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Advantages of Combining AI and Statistic for Knowledge Discovery on Functional Disability. Multivariate Analysis of Assessment Scales Using Clustering Based on Rules

Karina Gibert[1], R. Annicchiarico[2], U. Cortés[3], C. Caltagirone[2,4]
Statistics and Operation Research Department. Universitat Politècnica de Catalunya, Spain[1]
IRCCS Santa Lucia Foundation, Roma, Italy[2]
Software Department. Universitat Politècnica de Catalunya, Spain[3]
Universit`a Tor Vergata, Roma, Italy[4]

SUMMARY. In Europe, and other developed areas, senior citizens are a fast growing part of population. This increases proportion of disabled persons and proportion of persons with reduced quality of life. The concept of disability itself is not always precise and quantifiable. To improve agreement on the concept of disability, the World Health Organization (WHO) developed the clinical test WHO Disability Assessment Schedule, (WHO-DASII) that includes physical, mental, and social well-being, as a generic measure of functioning. From the medical point of view, the purpose of this work is to extract knowledge about the different kinds of disabilities from the responses to the WHO-DAS II of a sample of patients from an Italian hospital. This Knowledge Discovery problem has been faced by using clustering based on rules, an hybrid AI and Statistics technique introduced by Gibert (1994), which combines some Inductive Learning (from AI) with clustering (from Statistics) to extract knowledge from certain complex domains in form of typical profiles. In this paper, the results of applying this technique to the WHO-DAS II results is presented together with a comparison of other more classical analysis approaches. Four profiles of increasing degree of disability are identified together with the main characteristics associated to them.

Keywords: disability, scale (clinical test), assessment, neurological disease, knowledge discovery, clustering based on rules, knowledge-based applications in medicine.

1. INTRODUCTION

1.1. What was known before the study:

- WHO-DASII was validated. It measures the degree of disability of a person, taking into account either cognitive and physical impairments.
- Disability is a concept not very well established. Lack of consensus on taxonomies regarding disability. Lack of standardized protocols for disability treatments.
- *Clustering based on rules* behaves better than classical clustering in general. Never applied before to the disability domain. It is expected to improve interpretability of classes.

1.2. What was added by our research

Proposal of 4 four typical profiles of disability, associated with increasing global scores of WHO-DASII. It became even possible to distinguish between intermediate degrees of disability, which are qualitatively different

Surprisingly the discovered profiles are not directly related to the diagnosis of the patient, but to the characteristics of the disability itself, from a functional point of view, according to the geriatric approach, which considers the patient as a whole more than the isolated medical aspects.

The proposed profiles constitute the first step towards the proposal of standardized rehabilitation treatment protocols, which should be associated to every profile, and requires the previous identification of the profiles themselves. Since the main characteristics associated to each profile are known, the profile of a new patient can be easily determined and his improvement easily studied and evaluated.

This research also showed that the information provided by the individual items of an assessment scale may be much richer than the global score by itself, which, although useful for quantifying de degree of the assessed topic,

cannot be used for interpretation.

Finally, classical clustering techniques perform badly in this kind of domains, producing confusing classes with many shared characteristics that use to be non-sense from the experts point of view. The use of a Knowledge Base with clinical prior knowledge guarantees the interpretation of final profiles.

1.3. Formulation of the problem of research study

The senior citizens represent a fast growing proportion of the population in Europe and other developed areas. Today, [25] the number of persons aged 60 years or older is estimated to be 629 million around the world. This quantity is expected to grow to almost 2 billion by 2050, when the population of older persons will be larger than the population of children (0-14 years) for the first time in human history. The largest proportion (54%) of this people lives in Asia; Europe has the second larger (24%). This ageing population increases the proportion of individuals with physical and/or mental impairment that need any help for the daily tasks. According to Laselett [15], "*the human life span is now divided into four ages: the first is an age of dependency, childhood and education, the second is an age of independence, maturity, and responsibility, and although the third age is considered a period of fulfillment for physically and mentally fit people in retirement, the fourth age is associated with chronic diseases, disability and dependence*".

