked by one patient, and it must be answered to opponent patients. This was evaluated by the perforce by 50 marks, and then, the patients interchange their position;

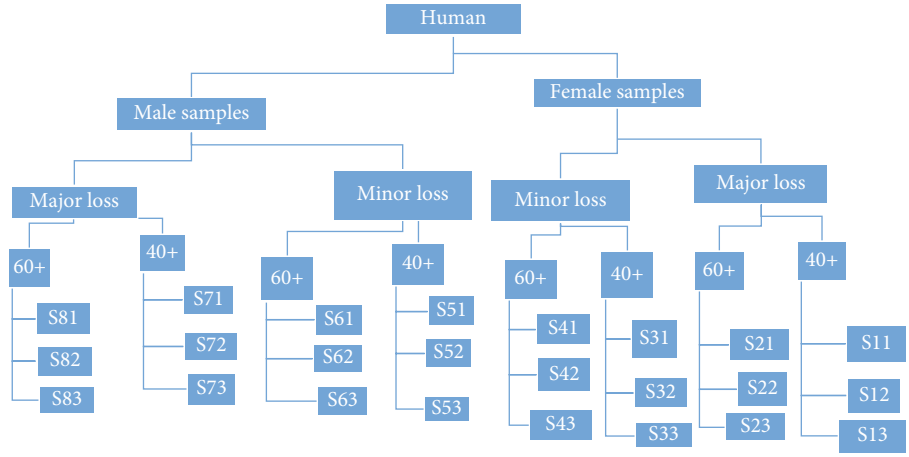

Figure 2: Samples from four different patient population.

Table 3: Taguchi L8 experimental design.

Expt No.	Male patient	Test method	Female patient	Hearing loss
1	42	App	48	Minor
2	42	App	48	Major
3	42	Audiometry	73	Minor
4	42	Audiometry	73	Major
5	64	App	73	Minor
6	64	App	73	Major
7	64	Audiometry	48	Minor
8	64	Audiometry	48	Major

the next patient asks questions, and opponent patient is now responding for the question; this is also evaluated for 50 marks. The total response for the respective experiment is the sum of these two marks. Hence, the response measurement is based on the answer of male patient for female patient's queries which is displayed on the backside of responder vice versa. This experimental procedure followed for 8 different combinations of patients without repeating the questions for queries for any turn for both female to male patients. The five different observers evaluated the performance, and their round off average score is considered as experimental observations. Table 3 shows the L8 Taguchi experimental design and net responses observed on respective experiment.

6. Results and Discussions

The observations are analysed by Taguchi analysis. The Taguchi analysis results are presented in Table 4, in which the average outcomes of three different observers were considered for avoiding the observational error. The signal here mentioned is favourable response, and noise is unfavourable response. Table 5 shows the factor wise level signal to noise ratio for the response of net response. Usually when quality character set is larger and better, the values come as negative. But high signal to noise ratio is a matter on this (Table 5). High value in that column indicates the level at which factor favours to the response. That is, the signals were observed for method of testing for adopting hearing aid, male category patients. Female category patients and loss category of them. The delta value indicates the nature of influence various factors on total response. The higher delta value indicates higher influence. Such a way that as the delta value is 2.067, the hearing nature of loss is a major influencing factor in attaining the response. The next higher influencing factor is method tested to adopt the hearing aid (delta = 1.90; refer to Table 5), the third influencing factor is male patients (delta = 1.90; refer to Table 5). The least influencing factor is female patients where delta value is 0.73.

Figure 3 shows that the nature of influence of four different factors was considered in this experiment as variable. The first plot shows the higher signal (Table 5, S/N ratio = −2.881, level 2, first graph of Figure 3) for aged male patients (senior citizen)). That is, the senior citizen responses found better than the young people. During the discussion, they disclosed that the young adults (age group 40-50) feel discomfort by mismatch of hearing aid for two different ranges. The adoption of new hearing aid degraded their ability as they are feeling about their inability. In the case of elder people, they said that as they feel something better than nothing, they can perform well but they could not understand some questions though they answered for the question of the same patient.

