Chapter #

CHI-SQUARED, YULE'S Q AND LIKELIHOOD RATIOS IN TABULAR AUDIOLOGY DATA

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Abstract: In this chapter, we have used the chi-squared test and Yule's Q measure to discover associations in tables of patient audiology data. These records are examples of heterogeneous medical records, since they contain audiograms, textual notes and typical relational fields. In our first experiment we used the chi-squared measure to discover associations between the different fields of audiology data such as patient gender and patient age with diagnosis. Then, in our second experiment we used Yule's Q to discover the strength and direction of the significant associations found by the chi-squared measure. Finally, we examined the likelihood ratio used in Bayesian evidence evaluation. We discuss our findings in the context of producing an audiology decision support system.

Keywords: Audiology, Chi-squared, Likelihood ratios, Yule's Q

1. INTRODUCTION

Association measures can be used to measure the strength of relationship between the variables in medical data. Discovering associations in medical data has an important role in predicting the patient's risk of certain diseases. Early detection of any disease can save time, money and painful procedures [1]. In our work we are looking for significant associations in heterogeneous audiology data with the ultimate aim of looking for factors influencing which patients would most benefit from being fitted with a hearing aid.

Support and confidence are measures of the interestingness of associations between variables [2, 3]. They show the usefulness and certainty of discovered associations. Strong associations are not always interesting, because support and confidence do not filter out uninteresting associations [4]. Thus, to overcome this problem a correlation measure is augmented to support and confidence. One of the correlation measures popularly used in the medical domain is chi-squared (χ^2).

In section II we describe our database of audiology data. We first use the chi-squared measure to discover significant associations in our data, as described in section III. We then use Yule's Q measure to discover the strength of each of our significant associations, as described in section IV. In Section V, we find the support and confidence for each of the significant associations, and contrast these with the strengths of the associations found in Section III. In Section VI, we use Bayesian likelihood ratios to find associations between words in the comments fields and the type of hearing aid fitted. We draw our conclusions in section VII.

2. AUDIOLOGY DATA

In this study, we have made use of audiology data collected at the hearing aid out-patient clinic at James Cook University Hospital in Middlesbrough, England, UK. The data consists of about 180,000 individual records covering about 23,000 audiology patients. The data in the records is heterogeneous, consisting of the following fields:

1 Audiograms, which are the graphs of hearing ability at different frequencies (pitches).

2 Structured data: gender, date of birth, diagnosis and hearing aid type, as stored in a typical database, e.g. |M|, |09-05-1958|, |TINNITUS|, |BE18|.

3 Textual notes: specific observations made about each patient, such as |HEARING TODAY NEAR NORMAL - USE AID ONLY IF NECESSARY|.

In general, these audiology records represent all types of medical records because they involve both structured and unstructured data.

3. DISCOVERY OF ASSOCIATIONS WITH THE CHI-SQUARED TEST TABLES AND FIGURES

The Chi-squared test is a simple way to provide estimates of quantities of interest and related confidence intervals [5]. It is a measure of associations between variables (such as the fields of the tables in a relational database) where the variables are nominal and related to each other [6]. The Chi-squared test is popular in the medical domain because of its simplicity. It has been used in pharmacology to classify text according to subtopics [7]. The resulting chi-squared value is a measure of the differences between a set of observed and expected frequencies within a population, and is given by the formula [5]:

$$X^2 = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

where r is the number of unique terms in a particular field of the patient records such as diagnosis or hearing aid type, corresponding to rows in Table 1. c is the number of categories in the data (such as age or gender) corresponding to columns in Table 1.

Table #1. Observed and Expected frequencies for diagnosis

Diagnosis	Age<=54	Age>54	Row Total
Not-Tinnitus	167 (121.98) [2027.24]	70 (115.02) [2027.24]	237
Tinnitus	535 (580.02) [2027.24]	592 (546.98) [2027.24]	1127
Column Total	702	662	1364

Expected frequencies are in ( )
(Observed frequency – Expected frequency)^2 are in [ ]

Table 1 is produced for 2 diagnoses occurring in the hearing diagnosis field. For example, if 535 of the hearing diagnosis fields of the records of patients 'Aged <= 54' years contained the diagnosis 'TINNITUS', we would record a value of 535 for that term being associated with that category. These values were the "observed" values, denoted O_{ij} in the formula above. The corresponding "expected" values E_{ij} were found by the formula:

Row total x Column total / Grand Total

The row total for ‘TINNITUS’ diagnosis is the total number of times the ‘TINNITUS’ diagnosis was assigned to patients in both age categories = 535 + 592 = 1127. The column total for ‘Age<=54’ is the total number of patients in that age group over all 2 diagnoses = 702. The grand total is the total number of patient records in the study = 1364. Thus the “expected” number of patients diagnosed with ‘TINNITUS’ in the ‘Age<=54’ group was 1127 * 702 / 1364 = 580.02. The significance of this is that the expected value is greater than the observed value, suggesting that there is a negative degree of association between the ‘TINNITUS’ diagnosis and the category ‘Age<=54’. The remainder of the test is then performed to discover if this association is statistically significant. Since we were in effect performing many individual statistical tests, it was necessary to use the Bonferroni correction [5] to control the rate of Type I errors where a pair of variables spuriously appear to associated. For example, for us to be 99.9% confident that a particular keyword was typical of a particular category, the corresponding significance level of 0.001 had to be divided by the number of simultaneous tests, i.e. the number of unique words times the number of categories. In the case of words in the text fields, this gave a corrected significance level of 0.001 / (2 * 2) = .00025. Using West’s chi-squared calculator [8], for significance at the 0.001 level with one degree of freedom, we obtained a chi-squared threshold of 13.41. Thus each word associated with a category with a chi-squared value of more than 13.41 was taken to be significantly associated with that category at the 0.001 level.

The overall chi-squared value for the relationship between the test variables age and hearing aid type is shown in Table 2. The overall chi-squared value for the relationship between the words in the comments text and hearing aid type was calculated by summing the chi-squared values of all possible text word - BTE/ITE right aid pairs, and is also shown in Table 2. This data shows, with 99.9% confidence, that these text words were not randomly distributed, but some text words are probably associated with hearing aid type. Similarly the associations of each of the variables (age, comments text, gender and hearing aid type) with tinnitus are shown in Table 3. Here we see that there are significant associations between age, comments text, and BTE/ITE right aid with a diagnosis of tinnitus, but there are no significant associations between gender and tinnitus diagnosis.

Table #2. Overall χ2 with BTE/ITE right aid

Fields	Overall χ2	Degrees of freedom (df)	P
Age	10.53	1	P < 0.001
Comments text	5421.84	663	P < 0.001
Gender	33.68	1	P < 0.001

Table #3. Overall χ2 with tinnitus diagnosis

Fields	Overall χ2	Degrees of freedom (df)	P
Age	41.45	1	P < 0.001
Comments text	492.26	60	P < 0.001
Gender	0.18	1	P = 0.6714
BTE/ITE raid	31.75	1	P < 0.001

To use the chi-squared test the expected frequency values must be all at least 1, and most should exceed 5 [9]. To be on the safe side, we insisted that for each word, all the expected values should be at least 5, so all words failing this test were grouped into a single class called "OTHERS".

Table #4. Categories with positive and negative keywords in records with BTE/ITE right aid

	positive keywords	negative keywords
Age<=70	* *Not found*	* *Not found*
Age>70	* *Not found*	* *Not found*
BTE	** mould, be34, map, gp, 92, audio, inf, be52, ref, staff, reqd, be36, contact	** fta, reshel, appt, it, nn, nfa, 2001, rev, lacquer, hn, km, imp, review, 2000
ITE	** fta, reshel, appt, it, nn, nfa, 2001, rev, lacquer, hn, km, imp, review, 2000, nh, vent, progress, aid, dt, taken	** mould, be34, map, gp, 92, audio, inf, be52, ref, staff, reqd, be36, contact, tri, n, order
Male	*** ITE	*** BE^{+}
Female	*** BE^{+}	*** ITE

Table #5. Categories with positive and negative keywords in records with a Tinnitus/Not-Tinnitus Diagnosis

	positive keywords	negative keywords
Age<=54	* Not-Tinnitus	* *Not found*
Age>54	* *Not found*	* Not-Tinnitus
Not-Tinnitus	** OTHERS, lost, ear, wax, L, aid *** BTE	** masker, tinnitu, rev, help, appt, 2001, 2000, counsel, ok, further, progress, fta *** ITE
Tinnitus	** masker, tinnitu *** *Not found*	** OTHERS *** *Not found*
Male	*** *Not found*	*** *Not found*
Female	*** *Not found*	*** *Not found*