The increasing number of people affected by chronic diseases is a direct consequence of the ageing of the population. Chronic illnesses, such as heart disease, cancer and mental disorders, are fast becoming the world's leading causes of death and disability. In fact, according to the *World Health Report 2001* [27], 59% of whole-world deaths relate to non-communicable diseases. In both developed and developing countries, chronic diseases are significant and costly causes of disability and reduced quality of life. The size and pattern of the fourth age is of critical importance not only for the quality of life of elderly people but also cause disability is closely associated with the use of health and social services [7].

Measurement of functional ability is increasingly important for the patient's health care and for health care research. This is because functional ability is an important determinant of quality of life and because it highly correlates with both physical and mental health [24].

However, there is lack of consensus in scientific community on the way of measuring disability [16] as well as on describing groups of disabled persons. Many assessment scales have been proposed to this purpose. Activities of Daily Living (*ADL*) rating scales are one of the more widely used with old people as a measure of functional ability [14]. However, *ADL* and other disability scales (typically including bathing, toileting, eating, dressing, and transferring from bed to a chair) have been criticized. Regarding this controversy, the World Health Organization, has recently proposed a new reference classification, *International Classification of Functioning, Disability and Health* (*ICF*) [1], introduced bellow. *WHO-DASII* (*World Health Organization Disablement Assessment Schedule*) [18] is an assessment instrument developed by the *WHO* to complement the process; it is described in next section.

On the other hand, clinician's most widely used approach is to get a single absolute or relative score (from the evaluation of those assessment scales) for each assessed patient [14] to classify the patient on a range of values. Thus, disability scores of each scale is a continuum related with increasing or decreasing degree of self-dependency. However, summarizing a multidimensional evaluation (usually containing a high number of items) into a single score is collapsing many different pieces of information together and really these scores hardly play a substantial role in clinical practice and decision-making. For better interpretation, sometimes specific cut-off values associated to particular profiles are identified [17].

In this work the possibility of identifying those profiles from a multivariate approach which takes into account the whole set of items of a scale is explored. The starting point is the evaluation of a neurological patients set, using *WHO-DASII* as the instrument to assess their functional disability degree. First part of the research deals with extracting knowledge contained in the collected database to see how the *WHO-DASII* provides information for identifying typical profiles of disabled patients. Afterwards, relationships between *WHO-DASII* and other scales, like *SF36*, will be analyzed as well. So, first, typical answers to *WHO-DASII* are to be identified, together with the characteristics of the groups of patients who provide each *type* of answers. In fact, this raises a clustering problem, which has to be solved, mainly consisting on finding distinct groups of homogeneous patients. The principles of clustering algorithms were firstly established in [20] from a statistical point of view. An excellent reference for statistical clustering techniques is [4]. From the Artificial Intelligence point of view, also different methods have been proposed [6]. It has been seen in [10] that classical clustering techniques cannot well recognize certain domain structures, so producing some non-sense classes, i.e. that cannot be interpreted by the experts. In fact, this arises when dealing with *ill-structured domains (ISD)* [8] [9] [10][12], where numerical and qualitative information coexists, and there exists some relevant semantic additional (but partial) knowledge to be regarded.

Clustering based on rules (ClBR) [9] is a technique described bellow especially introduced by Gibert to improve clustering results on *ISD*. In fact, one of its main advantages is that it guarantees the semantic meaning of the resulting classes. Since an *ISD* is faced here, this work will show the advantages of *ClBR versus* other more classical approaches.

Contents of the paper is: Introduction to the *WHO-DASII* scale, description of the target sample and the characteristics of the study, description of the analysis methodology, details on *ClBR*, results of applying *CLBR* to the sample and comparison with other approaches.

