Confounding Values in Decision Trees Constructed for Six Otoneurological Diseases

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Abstract. In this study, we examined the effect of example cases with confounding values on decision trees constructed for six otoneurological diseases involving vertigo. The six diseases were benign positional vertigo, Menière's disease, sudden deafness, traumatic vertigo, vestibular neuritis, and vestibular schwannoma. Patient cases with confounding values were inserted into original vertigo data and decision trees were constructed. Confounding values made classification tasks more difficult and decreased true positive rates and accuracies of decision trees. Despite decreased true positive rates and accuracies, new decision trees organised confounding values in a reasonable way into the reasoning process. The occurrence of confounding values simulates better the real life classification tasks.

1 INTRODUCTION

Diagnosis of a vertiginous patient is a difficult task even for specialised otologists. To assist this task, an otoneurological expert system ONE [1] was developed. In addition to diagnostic purposes, it can be used as a tutorial guide for medical students. ONE is beneficial for research, too, due to its capability to store data. In addition to expert systems, we have been interested in other computerized methods, such as genetic algorithms [2], decision trees [3], and neural networks [4], which can be used to support decision making process. We have applied these methods to acquire diagnostic knowledge for benign positional vertigo, Menière's disease, sudden deafness, traumatic vertigo, vestibular neuritis, and vestibular schwannoma [5-7], which are the six largest patient groups in the database of ONE [8].

Due to symbolic knowledge representation, decision trees are suitable for medical classification tasks, in which explanations for decisions are needed. Decision trees generated in the previous study [6] were intelligible and, overall, their true positive rates and accuracies were high. Sudden deafness was the most difficult disease to identify, partly due to the small number of these cases (only 3.7% of all the cases). Recently, data collection was continued to increase the number of example cases especially in the group of sudden deafness. New patient cases were inserted into the database of expert system ONE and subsequently retrieved for decision tree induction. New patient cases had confounding values, which weakened learning results [9] compared with results of the earlier study [6]. Because of the quite small number of cases with confounding values, these values did not occur in the constructed decision trees. This led us to a hypothesis that giving a large enough number of example cases for the decision tree program may result in decision trees which incorporate confounding values. In this study, we retrieved more cases with confounding values from the database of the expert system ONE and constructed decision trees using the See5 decision tree program [10], a descendant of C4.5 [11]. The constructed decision trees were compared with the trees of the earlier study [6].

2 MATERIALS AND METHODS

The data were collected at the Vestibular Laboratory of the Department of Otorhinolaryngology, in Helsinki University Central Hospital, Finland. In the data collection, the expert system ONE was employed. The database of ONE [12], stores a large amount of detailed information about patients. The information is presented in a total of 170 attributes. Use of the expert system does not require the user to answer all the questions, and accordingly, there are some attributes having a lot of missing information. The attributes can be divided into the following categories [12]:

- Patient demographics and referring physician.
- Symptoms: vertigo, hearing loss, tinnitus, unsteadiness, headache, anxiety, and neurological symptoms.
- Medical history: use of ototoxic drugs, head trauma, ear trauma and noise injury, ear infections and operations, specific infections and examinations, and other diseases.
- Findings: clinical findings, otoneurological data, audiometric data, imaging data, and fistula testing.

During the development of ONE, a database of 1167 vertiginous patients was collected prospectively [8]. Otologists were able to confirm the diagnosis of 872 patients, of which 746 belonged to the six largest patients groups. A linear discriminant analysis done by the otologists revealed that some patients had confounding values [8]. By confounding values we mean symptoms and signs that are not related to the current disease, but are rather caused by earlier diseases, medication, or some other factor [8]. Patients had age-related hearing loss, chronic noise exposure combined with hearing loss, chronic diseases such as diabetes, cardiac arrhythmia or major stroke. These diseases and processes caused signs and symptoms that interfered with the discrimination of diseases. Exclusion of patient cases having confounding values finally resulted in an 'original' data set with 564 cases [8]. This data set was used in the earlier studies with machine

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learning methods [5-7]. Recently, 76 new cases were inserted into the database of ONE. Especially new benign positional vertigo (BPV) cases (16) and vestibular neuritis (VNE) cases (8) had confounding values. For example, in the original data set, BPV cases did not have hearing loss symptoms. Of the 16 new BPV cases, again, five cases had hearing loss symptoms (Table 1).

Table 1. Distributions for attribute hearing loss.

Benign positional vertigo	Hearing loss	N	%
59 original cases	No	59	100.0
	Yes	0	0.0
16 new cases	No	11	68.8
	Yes	5	31.2
48 cases in extended data	No	17	36.2
	Yes	30	63.8
	Missing	1	

Decision tree tests with the 76 new cases and the 564 previous cases revealed that confounding values reduced the classification ability of decision trees [9]. Confounding values did not, however, occur in the constructed trees because of the quite small number of cases having these values. For this study, 48 BPV cases and 40 VNE cases, discarded in the earlier study [8] because of the confounding values, were retrieved from the database of ONE. These cases were combined to the original data set and to the 76 new cases resulting in the extended data set of 728 cases (Table 2).