Keywords associated with categories with 95% confidence were deemed typical of those categories if O > E, otherwise they were deemed atypical. The keywords most typical and atypical of the four categories (hearing aid type, age, tinnitus and gender) are shown in Tables 4 and 5. A "keyword" could either be a category type (where * denotes a diagnosis category, and *** denotes a hearing aid category), or a word from the free-text comments field (denoted **). The discovered associations seem intuitively reasonable. For example, it appears that the patients with 'Age<=54' do not have tinnitus, and not-tinnitus (not having tinnitus) patients had a problem of wax and were using BTE hearing aids. The words tinnitus (ringing in the ears) and masker (a machine for producing white noise to drown out tinnitus) were atypical of this category. It was found that males were using ITE hearing aids and females were using BTE hearing aids. The hearing aid types associated with BTE were those with high gain and had changes made to the ear mould. Similarly, ITE hearing aid types were used lacquer, vents, required reshelling of ear impressions, had changes made to the hearing aid, were reviewed and the wearers were making progress.

For these experiments, we used all the records available in the database for each field under study, keeping the criterion that none of the field values should be empty. In Table 4, 70 was calculated as the median age of the BTE/ITE right aid group and in table 5, 54 was the median age of the records with a Not-Tinnitus or Tinnitus diagnosis. In both tables (Table 4 and Table 5) some keywords in the comments text were abbreviations such as 'reshel' for 'reshell' and 'fta' for 'failed to attend appointment'. 'Tinnitus' appears as 'tinnitu' in the tables, since all the text was passed through Porter's stemmer [10] for the removal of grammatical endings.

4. MEASURES OF ASSOCIATION IN CATEGORICAL DATA

Yule's Q is a measure to find the strength of association between categorical variables. Unlike the chi-squared test, which tells us how certain we can be that a relationship between two variables exists, Yule's Q gives both the strength and direction of that relationship [6]. In the following 2 x 2 table,

	Present	Absent
Present	A	B
Absent	C	D

Yule's Q is given by

$$Q = \frac{AD - BC}{AD + BC} \qquad [2]$$

where A, B, C and D are the observed quantities in each cell. Yule's Q is in the range -1 to +1, where the sign indicates the direction of the relationship and the absolute value indicates the strength of the relationship. Yule's Q does not distinguish complete associations (where one of the cell values = 0) and absolute relationships (where two diagonally opposite cell values are both zero), and is only suitable for 2 x 2 tables.

In Tables 6 – 9, Yule's Q values for age with comment text, diagnosis, hearing aid type, and mould are given. Similarly, in the Table 10 – 12, Yule's Q values for gender with comment text, hearing aid type and mould are given. “(P)” and “(A)”, stand for present and absent.

In Table 6, a Yule’s Q value of 0.75 shows that there is a positive association between the keyword ‘progress’ and the category ‘Age<=70’, which can be restated as a negative association between the keyword ‘progress’ and the category ‘Age>70’.

Table #6. Yule’s Q for comment text and age

Comment text	Age<=70 (P)	Age>70 (P)	Age<=70 (A)	Age>70 (A)	Yule’s Q
Progress	93	13	46833	45555	0.75
Dna	105	20	46821	45548	0.67
Masker	565	126	46361	45442	0.63
Tinnitus	385	123	46541	45445	0.51
Help	222	84	46704	45484	0.44
Counsel	191	80	46735	45488	0.40
2000	288	125	46638	45443	0.38
Fta	542	332	46384	45236	0.23
Gp	370	615	46162	55060	-0.16
Wax	341	601	46191	55074	-0.19
Ref	248	487	46284	55188	-0.24
Contact	37	129	46495	55546	-0.49
Insert	23	102	46509	55573	-0.58
Reqd	15	111	46517	55564	-0.72
Cic	10	76	46522	55599	-0.73
Staff	17	132	46515	55543	-0.73
Map	15	125	46517	55550	-0.75
Dv	29	245	46503	55430	-0.75
Reinstruct	8	68	46524	55607	-0.75

Table #7. Yule’s Q for diagnosis and age

Diagnosis	Age<=54 (P)	Age>54 (P)	Age<=54 (A)	Age>54 (A)	Yule’s Q
FAMILIAL	18	0	684	662	1.00
OTHERS	113	44	589	618	0.46

In Table 7, for ‘diagnosis’ there is an absolute association between ‘FAMILIAL’ and ‘Age<=54’, resulting in a Yule’s Q value of 1. This should be viewed in comparison to the chi-squared value for the same association, 17.20 ($p < 0.001$), showing both that the association is very strong and that we can be highly confident that it exists. The presence of this association shows that a higher proportion of younger people report to the hearing aid clinic with familial (inherited) deafness than older people.