The second plot in Figure 3 resembles that high app-based hearing aid selection gave high signals than the audiometry-based selection hearing aid for the same patients (Table 5, S/N ratio = −3.373, level 1, 2nd graph of Figure 3). The group response was much higher sound on hearing than another hearing aid (audiometry test-based selected). So, they can perform much better when compared to use of audiometry test-based selected. They added higher noise may shorter duration of wear for hearing by discomfort.

In Figure 3, third plot shows that signal is higher for young female adults (aged 40 to 50 years) than senior citizen category (Table 5, S/N ratio = −2.789, level 1). Though that factor did not influence significantly in the overall response (Table 6, $P = 0.153$; $P > 0.05$). But discussion disclosed the

Table 4: Experimental observations and Taguchi output of signal to noise ratio.

Expt. No.	Trail 1	Trail 2	Trail 3	Average	Net response	SNRA1	FITS
1	71	82	78	77.00	77.00%	-2.270185497	0.7675
2	64	59	61	61.33	61.00%	-4.2934033	0.6125
3	58	53	59	56.67	57.00%	-4.882502887	0.5875
4	47	43	46	45.33	45.00%	-6.935749724	0.4325
5	83	81	84	82.67	83.00%	-1.618438152	0.8475
6	69	73	70	70.67	71.00%	-2.974833026	0.6925
7	81	77	79	79.00	79.00%	-2.047458174	0.7575
8	59	57	54	56.67	57.00%	-4.882502887	0.6025

Table 5: Results of Taguchi analysis-signal to noise ratio and ranking of parameters.

Level	Male patient	Test method	Female patient	Hearing loss
1	-4.595	-2.789	-3.373	-2.705
2	-2.881	-4.687	-4.103	-4.772
Delta	1.715	1.898	0.729	2.067
Rank	3	2	4	1

acceptance of the inability and lack of confident on support of the hearing aid. The young adult group females had intention to prove themselves as they are not deaf so they paid over concentration on the examinations. There was controversy on senior citizen side that by habitual, they respond little and have doubt on the hearing. In Figure 3, the fourth plot resembles the nature of hearing loss influences on completing the conversation between patients (Table 5, S/N ratio = −2.705, level 1). The hearing loss is highly influencing factor (rank 1, delta = 2.07, Table 5) to complete the conversation cycle (response). The signal is high when the loss is less; that is, those samples under the minor loss responded well than the major loss persons.

The experimented statistics was further analysed by ANOVA by considering the general liner model. Figure 4 confirms that the observations are obeying the natural law that is statistical assumption well. The observations are closely appearing to the mean line.

Table 6 demonstrates statistics results for the experimental observations which were obtained from ANOVA output from the statistical model developed in Minitab v.18. The results of ANOVA confirm the contribution which was classified in the Taguchi analysis. The lower P value indicates the higher contribution in generating the response. According to value of P, if it is less than 0.05, the factor is significantly influencing on generating the response. If the P value is greater than 0.1, it is said to be insignificant in generating the response. Apart from 4 factors, only one factor is found insignificant so the model can be accepted. The P value is very low for hearing loss ($P = 0.007$; $P < 0.05$). It meant that hearing loss nature has low sensitiveness of nanoporous membrane. The next high influencing factor was test method as $P = 0.011$ and $P < 0.05$. Then, age is one of the influences but less than nature of loss and test method. The gender is either not influencing significantly or the influence of the gender factor is not significant in the measurement of sensitiveness of nanoporous membrane. Figure 5 shows the percentage of contribution in the response generation was 40% by nature of hearing loss. Similarly, for method of testing employed in adaption of hearing aid, it was 30% and patient of male category found 26% and female found very little, that is, 4% only. Table 7 gives the validation of statistical model and observations recorded. In the model summary, the R^2 must be at least 95%. As the statistical model yielded 97.28%, the model is fit which did not violate the statistical assumptions.

