Computer Based Neuroradiology Training

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Using a "Small Worlds" Approach to Differential Diagnosis.

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INTRODUCTION

Radiological diagnosis presents a particularly difficult task as it requires the extraction and interpretation of information on individual patients from complex medical images and reasoning in relation to competing pathologies that often exhibit similar abnormal features in the images. Studies of expertise in diagnostic medical cognition examine differences between practitioners with different levels of experience in terms of their cognitive processes and skills (including hypothesis generation and evaluation, memory performance, diagnostic reasoning and the organisation of clinical knowledge).

According to Kushniruk, Patel & Marley (1) expert physicians organise diagnostic knowledge on the basis of small subsets of diseases and their distinguishing features. They speculate that the process of diagnosis involves the physician rapidly focusing on relatively small sets of logically related diseases (i.e. “small worlds”) and carrying out a limited number of comparisons among these diseases to complete the diagnostic process. It is hypothesised that diseases contained within a small world would typically share certain overlapping features, and this is the basis for their membership of that particular small world. However, the diseases contained within a small world differ in terms of the presence or absence of certain other features, allowing the expert to distinguish between the candidate diseases contained within a small world.

In order to investigate the small worlds hypothesis, Kushniruk et al. re-analysed the verbal protocols collected in the studies carried out by Joseph & Patel (2) and Patel, Evans & Kaufman (3). They were particularly concerned with examining the networks of relationships among the hypotheses and findings generated by experts (endocrinologists solving endocrine cases) and sub-experts (cardiologists solving endocrine cases). The networks produced by the experts were found to contain few elements (i.e. a limited number of hypotheses and findings) and these were tightly connected, displaying a high degree of coherence and relatedness. Furthermore, expert physicians quickly focused on those cues and critical findings (‘critical cues’) that most clearly distinguished among compenguioscases) andacritical cues’) that

1. Teach trainees a structured Magnetic Resonance (MR) Image Description Language (IDL). With reference to radiology in general, Rogers, Arkin, Baron, Ezquerra & Garcia (4) discuss the need for a "lexicon of both anatomical landmarks and diagnoses which is understood and accepted by experts and residents alike".
2. Ensure that trainees are exposed to a wide range of cases representing the major brain diseases and gain an indication of the variation in visual features both between and within a disease category. Cases of the same disease can vary tremendously in terms of their MR presentation: Mervis and Pani (5) demonstrated that classification learning is maximised when subjects are first introduced to instances that best (most typically) represent the class under study and are only later exposed to less typical instances.
3. Expose trainees to cases drawn from a variety of small worlds, where each small world consists of cases from diseases that produce similar images, and so help them to discriminate between potentially competing hypotheses.

assisting trainees to use the terminology correctly. The vocabulary is derived from an understanding of the development and histology of lesions but can be applied and understood by radiologists working from images. The particular terms are derived from knowledge of underlying anatomy and histology, but they all refer to visual cues. The language describes both the position and appearance of abnormalities visible in the images. We have accumulated a database of the brain MR images of some 1,200 patients. These have been described by one author, expert in terms of the IDL, allowing trainees to compare their image descriptions with that of an expert (8).

Image Feature Overview Space

The MR-tutor uses a visualisation method to illustrate case typicality and the variation of presentation within and between diseases. The position of cases is computed from their image description with Multiple Correspondence Analysis (MCA) applied to the raw descriptions. Effectively, a multi-dimensional representation (the image description) is reduced to a two-dimensional visualisation, with the data points maximally spread out over the surface. The more similar two cases are, the closer their points will appear in the space. From the image description database we are also able to compute the position of the 'typical case' for each disease, and display it as the disease centroid in the overview space. Cases in physical proximity to this centroid can be classed as highly typical of the disease whereas those further away are less typical. Typicality contours representing the 25th, 50th and 75th percentiles are also contained in the overview space and these allow estimates of case typicality to be made (7). Figure 1 illustrates a typical overview space, in this case constructed from 16 cases of glioma.

diagnosis. Figure 2 presents a joint overview space with fitted typicality contours constructed for three diseases (glioma, infarct and meningioma). The overview space represents an example of the representation of a group of confusable diseases. The space reveals that in the case of the MR description data there is considerable overlap between gliomas and meningiomas, but good separation between infarcts and meningiomas (at least from the descriptions of the T2 weighted images used to construct Figure 2).