Table #8. Yule's Q for hearing aid type and age

Hearing aid type	Age<=70 (P)	Age>70 (P)	Age<=70 (A)	Age>70 (A)	Yule's Q
PFPPCL	42	1	11105	10899	0.95
PPCL	78	5	11069	10895	0.88
BE101	44	4	11103	10896	0.83
PPC2	53	6	11094	10894	0.79
ITENL	123	35	11024	10865	0.55
OTHERS	103	37	11044	10863	0.46
ITEHH	536	317	10611	10583	0.26
-	4668	3947	6479	6953	0.12
BE34	640	882	10507	10018	-0.18
ITENH	403	592	10744	10308	-0.21
ITENN	683	1063	10464	9837	-0.25
BE36	97	203	11050	10697	-0.37

Table #9. Yule's Q for mould and age

Mould	Age<=70 (P)	Age>70 (P)	Age<=70 (A)	Age>70 (A)	Yule's Q
N8	261	94	10873	10805	0.47
SIL	255	101	10879	10798	0.43
V2	575	397	10559	10502	0.18
2107V1	601	913	10533	9986	-0.23

Table #10. Yule's Q for comment text and gender

Comment text	M (P)	F (P)	M (A)	F (A)	Yule's Q
He	67	2	46465	55673	0.95
Wife	44	2	46488	55673	0.93
Dv	80	254	46452	55421	-0.45

Table #11. Yule's Q for hearing aid type and gender

Hearing aid type	M (P)	F (P)	M (A)	F (A)	Yule's Q
ITEHH	665	201	11080	12467	0.58
ITENH	725	295	11020	12373	0.47
ITEHN	1280	1732	10465	10936	-0.13
ITENN	734	1038	11011	11630	-0.14

Table #12. Yule’s Q for mould and gender

Mould	M (P)	F (P)	M (A)	F (A)	Yule’s Q
IROS	80	24	11671	12644	0.57
V2	640	342	11111	12326	0.35
N8	253	141	11498	12527	0.32

Familial deafness is relatively rare but can affect any age group, while “others” would include “old-age deafness” (presbycusis) which is relatively common, but obviously restricted to older patients. However, in Table 9, Yule’s Q for ‘V2’ is 0.18, which shows only a weak association between mould and ‘Age<=70’, while the chi-squared value for the same association of 30.25 (P < 0.001), showed that it is highly likely that the association exists. In Table 11, Yule’s Q for ‘ITEHN’ (a type of hearing aid worn inside the ear) is -0.13, which shows a weak negative association between ‘ITEHN’ and ‘male’, or in other words, a weak positive association between ‘ITEHN’ and ‘female’. In comparison, the chi-squared value for the same association of 43.36 (P < 0.001), showed that we can be highly confident that the relationship exists. These results show the complementary nature of the chi-squared and Yule’s Q results: in all three cases the chi-squared value was highly significant, suggesting that the relationship was highly likely to exist, while Yule’s Q showed the strength (strong in the first case, weak in the others) and the direction (positive in the first two cases, negative in the third) of the relationship differed among the three cases.

5. SUPPORT AND CONFIDENCE FOR ASSOCIATIONS

We examined two measures of association commonly used in market basket analysis, support and confidence [4], for all relations between age and diagnosis, and gender and diagnosis. We were unable to find many rules with high support and confidence due to the very high proportion of one type of diagnosis (‘TINNITUS’) in the records. However, we feel that given an audiology database where a diagnosis was routinely recorded for every patient, more rules in the form $A \Rightarrow B$ (A implies B) would be found. Our results are given in [15].

6. LIKELIHOOD RATIOS FOR ASSOCIATED KEYWORDS

In Bayesian Evidence Evaluation [6], the value of a piece of evidence may be expressed as a likelihood ratio (LR), as follows:

$$LR = \Pr(E|H) / \Pr(E|\bar{H})$$

For example, our hypothesis (H) might be that a patient should be fitted with a BTE hearing aid as opposed to an ITE hearing aid. E is a piece of evidence such as the word "tube" appearing in the patient's comments field of the database. Pr(E|H) is then the probability of seeing this evidence given that the hypothesis is true. Of all the 34394 records where a patient was given a BTE aid, 29 of them contained the word "tube", so in this case Pr(E|H) = 29 / 34394 = 0.000843. $\Pr(E|\bar{H})$ is the probability of seeing the word "tube" when the hypothesis is not true. Of all the 29455 records where a patient was given an ITE aid, only 2 of them contained the word "tube", so here $\Pr(E|\bar{H})$ was 2 / 29455 = 0.0000679. This gives an LR of 0.000843 / 0.0000675 = 12.41. Using Evett et al.'s [14] scale of verbal equivalences of the LR, an LR in the range 10 to 100 indicates moderate support for the hypothesis. LRs in the range 0.1 to 10 indicate only limited support either way, while an LR in the range 0.01 to 0.1 would indicate moderate support for the complementary hypothesis. The words giving the highest and lowest LR values with respect to a BTE fitting as opposed to an ITE fitting are shown in Table 13, where NA indicates division by zero as the word never appeared in records for patients fitted with an ITE hearing aid. All words which were used in the chi-squared analysis (since their expected values were all 5 or more) were also considered for this analysis.

LR values are useful for the combination of evidence. Using the evidence that the text comments field contains "lacquer", "reshell" and "progress", we can estimate the likelihood of the patient requiring a BTE hearing aid by iteratively using the relationship "posterior odds = LR x prior odds". Initially we obtain a prior odds (Pr(BTE) / Pr(ITE)) from a large sample or manufacturer's data. Using the column totals in table 16, the prior odds in favour of a BTE aid before any other evidence has been taken into account would be 34394 / 29445 = 1.168 to 1. Taking the first piece of evidence (the presence of the word "lacquer" into account), the posterior odds are 0.03 x 1.168 = 0.035. This posterior odds value now becomes the prior odds for the second iteration. The LR for "reshell" is 0.04, so the posterior odds become 0.04 x 0.035 = 0.0014.

Table #16. Likelihood ratios for comments text and BTE/ITE right aids

Word	BTE	ITE	LR
Adequ	14	0	NA
Audiometer	10	0	NA
Be10	18	0	NA
Be201	18	0	NA
Be301	13	0	NA
Be37	12	0	NA
Be51	13	0	NA
Hac	11	0	NA
Temporari	11	0	NA
Therapy	13	0	NA
Be52	68	2	29.11
Be53	26	1	22.26
Be36	57	3	16.27
Be54	35	2	14.98
Retub	34	2	14.55
Seri	16	1	13.70
Cwc	15	1	12.84
Tube	29	2	12.41
Couldn’t	14	1	11.99
Orig	14	1	11.99
“map	13	1	11.13
Map	116	9	11.03
E	12	1	10.27
Hn	8	77	0.09
Progress	4	39	0.09
Readi	1	10	0.09
Concertina	1	11	0.08
Unless	1	11	0.08
Coat	1	13	0.07
Cap	1	15	0.06
Vc	1	15	0.06
Hnv1	1	17	0.05
Hh	1	20	0.04
Reshel	6	136	0.04
Lacquer	2	65	0.03
Facepl	0	15	0
Window	0	16	0
TOTAL	34394	29445	

This posterior odds value now becomes the prior odds for the third iteration. The LR for "progress" is 0.09, so the final posterior odds become 0.09 x 0.0014 = 0.000126. Since these posterior odds are much less than 1, it is much more likely that the patient should be fitted with an ITE hearing aid. This simple example shows the basis by which a Bayesian decision support system which returns the more suitable type of hearing aid could be constructed.

7. CONCLUSION

In this work we have discovered typical and atypical words related to different fields of audiology data, by first using the chi-squared measure to show which relations most probably exist, then using Yule's Q measure of association to find the strength and direction of those relations. The Likelihood Ratio, also based on the contingency table, provides a means whereby all the words in the comments field can be taken into account in a Bayesian decision support system for audiologists. We are currently working on the development of a Logistic Regression model, where the overall value log(Pr(BTE) / Pr(ITE)) will be linear combination of the presence or absence of each of the discovered associated variables described in this chapter. Analogous reasoning will be used for models to predict whether or not a patient should be given a tinnitus masker, and whether or not he or she would benefit from a hearing aid fitting.

Rules found by data mining should not only be accurate and comprehensible, but also "surprising". McGarry presents a taxonomy of "interestingness" measures whereby the value of discovered rules may be evaluated [13]. In this paper we have looked at objective interestingness criteria, such as the statistical significance of the discovered rules, but we have not yet considered subjective criteria such as unexpectedness and novelty. These require comparing machine-derived rules with the prior expectations of domain experts. A very important subjective criterion is "actionability", which includes such considerations as impact: will the discovered rule lead to any changes in current audiological practice?

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