Table 8 discloses the deep analysis results though the hearing loss highly influences on response generation as the low hearing loss patients ($P = 0.007$; $P < 0.05$) performed well in the experiments conducted. Similarly, in the male patients, particularly young adult performed well, and the young adult man contribution influences positively ($P = 0.013$;$P < 0.05$) in completing the conversation, and in selection of hearing aid with the test results, mobile app method influence ($P = 0.011$;$P < 0.05$) is better than audiometry in completing the conversation cycle. The response relationship is diagrammatically depicted in the 3D surface plot (Figure 6). The mathematical relation between variable on net outcome of response is presented in the following equation:

$$\begin{aligned}\text{Net response} = {} & 0.6625 - 0.0625\,\text{male patient\_42} \\ & + 0.0625\,\text{male Patient\_64} + 0.0675 \\ & * (\text{test method\_app}) - 0.0675 \\ & * (\text{test method\_audiometry}) + 0.0225 \\ & * (\text{female patient\_48}) - 0.0225 \\ & * (\text{female patient\_73}) + 0.0775 \\ & * (\text{hearing loss\_minor}) - 0.0775 \\ & * (\text{hearing loss\_major})\end{aligned} \quad (1)$$

As Table 7 shows that $R^2 > 95$, the above mathematical prediction model exhibits good agreement with the tested results.

7. Experimented Model: Evaluating Hearing Attainment

In this experimented model, interacting the male and female completes conversation. Though the samples (patients)

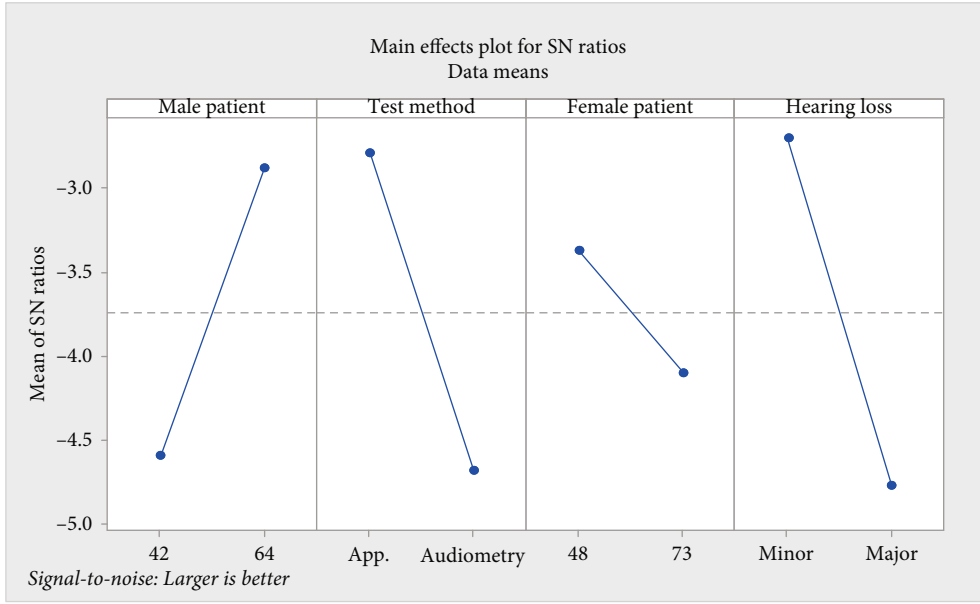

Figure 3: Results of Taguchi analysis nature of influence of factors for completing the conversation of two patients with respect to mean signal to noise ratio.

Table 6: ANOVA results on net response.