2. METHODS

2.1. Scales and ontologies

The International Classification of Functioning

Regarding the controversy about disability, the *World Health Organization (WHO),* provided a common framework and language for the description of health and health-related domains. A new *International Classification of Functioning, Disability and Health* (*ICF*), defining components of functioning and disability, activities and participation [27] .

ICF, is a review of ICIDH-2 [26], moving away from a classification of "*consequences of disease*" (1980 version) to a "*components of health*". *ICF* is the newest version of disability classification, systematically grouping different domains for a person in a given health condition (e.g. what a person with a disease or disorder does or can do). As well as f*unctioning* is an umbrella encompassing all body functions, activities and participation, *disability* is an umbrella for impairments, activity limitations or participation restrictions. *ICF* lists environmental factors interacting with all these constructs, allowing records of useful profiles of individuals' functioning, disability and health in various domains.

WHO-DAS II scale

WHO-DASII is a scale, especially designed and proposed by the *WHO* [18], for assessing disability levels according to *ICIDH-2* (and, consequently, with *ICF*). Is also incorporates mental health factors related to disability together with physical ones in the same set of instruments. It is a fully-structured interview measuring self-reported difficulty of functioning in six major domains that encompass activities considered important in most cultures: *Understanding & Communicating* (6 items), *Getting Around* (5 it), *Self Care* (4 it), *Getting Along with People* (5 it), *Life Activities* (8 it) and *Participation in Society* (8 it).

The *WHO-DASII* employs a 5 point rating scale for all items where 1 is used for no difficulty and 5 for extreme difficulty or the inability to perform the activity. Six *WHO-DASII* domain scores may be obtained by summing the answers in each domain, normalizing them on a 0 to 100 scale (expressing percentages) in such a way that higher values represent greater disability. Information related to the extent of disruption in life caused by these difficulties, extends of difficulties experienced in life and extends of dependence of assistive devices or other persons is considered as well. Items usually enquire about the last 30 days.

Validation of *WHO-DASII* is in progress in international field trials (in 16 centers of 14 countries). Men and women (1564) were drawn from the general population, and from persons with physical, mental, drug, and alcohol problems.

2.2. Experimental procedure

The target sample includes 96 neurological patients between 17 and 80 years, who were recovering at the *IRCCS Fondazione Santa Lucia di Roma* between October 1999 and February 2000. A control group of 20 healthy people, have also been enrolled.

All patients were assessed with *WHO-DASII* at admission and their functional status and health-related quality of life was measured. Each patient was evaluated upon two other standardized clinical scales. Functional status was quantified using the *Functional Independence Measure (FIM).* The *FIM* is a well-established measure for which reliability and validity have been proved. Patients' Quality of Life *(QOL)* was quantified using the *Short Form (SF-36);* see [22] for details on its reliability and validity. For this specific work only the items corresponding to the *WHO-DASII* are considered for clustering.

2.3. Data analysis methodology

Here, a brief description of the whole proposed analysis methodology is presented: First, d*escriptive statistics of every variable* was done. Very simple statistical techniques [21] were used to describe data and to get preliminary information about: histograms or bar charts, to display variability, plots and multiple boxplots, to observe, the relationship between some pairs of variables, etc; classical summary statistics were also calculated.

Next, *data cleaning*, including missing data treatment or outlier detection was performed. It is a very important phase, since the quality of final results directly depends on it. Decisions are taken on the basis of descriptive statistics and background knowledge of the experts.