Table 2. Data sets.

		Original		Extended	
Diagnosis		N	%	N	%
Benign positional vertigo	BPV	59	10.5	123	16.9
Menière's disease	MEN	243	43.1	283	38.9
Sudden deafness	SUD	21	3.7	30	4.1
Traumatic vertigo	TRA	53	9.4	56	7.7
Vestibular neuritis	VNE	60	10.6	108	14.8
Vestibular schwannoma	VSC	128	22.7	128	17.6
Total		564	100.0	728	100.0

Decision trees were constructed in the form of one disease (positive cases) versus other diseases (negative cases) using the decision tree generator See5 [10]. From the 170 attributes of the expert system ONE, 110 [6] were used in the decision tree construction. The group of 110 attributes was formed on the basis of the physicians' knowledge; for example, attributes having a large number of missing values were excluded [6].

3 RESULTS

The measures used to evaluate the performance of the constructed decision trees were true positive rate (*TPR*) and accuracy (*ACC*):

$$TPR = (Tpos / Pos) \cdot 100\%,$$

where *Tpos* is the number of correctly classified positive cases and *Pos* is the total number of positive cases, and

$$ACC = ((Tpos + Tneg) / N) \cdot 100\%,$$

where *Tneg* is the number of correctly classified negative cases and *N* is the number of all cases. Table 3 presents estimated true positive rates and accuracies given by 10-fold cross-validation [11]. These estimates were compared with the results of the original data set [6]. Furthermore, the experienced physician evaluated decision trees by scrutinising them branch by branch.

Table 3. True positive rates, accuracies and number of attributes for decision trees constructed from original (ORG) and extended (EXT) data sets.

	True positive rate %		Accuracy %		Attributes (N)	
	ORG	EXT	ORG	EXT	ORG	EXT
BPV	98.3	71.5	99.3	92.0	3	18
MEN	98.8	95.1	94.1	91.7	15	18
SUD	52.4	56.7	98.0	98.1	7	5
TRA	96.2	87.5	99.3	98.1	3	6
VNE	98.3	80.6	99.5	96.2	4	9
VSC	82.0	78.1	95.2	95.3	9	11

The true positive rate for benign positional vertigo reduced from 98.3% to 71.5%, and the accuracy from 99.3% to 92.0%. The number of attributes used in the decision tree increased from 3 to 18 (Table 3). In the decision tree constructed from the original data set, the root attribute was hearing loss. This tree classified all cases having hearing loss as not having BPV. In the branch corresponding cases not having hearing loss, frequency of vertigo attacks and occurrence of head injury were tested. In the new decision tree (Figure 1), effects of confounding values are seen in both subtrees branching from the root. For patients not having hearing loss (hearing loss = 0), the attribute concerning Tumarkin-type drop attacks was used to discriminate BPV patients from patients with Menière's disease or vestibular schwannoma. For patients having hearing loss, normal finding in electronystagmography and posturography confirmed BPV diagnosis, whereas deviant findings fit better for vestibular schwannoma and Menière's disease. The audiometry in these BPV patients revealed mostly a mild hearing loss.

For Menière's disease, the true positive rate reduced from 98.8% to 95.1%, and the accuracy from 94.1% to 91.7%. The number of attributes increased from 15 to 18. An essential triad of hearing loss, vertigo, and tinnitus [8] was found in both trees. Further, strong nausea, Tumarkin-type sudden slipps of falls, and fluctuation in hearing appeared in a sensible way in the trees. Some attributes of the old tree were replaced in the new tree by new attributes more valuable in the diagnostic work-up. These new attributes held descriptive characteristics of vertigo and visual blurring.

The true positive rate of the decision tree constructed for sudden deafness increased from 52.4% to 56.7%. The accuracy remained almost the same, 98.1%. Type of hearing loss, which is an essential attribute in diagnosing sudden deafness [8], occurred in both trees, as well as the fluctuation in hearing. Other attributes concerned injury and detailed information about hearing loss. The new decision tree contained five attributes, two attributes less than the tree constructed from the original data set.

The true positive rate for traumatic vertigo reduced from 96.2% to 87.5%, and the accuracy from 99.3% to 98.1%. The number of attributes used in the decision tree constructed for traumatic vertigo increased from three to six. Both trees tested attributes concerning head injury. New attributes concerned nausea and detailed information about head trauma.