Source	DF	Adj SS	Adj MS	*F* value	*P* value
Male patient (age in years)	1	0.031250	0.031250	22.99	0.013
Test method (choice of testing)	1	0.036450	0.036450	32.64	0.011
Female patient (age in years)	1	0.004050	0.004050	3.63	0.153
Hearing loss (classification)	1	0.048050	0.048050	43.03	0.007
Error	3	0.003350	0.00111		
Total	7	0.123150			

possess similar as well as different hearing loss, all patients (samples) were compensated with their hearing loss by adapting 2 different hearing aids based on the test result of audiometry as well as mobile app test. The experimented results not only depend on the instrument supplied, test for hearing loss, male and female voice, etc., but something beyond according to the behavioral theories. So, the supply of hearing aid must increase the confident and really support for them when they use. Most of the patients do not know how to handle the situation when hearing aid is not supporting as per their expectation/need based on the situation and environmental condition, especially at interviews, some important meetings, etc.

8. Proposed Model

It is a magic model so this can be fulfilled by IoT technologies, which will increase the trust on hearing aid for new patient. The mismatch of requirements of hearing supplement which measured (at tested condition/environment/state of mind) with performance while using at real-world environment made him hurt and induces the nonuse of hearing aid. The allowances and ranges provided shall be insufficient for some occasions for many reasons. Based on brainstorming with doctors and hearing aid center experts, it was found that trust on device supplied plays vital role. Such worthful trust cannot be completely made by simple sweet motivational words but his experience can do it easily. So, the proposed method is allowing the patients to validate the use of hearing aid many of his real-world situations. This allows him to adapt a suitable hearing aid to provide almost complete solution for his hearing deficiency.

This proposal measures exactly how much supplement the patient needs to compensate his hearing loss. In the proposed measuring system, a voice sensor or a mind sensor is coupled to self-fitting hearing aid through the IoT device. The IoT device extracts the data and stores in the cloud as well as supports for online monitoring and supports to the patient as and when he needs. Initially, self-fitting hearing aid for testing hearing supplement requirement for the patient is measured by means of audiometry test. The wireless connection will be provided between the IoT device and hearing aid. The voice sensor regulates the hearing aid. The voice sensor acts when the patient says “pardon” to augment the supplement (receiving capacity) until the patient says “okay.” If he feels loud, he must say “please” to reduce the hearing supplement. The patient must add “okay” if he understands conversation either from person or media or