Data was analyzed using three methods**:** ***i)*** Following the classical approach, the behavior of g*lobal WHO-DASII score* regarding the patient's pathology was studied. Since the global score is not normal, Kruskall-Wallis test was used to assess significant differences between groups. In case of rejecting null hypothesis, graphical representation is used for interpretation of differences. ***ii)*** Going into the multivariate approach, first a selection of *WHO-DASII* items was done, avoiding redundancies or inconsistencies. A hierarchical clustering was performed, using chained reciprocal neighbors method [5], with Ward criterion and the Gibert's *mixed metrics* [9], since both numerical and categorical variables were considered. ***iii)*** Finally, *clustering based on rules (ClBR),* described bellow, was used on the same items selection. This paper do not goes into mathematical details, just gives an intuitive idea of the method. The development of this method is in [9]. It is a hybrid AI and Statistics technique which combines inductive learning (AI) and clustering (Statistics) especially designed for knowledge discovery in *ISD*. A *KB* is considered to properly bias the clustering on the database. It is implemented in the software KLASS and it has been successfully used in several real applications. Our experience from previous applications [3] [8] [9] [10][12] [19] is that using ClBR use to be better than using any statistical clustering method by itself, since an important property of the method is that semantic constraints implied by the *KB* are hold in final clusters; this guarantees interpretability of results, the *meaning* of the resulting classes. Also, it uses to be better than pure inductive learning methods, since it reduces the effects of missing some implicit knowledge in the *KB*. The

general idea of *ClBR* is:

1. build a *Knowledge Base (KB)* with additional prior knowledge provided by the expert, which can even be a *partial* description of the domain (In [5] extended discussion on how to use ClBR in real applications is provided. When the domain structure is quite unknown by the experts, the methodological recommendation is to perform first a classical hierarchical method and, by analyzing the results, to identify where and nonsense results were produced. From this analysis a first prior knowledge base can be built only including the semantic constraints required to avoid the detected conceptual errors in the discovered classes. This is the approach followed in this paper.).

2. evaluate the *KB* on data for *inductive learning* of an initial partition on part of the data; put the data not included in this partition into the *residual class (RC).*

3. perform one independent hierarchical clustering for every *rules-induced class (RIC).*

4. generate prototypes of each *rules-induced class*.

5. build the *extended residual class* as the union of *RC* with the set of prototypes of *RIC*, conveniently weighted by the number of objects they represent.

6. use a hierarchical clustering for weighted clustering of the *extended residual class*.

7. in the resulting dendrogram, substitute every rules-induced prototype by its hierarchical structure, obtained in 3. This integrated all the objects in a single hierarchy.

For methods *ii)* and *iii),* the resulting clustering process can be graphically represented in a *dendrogram* (a binary tree where the height of each node indicates the homogeneity of the class composed by their leafs). Final number of classes was determined on best horizontal cut (where the largest gap exists) of the dendrogram. This identifies a partition of the data in a set of classes. *Interpretation of the classes* was based on conditional distributions of the *WHO-DASII* items through the classes, displayed through multiple boxplots. From the structural point of view, separability of classes is analyzed through the corresponding significance tests to assess relevance of differences between classes (ANOVA, Kruskall-Wallis or χ^2 independence test, depending on the item). The aim is to extract qualitative information from the classes, to obtain a meaningful description for the user and which indicates particularities of every class regarding the others.

The validation of the clustering results, either for classical hierarchical clustering or clustering based on rules, constitutes an open problem since usually in real applications, as it is the case, underlying real classes are completely unknown–even more, to discover them use to be the goal of the clustering–and there is no way to measure how close to those real classes are the ones produced by the clustering algorithm [13]. In many applications the better criterion for assessing validity of clusters is the possibility to understand their meaning and to use them in posterior decision-making. This use to be easier when separability of classes is better (more variables appear as significant against the classes). In this work, the clustering which makes more sense from the medical point of view will be considered the best one.