For vestibular neuritis, the true positive rate reduced from 98.3% to 80.6%, and the accuracy from 99.5% to 96.2%. The decision tree contained nine attributes, five attributes more than the old tree. An important attribute in both decision trees concerned the low frequency of vertigo attacks. Duration of vertigo attack and hearing loss appeared in both trees, also. New attributes concerned descriptive characteristics of vertigo, movement difficulties, occurrence of head injury, gain latency in pursuit eye movements, and tone burst audiometry at the frequency of 2 kHz. Neurological findings appearing in the new decision tree were also important.

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Hearing loss = 0:
:...Duration of vertigo attack > 2: not
:   Duration of vertigo attack <= 2:
:   :...Injury = 1:
:       :...Duration of tinnitus <= 5: not
:       :   Duration of tinnitus > 5: bpv
:       Injury = 0:
:       :...Frequency of vertigo attacks <= 1: not
:           Frequency of vertigo attacks > 1:
:           :...Cranial nerve palsy = 0: bpv
:               Cranial nerve palsy = 1:
:               :...Tumarkin-type drop attacks <= 1: bpv
:                   Tumarkin-type drop attacks > 1: not
Hearing loss = 1:
:...Position induced vertigo <= 39.5: not
    Position induced vertigo > 39.5:
    :...Duration of vertigo attack > 2: not
        Duration of vertigo attack <= 2:
        :...Stapedectomy = 1: bpv
            Stapedectomy = 0:
            :...Duration of hearing loss <= 4: not
                Duration of hearing loss > 4:
                :...Head trauma = 1: not
                    Head trauma = 0:
                    :... Injury = 1:
                        :...Duration of tinnitus > 5: bpv
                        :   Duration of tinnitus <= 5:
                        :   :...Rotational vertigo <= 40: not
                        :       Rotational vertigo > 40: bpv
                        Injury = 0:
                        :...Ear illness = 1:
                            :... Audiometry at 500 Hz, right ear <= 60: bpv
                            :    Audiometry at 500 Hz, right ear > 60: not
                            Ear illness = 0:
                            :...Spontaneous nystagmus > 0: not
                                Spontaneous nystagmus <= 0:
                                :...Age at first vertigo symptoms <= 52:
                                    :...Posturography, eyes open <= 0.75: bpv
                                    :   Posturography, eyes open > 0.75: not
                                    Age at first vertigo symptoms > 52:
                                    :...Audiometry at 2000 Hz, right ear <= 35: bpv
                                        Audiometry at 2000 Hz, right ear > 35: not
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Figure 1. New decision tree for benign positional vertigo (bpv) and other diseases (not).

The true positive rate for vestibular schwannoma reduced from 82.0% to 78.1%. The accuracy remained almost the same, 95.3%. An important attribute occurring in both decision trees was caloric asymmetry: in vestibular schwannoma, this value is high. The attribute concerning Tumarkin-type drop attacks discriminated VSC patients, who seldom have these drop attacks, from Menière's disease patients, who have them often. Attributes concerning vertigo, hearing loss, use of ototoxic or vestibulotoxic drugs, and results of computerized tomography appeared also in both trees. Three new attributes were hearing loss of left ear, headache, and tone burst audiometry at the frequency of 1 kHz. The new decision tree showed that about half of VSC patients do not have vertigo symptoms.

4 DISCUSSION

Overall, the generated decision trees were intelligible, although we found some strange branches formed by chance. New attributes occurring in the decision trees were sensible. Attributes concerning confounding values were found especially in the decision tree constructed for benign positional vertigo. In the previous studies [6,8], test results were of minor value in classification of these six diseases. Results of this study suggest that they are important when cases with confounding values are classified.

True positive rates decreased for all diseases, except for sudden deafness, which had the true positive rate of 56.7%, 4.3% more than for the decision tree constructed from the original data set. Sudden deafness seems to be a difficult disease to identify, partly due to the small number of cases, partly due to its nature [5-9]. For Menière's disease (95.1%), traumatic vertigo (87.5%), and vestibular schwannoma (78.1%), the decrease in the true positive rate was less than 10%. The largest decreases (26.8% and 17.7%) were found for benign positional vertigo (TPR of 71.5%) and vestibular neuritis (TPR of 80.6%), respectively. These large decreases can be explained by confounding values, which made BPV and VNE cases to resemble more Menière's disease cases. Overall, classification accuracies reduced slightly, varying from 91.7% to 98.1%. Reductions in true positive rates and accuracies agreed with results of the linear discriminant analysis and the expert system ONE [8,9].

Confounding values made classification tasks more difficult. Although true positive rates and accuracies decreased, the constructed decision trees are valuable. The benefit of the new trees is that they simulate more the real life situation with patients who have confounding symptoms. The value of otoneurological tests increases in the diagnostic work. In the future, our aim is to find different ways to handle confounding values in the reasoning process.

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