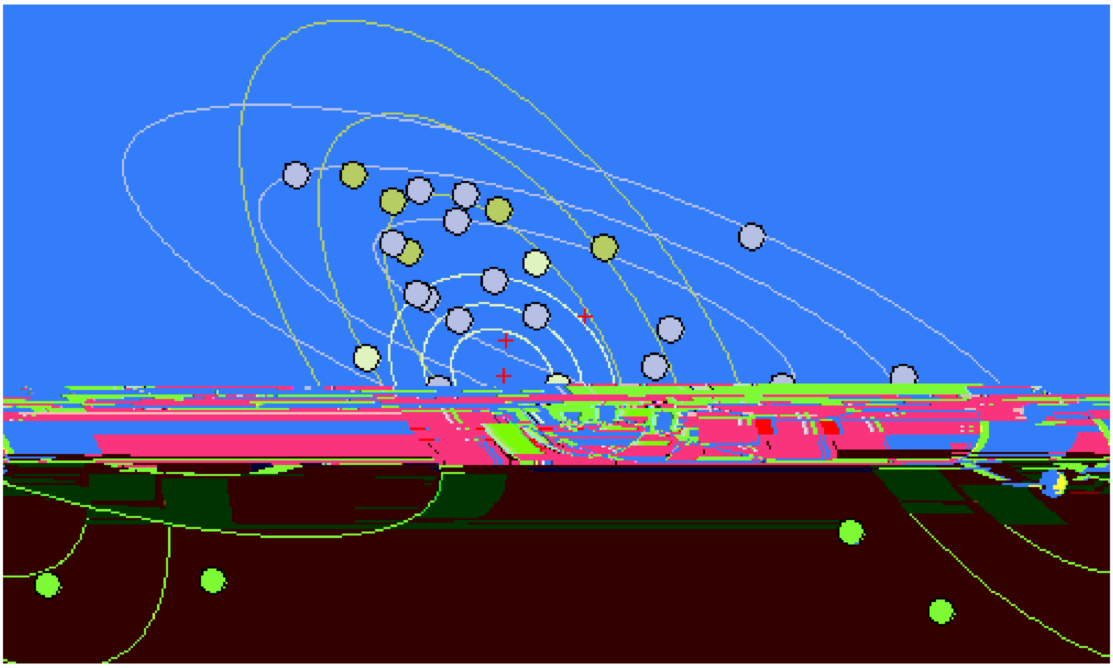

Figure 2. Overview space for case of Glioma, Infarct and Meningioma

Empirical research was needed to establish the differential diagnoses that are problematic, (i.e. diseases that are difficult to distinguish) and therefore represent clinically relevant issues. At present there is only a single group of confusable diseases included in the tutor (the glioma, meningioma & infarct group) and furthermore, this group was based upon the image descriptions of a single expert with empirical work needed to verify his views. The implementation of more confusable subgroups is a necessary condition for a functional decision support system (and training system). This paper describes empirical work undertaken to examine the disease differentiation that expert neuroradiologists find genuinely difficult to make. These groups of confusable diseases can then be implemented in the MR-tutor.

In order to examine what constitutes groups of confusable diseases for experts examining MRI scans of the head, a pro-forma was devised, and distributed to a group of expert neuroradiologists. The pro-forma asked experts to identify a number of scenarios in which examination of MR scans presents differential diagnostic difficulties. They were instructed that the diagnoses should be difficult to make, but at the same time worth making, and asked to list examples of MR based differential diagnostic problems which were not readily solvable and where a decision support tool might be of some assistance. For each differential diagnosis listed by the experts, they were asked to:

6. Rate the difficulty of the differential diagnosis on a scale from 1 - 5 (where 1 was tied to the semantic anchor ‘not normally difficult’, 3 - ‘sometimes difficult’, and 5 - ‘often very difficult’).

7. Rate the degree of clinical significance of the differential diagnosis (i.e. the degree to which this distinction affects future treatment of the patient) on a scale from 1-5 (where 1 had the semantic anchor ‘clinically insignificant', 3 - ‘sometimes clinically significant’, and 5 - ‘always clinically significant').

8. Rate the frequency with which this particular differential diagnosis is encountered in clinical practice. Again a scale of 1-5 was used where 1 had the semantic anchor ‘very infrequently’, 3 - ‘occasionally’ and 5 - ‘regularly’.

Subjects

The pro-formas were distributed to expert neuroradiologists at a number of specialist neuroradiology units in the UK and a further two in Barcelona, Spain. Respondents ranged in terms of their experience in MRI imaging in neuroradiology (12-204 months, Mean 98.3 months, SD 64.9 months). 24 completed questionnaires were returned to the research team (6 from Spanish recipients and a further 18 from British neuroradiology specialists). In total 117 problems were identified in the questionnaires (mean 4.88 per questionnaire).

RESULTS

As expected, the experts identified a large number of difficult differential diagnoses. The greatest practicable agreement about disease names and definitions is required in order to progress the studies. However, it was noted that the complexity and variety of disease classification soon obtruded into such an enquiry. Two different, not necessarily incompatible, classifications were investigated. The more detailed is the latest version of the WHO International Classification of Disease (ICD-10) (9), the simpler and more general is the traditional grouping into 10 categories used in neuroradiology training (Developmental, Inflammatory etc., see Table 1). In detail, analysis of the raw data involved examining clusters of responses that appeared to identify similar groups of diagnostic problems. Two expert neuroradiologists (authors of this paper) helped with the analysis which involved identifying similar differential diagnoses in the experts' responses. Firstly all the responses were coded using the WHO International Classification of Disease (ICD-10) and then the experts and a third author looked for overlap in the codes at some level of the ICD hierarchy. By combining overlapping responses, twenty-one disease pairs or groups were identified from the expert questionnaires. Many of the problems were identified by several respondents. However, other problems were idiosyncratic but were deemed sufficiently difficult to be worthy of inclusion. Of the 117 problems identified in the expert questionnaires, 105 were successfully included within this 21-item framework, leaving only 12 outliers. All 21 disease pairs or groups were then named using terms that best described the nature of the items contained within them. Table 2 shows the disease pairs or groups and also examines the extent of the support for each (i.e. how many experts identified a problem that was included under this heading).