3. RESULTS

In the sample, 58 patients were males (60.4%) and 38 females (39.6%). Average age was 56 years. Twenty patients had spinal cord injury (age 47.20, s= 17.6), 20 Parkinson (69.25, 6.53), 20 stroke (63.40,15.96), 16 depression (46.56,11.15) and 20 control (55.05,s=15.57)

i) Upon the classical approach, Kruskall-Wallis of *WHO-DASII* global score (GS) *versus* pathology showed significant difference ($p<0.05$). Fig. 1 displays multiple boxplot of GS *vs* pathology: GS only allows distinction between non-disable and disable patients.

ii) With classical hierarchical clustering, 4 classes emerged. However, their interpretation was confusing and physicians could neither identify their *meaning* nor explain *why* depressed patients scattered along classes with other diseases fig.2. Many of the variables were not statistically significant against classes, what is assessing difficult separability of classes, even from a structural point of view.

iii) Using *ClBR*: The additional knowledge supplied by the experts for *ClBR* regards to emotive problems, since results of method *ii)* show especially high confusion on this topic. In *ClBR*, the additional knowledge provided by experts is expressed by means of logical rules; it use to be a *partial* description of the domain (as usual for *ISD*, it is very difficult to make explicit a complete *KB* for the domain, and this is a great handicap for using pure AI methods). Thus, since patients with emotive problems are not well grouped in the previous classification, rules used in this application of *ClBR* concern the items (questions of the scale) of the *WHO-DASII* asking for *emotive behavior*, which are the following:

B4: *Rate your mental or emotional health in past 30 days?*

B9: *Worry or distress about your health in the past 30 days?*

S5: *Emotionally affected by your health condition?*

R2: *Have difficulties been caused by mental health or emotional problems?*

It is considered that people who provides values 4 or 5 to that questions should have any kind of emotive problem. So, the proposed *KB* for biasing cluster in method *iii)* is:

KB=*{r1:If B4 is in [4,5] then emotive-problems,*

r2: If B9 is in [4,5] then emotive-problems,

r3: If S5 is in [4,5] then emotive-problems,

r4: If R2 is in [4, 5] then emotive-problems}

ClBR was used with *KB* on the target sample. Rules divided the sample and clustering was done in the single *rules-induced part* (which contains 56 patients) as well as on the *extended residual class,* building a global hierarchy. Finally, a set of 7 classes was recommended by the system. Three of them contain isolated patients that have outlier behavior; they were studied individually, and the remaining 4 classes were considered for profiles proposal. Experts could associate them to 4 functional disability profiles. From a structural point of view, the number of vari-

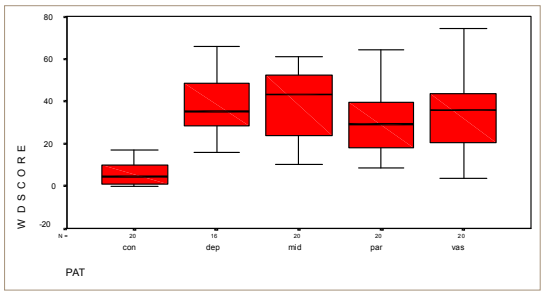

Figure 1. Multiple boxplot of WHO-DASII Score vs pathology (i).

ables statistically significant against classes is greater than in case ii). Fig. 3 shows the *class-panel graph* of some variables *versus* classes where conditional distributions can be analyzed. From the medical point of view, a clearer conceptual interpretation is now possible, looking at different variables (see [11]) and experts identified the following four profiles:

Low (Cr93): no problems self-sufficient subjects, neither physical nor mental problems (includes all control patients and a few patients without apparent functional disability).

Intermediate-I (Cd52): moderate mental and/or cognitive disability and physical disability with a low to moderate degree of disability, physical and emotional, with perception of high disability but really showing lower level (e.g. on daily work or standing up to 30 minutes).

Intermediate-II (Cr89): moderate/severe disabilities with exclusive moderate physical disability related to autonomy (difficulties on toileting and dressing), non emotive problems.

High (Cd53): higher disability degree, physical and mental.