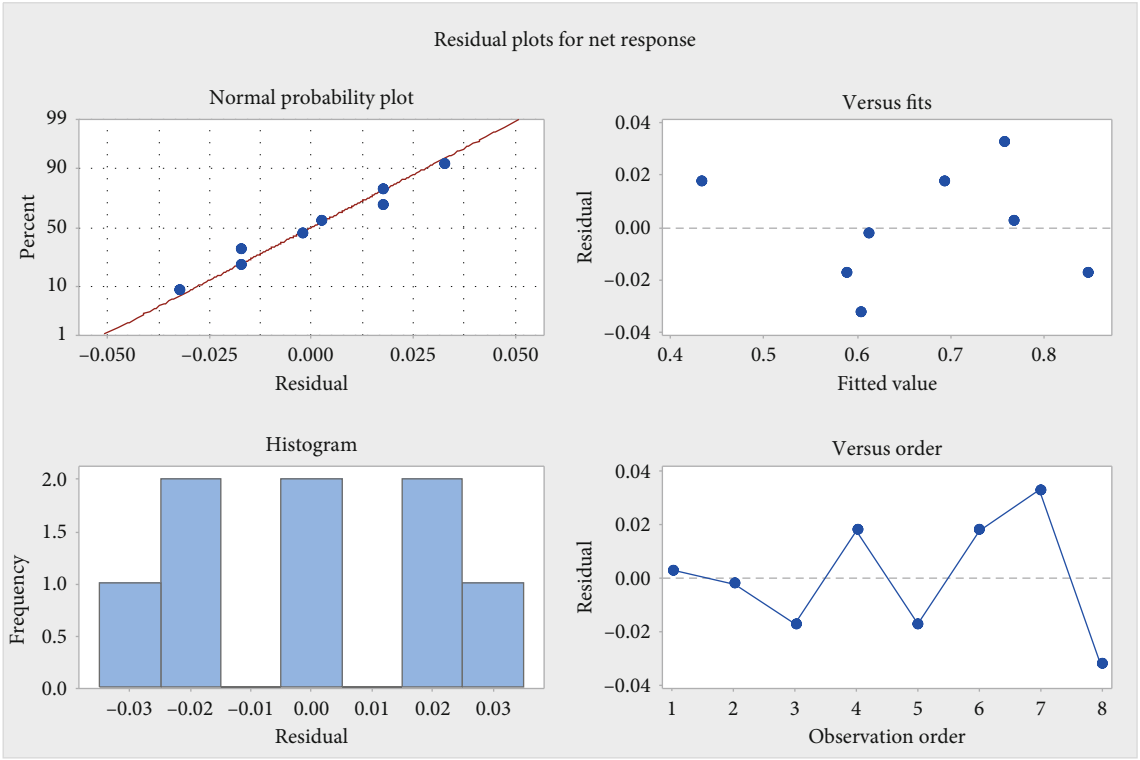

Figure 4: Statistical validation of observation with respect to mean line.

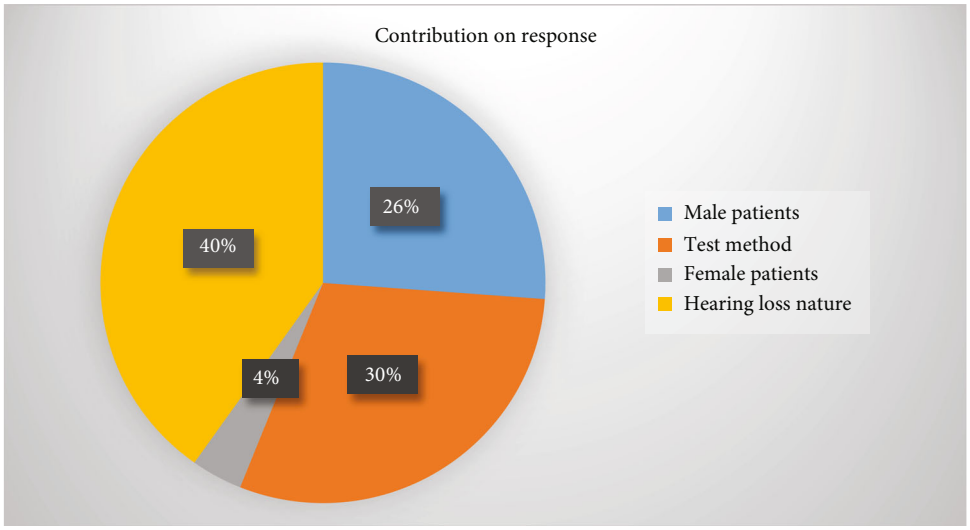

Figure 5: Percentage of contribution of factors in completing the conversations (response).

Table 7: Model summary—a result of model validation.

S	R-sq	R-sq (Adj)	R-sq (pred)
0.0334166	97.28%	93.65%	80.66%

accepting the music or sounds from various nonverbal sources like birds and instrumental music, to maintain the level of supplement. The okay is the level which is to be measured and considered as sample observation of required supplement. From these observations, the real supplement requirements could be identified.

Limitation of this study may be stated as the hearing loss level of major and minor are considered but could not found the patient samples with the same hearing loss at the same age but age group considered as 40+ and 60+. But after experimented, it was coming to realize that it is sufficient to justify the deficiency on methods.

Table 8: The ANOVA results on level of individual factor.