Table 1 TRADITIONAL GENERAL PURPOSE CLASSIFICATION

Normal
Developmental
Infectious
Inflammatory
Neoplastic
Vascular
Metabolic
Degenerative
Iatrogenic
Traumatic

Table 2 SMALL WORLDS CONSIDERED WORTH EXPLORING BY EXPERTS

Specified by this number of experts	Diagnosis 1	Diagnosis 2	Enough material in database for preliminary study?
16	**Inflammatory** Inflammatory mass	**Neoplastic** Neoplastic mass	
11	**Vascular** Thrombo-embolic disease	**Inflammatory** Demyelination or encephalomyelitis	Yes
9	**Degenerative** Atrophy	**Degenerative/ Miscellaneous** Hydrocephalus	
8	**Neoplastic** Metastasis	**Neoplastic** Primary tumour	Yes
7	**Iatrogenic** Radiation necrosis	**Neoplastic** Recurrent tumour	
7	**Vascular** Haemorrhage – underlying cause?	**Vascular** Haemorrhage- primary cerebral?	
7	**Infective** HIV related infectious and parasitic diseases		
6	**Neoplastic** Identification of tumours in the pituitary region		
5	**Neoplastic** Glioma	**Vascular** Infarct	Yes
5	**Neoplastic/Infective/Inflammatory** Intra-axial mass	**Neoplastic/Infective/Inflammatory** Extra-axial mass	
4	**Vascular** Vasculitis	**Inflammatory** Demyelination (MS)	
4	**Metabolic/Degnerative/Toxic/Diffuse Inflammatory** Differential diagnosis		
4	**Neoplastic** Differential diagnosis of masses in the Cerebellopontine Angle		
3	**Vascular** Lacunar infarct	**Normality** Prominent Perivascular spaces	
3	**Metabolic** Differential diagnosis of Metabolic/White matter diseases – children		

DISCUSSION

The aim of the reported study was to examine those groups of diseases (small worlds) neuroradiologists find difficult to distinguish when examining MR images of the head. These results, it was hoped, would allow us to focus the aims and objectives of a decision support/training system, and in so doing increase its utility. The study worlds identified will be made available from the database of the MR Tutor, with the aim of providing decision support training in difficult cases. Hence, for instance, when a trainee (or indeed an expert) has a difficult case thought to be either a glioma or an infarct (sometimes a difficult differential diagnosis identified in five questionnaires), inputting its image description will show where it lies in relation to the glioma and infarct clusters derived from the archived material. This may suggest that the target case is of one or the other pathology or perhaps neither and further trials with other clusters may provoke reconsideration of the possibilities. Examining the overview space of any two or more diseases may throw light on the power of individual image descriptors under different pre-suppositions.

ICD 10 was chosen because of its extensive use, but in spite of its richness and flexibility of choices between broad and narrow levels of classification, new knowledge has already left it behind for some categories of neurological disease. For the degenerative dementias, for example, the four following categories would be better and will now be employed:

a. Dementia of the Alzheimer's type, McKhan, G et al., 1984, (10),
b. Frontotemporal lobar degeneration, Neary, D et al., 1998, (11),
c. Dementia with Lewy-bodies, McKeith, I et al., 1996, (12),
d. Vascular Dementia, Roman, GC et al., 1993, (13)

How should the compiler of a reference or teaching archive of cases cope with the inescapable fact that classifications inevitably expand and change? Parts of the archive that do not change may have a long and useful life. For others, if the future users can be made aware of the details of the disease classification adopted when the classification. In adding new cases it is the intention to record the greatest detail included in the case records.

The list of significant differential diagnoses (small worlds) suggested by the experts' answers to the questionnaire originates from their practical experience. It is based partly on image appearance and partly on clinical presentation or expectations prompted by referring neurologists or neurosurgeons. Many of the small worlds bridge across diverse aetiologies. Systematic knowledge and teaching in medicine on the other hand begins with a classification of disease under about 10 headings (Table 3). It could be useful also to place the identified small worlds, when practicable, within the structure of this time-honoured systematic classification of disease. Indeed, in quoting the diagnostic codes from ICD10 one is already building bridges between the practical work of image interpretation and the systematic scaffolding of nosology.

Table 3 ADDITIONAL SMALL WORLDS FOR WHICH ARCHIVE MATERIAL

MAY BE SUFFICIENT FOR PRELIM IWORLDS3at 1 yNa9D380 /56IrTn9a Q q BT /Fcpdf1 U1 U1i

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