Relationship between the discovered classes and the global score of the *WHO-DASII* was also studied and significant differences were found ($p<0.05$). Fig. 4 displays distribution of global score *versus* classes and shows increasing scores from group **Low** to **High**, according to the increasing degree of disability represented by the four groups. Moreover, fig. 4 shows that depressed patients (which are supposed to have emotive problems, and referred by the rules), are captured all of them by the *KB*, but divided into two main subgroups by the clustering. Such a subdivision corresponds to understandable criteria: Cd53 has greater physical and mental problems (learning new computes, participating in community, concentrating, working) compared with Cd52, and also patients in Cd53 feel that difficulties (including those of toileting and dressing) affect much more to their life; on the contrary, Cd52 cannot stand up, while Cd53 can do; Cd52 have no difficulties on interacting with other people and daily activities, while Cd53 have high difficulties on these topics. Even with this subdivision, the final classes fit on the semantic constraints expressed in *KB* (not to scatter patients with emotive problems along all the classes without criteria).

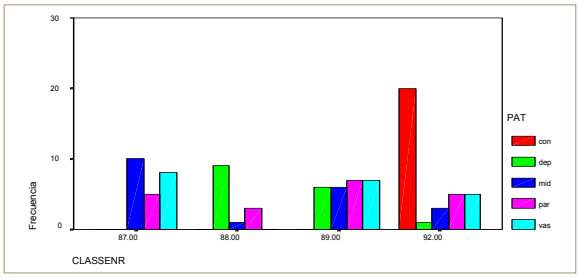

Figure 2. Pathology versus classes with classical clustering (ii).

The proposed profiles really face disabilities *from a functional point of view*. Furthermore it was seen that the proposed profiles are not directly associated with underlying pathology (fig. 5).

4. DISCUSSION

As said before, the study is mainly focused on identifying different kinds of responses to the *WHO-DASII* as well as to characterize the groups of respondents of any kind.

The analysis of the data under method *i)* only allows a trivial distinction between able and disable patients (Fig. 1), missing the whole potential of the *WHO-DASII*, which in fact provides lots of information that, for sure, can sensibly enrich the analysis. Facing such a complicated phenomenon as disability, concerned with a lack of clear definition and

