Decision support for teletraining of COPD patients

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Abstract — **Supervised physical training has been shown to promote rehabilitation of patients affected by chronic obstructive pulmonary disease (COPD). Currently, due to limited resources, not all COPD patients can be trained by an expert supervisor. The objective of our research is to construct a clinical decision support system (DSS) which observes and controls physical ergometer training sessions of COPD patients. A systematic literature review and expert interviews were carried out to build up the knowledge base for the DSS. Nine production rules were established and standardized by Drools and Arden Syntax. The developed software autonomously controls training sessions on a bicycle ergometer. Thus it offers a new way for the rehabilitation of COPD patients. Tests in a laboratory environment have confirmed its correct function, but the effects of its use for COPD patients' rehabilitation and their quality of life have to be investigated in a further study.**

Index Terms — COPD, decision support, web service, JBoss Drools, Arden Syntax, training control

I. INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is a research focus in medicine. In recent years, new relevant works for essential aspects of the disease (diagnosis, medication and non-medication therapy, management of exacerbations, operational procedures) have been published [1]. There are mainly two reasons. First: The large number of patients and the high mortality. The global prevalence of COPD is estimated to be 8.5% among the population aged over 40 [2]. COPD is the sixth leading cause of death and the fifth leading cause of disability worldwide [3]. Second: The enormous socioeconomic importance of COPD. In several studies, the annual costs of COPD have been calculated: in the United States the annual cost of COPD in 2002 is estimated to be $32.1 billion [4], in Germany to be €5.93 billion in 2000 [5], and in Japan to be ¥805.5 billion (US$6.8 billion) [6].

COPD can't be fully cured according to current medical standards. Medication therapy can only reduce the symptoms. Therefore, a concurrent training therapy appears to be very important [7]. Long-term physical training improves strength and endurance, relieves dyspnea, reduces the fear of dyspnea and increases the quality of life [8]. Ergometer training is one of the traditional training methods for COPD patients [9]. A supervision during ergometer training of COPD patients is preferable, because it makes training more effective [10]. But due to limited resources, not all COPD patients can be trained by an expert supervisor, especially because frequent sessions (3 to 5 times per week) are indicated [11]. With the development of information and communication technology, decision support systems (DSS) are widely researched in health care. A knowledge-based DSS may autonomously supervise and control physical training of COPD patients.

Teletraining is defined as: "enabling the person to train at his preferred time and at his preferred place, thereby supervised adequately on distance by a care provider" [12]. The effect of teletraining of COPD patients should preferably have the same quality as the traditional training method (face to face feedback). In order to achieve this goal, telemonitoring and a DSS may be utilized. Telemonitoring is defined in [12]: "guarding the health condition of a subject by measuring and interpreting vital biosignals without interfering of the subject's activities of daily living but assure assistance and react when required". Telemonitoring and teletraining, which are indispensible parts of pervasive health [13, 14], enable COPD patients to exercise at home under supervision. Training intensity and mode are very important factors in telemonitoring and teletraining of COPD patients, because they are directly related to patients' safety and training effectiveness.

II. OBJECTIVES

The aims of our research for this paper are to

1) establish and standardize a knowledge base for physical training of COPD patients,

2) develop a software including a DSS which can remotely supervise and partly control the training of COPD patients autonomously.

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III. METHODS

A. Knowledge acquisition

Production rules are used as a means for knowledge representation in our DSS. A systematic literature search and expert interviews were carried out to acquire relevant rules.

1) Literature review

Three literature databases have been used in this phase to extract rules. These are: PUBMED/ MEDLINE, BISP (Federal Institute for Sports Science, Germany) [15] and IEEE Xplore. The search was peformed from March 30th to April 6th, 2008. The keywords used and returned numbers of hits are listed in Table I. It shows that there are many articles about training of COPD patients, but very few contain training rules. The hits were screened for subject and language, and abstracts were selected on the basis of a protocol that included exercise types, supervision parameters, and existence of a control group. Review articles on physical exercise and COPD were analyzed, and reference lists of selected articles were screened for relevant studies. Despite the magnitude of scientific literature, we found only two rules during this phase.