Term	Coef	SE Coef	T value	P value
Constant	0.6625	0.0118	56.07	0.000
Male patient (42)	-0.0625	0.0118	-5.29	0.013
Test method (app)	0.0675	0.0118	5.71	0.011
Female patient (48)	0.0225	0.0118	1.90	0.153
Hearing loss (minor)	0.0775	0.0118	6.56	0.007

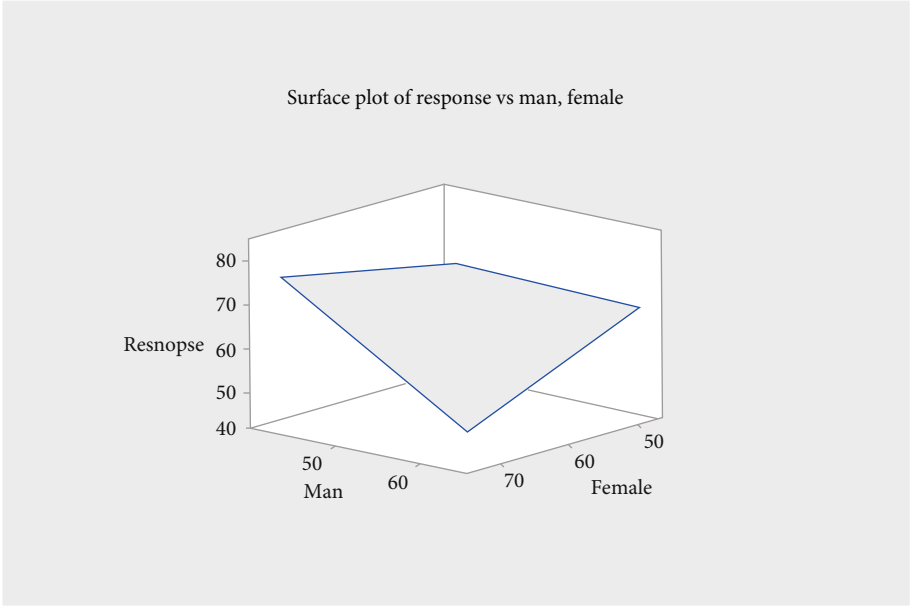

Figure 6: 3D surface plot response of male and female samples with respect to age.

9. Conclusion

Ability of nanopore tectorial gel membrane (nanomaterial) or loss of human ear testing is considered as sensitive material and measured its physical capabilities to measure the compensation/supplement need. This investigation addressed that measure of supplement requirements for understanding the nonverbal sounds/nonverbal vocalizations is not enough, and of measure supplement requirements for understanding the verbal sound is mandatory to supply appropriate hearing aid to compensate the deficient of the ear material. The following are the findings:

(i) It was found that the nonuse of supplement instrument for compensating nanopore tectorial gel membrane not only depends on the instrument supplied, test for hearing loss, male and female voice, etc., but something beyond that according to the behavioral theories

(ii) From the experimental results, it reveals that measure of supplement need for ear material is to listen well, not measure to hear well, because many patients repeated this reasons that they heard the sound but could not understand. From the behavioral theory, it is suggested that understanding can be improved by enhancing the trust on device by the proposed testing method and based testing and supply of the hearing aid based on the IoT-based test outcomes

(iii) Hence, the supplement for compensating nanopore tectorial gel membrane (hearing) is to be highly personalized and must take personalized care on observing supplement requirements. The patient himself believes that the supplement works for compensating well supplement instrument for compensating well the sensitiveness loss of his nanopore tectorial gel membranes on his respective ear. The conversion of patient requirements into technical data by the hearing aid center is through IoT. Hence, the supplied device will bring the entire satisfaction on hearing for complete day to day conversation through his best responses at his living environments

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information

be required, they can be obtained from the corresponding author upon request.

Disclosure

This research was performed as a part of the employment of Hawassa University, Ethiopia.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

Acknowledgments

The authors thank Annamalai University and Tamil Nadu Teachers Education University for providing facilities and support to complete this research work.

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