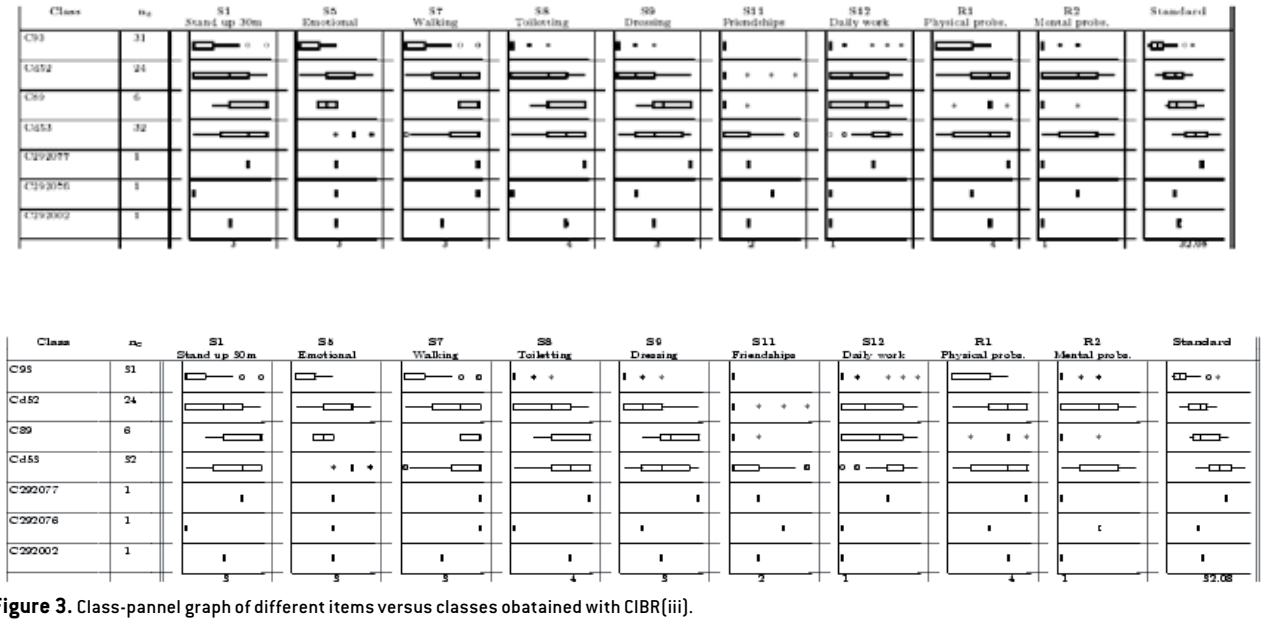

Figure 3. Class-pannel graph of different items versus classes obatained with CIBR(iii).

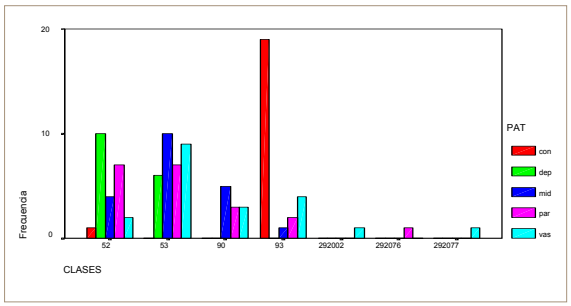

Figure 4. Pathology versus classes with CIBR

pannel graph proposed in [12], which provides a compact view of the conditional distributions of the responses to each item through the classes. From the medical point of view, the composition of the classes is, in case iii), difficulties for establishing different levels, requires indeed a *multivariate approach* that takes into account all the items of the test.

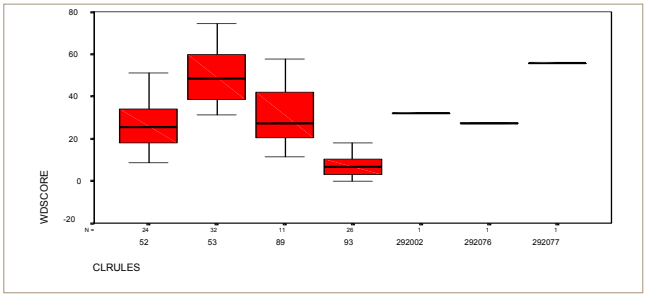

Figure 5. Multiple boxplot of GS vs classes of CIBR.

Clustering techniques are the appropriate for detecting groups of using the responses to the individual items of *WHO-DASII*. First, an standard clustering method *(ii)* was used with the parameters declared in section Methods. It has been seen that experts were no able to *understand* the underlying clustering criteria (Fig. 2). Although theoretical properties of the solution could be clearly established, meaningless classes are completely useless in real applications, and something more has to be explored. Actually, patients with disabilities can be considered an *ISD*, as stated in [9] and clustering use to be unable to capture the complex structure of *ISD* by itself.

So it was decided to use a more suitable approach (iii) *ClBR*. None of the classical statistical methods [23, 24] supports expert knowledge influencing the analysis. *ClBR* is a hybrid technique which sensibly improved results, with respect to method *ii)* [11], by integrating clinical knowledge inside the analysis, which produces classes with proper interpretation. In fact, the methodology is designed in such a way that expert constraints are satisfied by the proposed classes.

Separability of classes was measured by statistical tests of variables against classes. Several tools were used to assist the interpretation of final classes. Among them the *class-*well corresponding with different types of functional disability.

Results of *ClBR*, summarized in previous section, enabled identification of four disability profiles. It represents a new taxonomy that contributes to improve the knowledge about disability. It is important to remark here than the proposed profiles really face disabilities *from a functional point of view* (fig. 5) and the role of the pathology is not so determinant on the profile identification as initially expected. This makes clear sense from the geriatric approach which considers the patient as a whole, focusing on his functional improvement rather than on the medical aspect.

It can be said that assessment scales interpreted under a multivariate approach (that is taking into account the individual items of the scale, besides the total score) are a rich source of information. Also, an appropriate analysis is a basic condition to obtain good results. *ClBR* clearly improved the usefulness of the results, providing 4 profiles associated with increasing global scores of *WHO-DASII*. From the analysis it became even possible to distinguish between intermediate degrees of disability, which are qualitatively different.

This work is relevant because it constitutes a first step towards the establishment of standardized rehabilitation protocols for disabled patients. In a recent review Wells et al. [23] maintain that rehabilitation in the elderly will be an increasingly important part of health care provision for the frail older population in the coming years. Because of the high utilization of health care resources by older persons, more appropriate use of rehabilitation resources could have important cost implications. Finally they recommend that older patients be screened for inpatient rehabilitation potential and that standardized assessment tools be used to aid in diagnosis, assessment, and outcome measurement. The need to apply evidence-based assessment criteria to the field of disability and rehabilitation is clear [2]. One of the easiest ways of defining standardized treatment protocols if to previously identify standardized and distinct groups of homogeneous patients, to be treated with the same protocol and after that to design a standard protocol to any group. Identification of disability profiles are a first contribution to this long term goal. For this purpose, it is also important to develop an instrument that permits quick and easy identification of the patient profile for quick assignment of initial treatment as well as easy follow up of the patient response to the treatment. The research of such an instrument related to the proposed profiles is in progress.

And it should help clinicians to evaluate patient's potential for rehabilitation at an early stage, thus helping in making decisions about the most efficient use of services, as well as facilitating effective treatment strategies.

5. CONCLUSIONS AND FUTURE WORK

Multivariate analysis of *WHO-DASII* items produces a much more rich results than using only the global score. In this application, the use of *ClBR* produces meaningful classes and sensibly improves, from a semantics point of view, the results of classical clustering, according to our opinion that *hybrid* techniques that combine AI and Statistics are more powerful for *Knowledge Discovery* than pure ones, even in Disability.

Even representing partial knowl-

edge on *functional disability* (*FD)*, the rules proposed by experts selected all the depressed patients (which are supposed to have emotional problems). Although final hierarchy suggests a split of selected patients in two classes, underlying criteria for splitting is meaningful.

A taxonomy of four groups of *FD* is proposed; groups are associated with increasing *WHO-DASII* global score. On the basis of main characteristics of every group, it was seen that groups indeed refer to 4 *different profiles* of *FD*, which can be ordered according to increasing disability gravity, making even possible distinction between intermediate degrees, which are qualitatively different. The profiles are not pathology dependent, according to geriatric approach.

There is no a group with high cognitive and no physical disability, probably depending on the apraxia (impossibility of performing coordinate and finalized tasks) strongly related to severe degrees of cognitive impairment. There may be some kind of correlation between the gravity of the disability and the depression; this is being studied at present. Relationship with *FIM* and *SF-36* is also in progress.

Response of level 5 (extreme difficulty) to the *WHO-DASII* items puts together people with great difficulties in doing something and people absolutely disabled for that; this introduces some kind of ambiguity in the data that may disturb some results. In the future, it should be convenient to consider this ambiguity.

According to Wells [23], once the profiles are well identified, it would be interesting to define standardized rehabilitation protocols to every profile.

A new graphical tool to provide a quick assignment of a new patient to one of the proposed profiles is at present in progress. This will provide an easy framework to evaluate the improvement of the patients along the therapy and to evaluate the effectiveness of the stardard therapy associated to every profile itself.

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Corresponding author: Karina Gibert, PhD. Department of Statistics and Operation Research, UPC. C. Pau Gargallo 5. 08028 Barcelona, SPAIN. E-mail:karina.gibert@upc.edu.