TABLE I
RETURNS FROM THE DATABASES

ID	key words	hits		
		PUBMED	*BISP*	*IEEE*
1	COPD	32703	44	42
2	Training COPD	1351	0	0
3	Exercise COPD	2738	0	0
4	Training COPD rules	1	0	0
5	Exercise COPD rules	1	0	0
6	Training COPD recommendations	44	0	0
7	Exercise COPD recommendations	31	0	0
8	Training COPD guideline	84	0	0
9	Exercise COPD guideline	50	0	0
10	Expert system training COPD	2	0	0
11	Decision aid training COPD	14	0	0
12	Decision support training COPD	14	0	0

2) Expert interviews

An expert with many years of experience in training COPD patients (co-author UT, director of Institute for Sports Medicine at the Medical School Hanover), was interviewed twice to identify training planning and control rules. The interviews took place at two sessions on April 29th and May 05th, 2008. The following are main statements:

- Training should be planned by using parameters gained in a level test and an endurance test (see section C).
- COPD patients should perform a 20-30 minute training every two days.
- Constant load is the most important factor during a training session.
- Training intensity can be assessed by measuring heart rate (HR).
- During the training, the oxygen saturation (SO_2) of COPD patients should not be less than 90%. HR, blood pressure (BP) and lactate levels should not rise continuously.

The expert interviews were focused on obtaining rules. In this phase, we found seven rules.

B. Knowledge standardization

We use the Drools rule language to standardize the acquired rules [16]. A standardized rule contains a rule name, rule attributes, a left hand side and a right hand side. The rule name and rule attributes are optional. The left hand side is the conditional part of the rule, which follows a fixed syntax. The right hand side is basically a block that allows dialect-specific semantic code to be executed. In Drools, a standardized rule has a simple structure, e.g.:

```
rule "check SO2"
    salience 2
    when
            m : Message( SO2 < 90 )
    then
            m.reduceWatt();
end
```

Drools use the Rete algorithm for rule matching [17]. This algorithm reorganizes all of the rules in a Rete net during the parsing phase. It can efficiently match the rules that have complex relationships. In addition, this algorithm can visualize rules through Rete nodes and their associations. This facilitates rule sharing and verification.

To facilitate knowledge sharing among health care providers, we also use the Arden Syntax for Medical Logic Modules [18], which is a part of the Health Level Seven (HL7) [19] standards since 1998, to standardize the rules. With Arden Syntax, a rule should be encoded into a Medical Logic Module (MLM). Thus, the above rule can be standardized in an MLM like this:

```
maintenance:
   title: MLM for test purposes;;
   mlmname: check SO2;;
   arden: Version 2.5;;
   version: 1.00;;
   institution: PLRI;;
   author: BS;;
   specialist: BS;;
   date: 2008-08-20;;
   validation: testing;;
library:
   purpose: test;;
```

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```
    explanation: simple test MLM;;
    keywords:;;
    citations:;;
    links:;;
  knowledge:
    type: data_driven;;
    data: (times, so2, performance, type) :=
          argument;
    ;;
    priority:;;
    evoke:;;
    logic:
    if so2 < 90 then
       performance := performance*0.85;
       conclude true;
    endif;
    ;;
    action:
    return performance;
    ;;
    urgency:;;
  end:
```

The advantages and disadvantages of the two standardization methods are discussed later.

C. Defining the training schedule

Due to the individual physical fitness of COPD patients, level test and endurance test are used for defining a personal training plan. Training duration is set to 20 minutes. The training intensity performance is increased from 50% to 100% of the target performance intensity in the initial phase (the first two minutes) and reduced accordingly in the final phase (the last minute). In the remaining 17 minutes the COPD patients perform their training with the target performance.

1) Level test

A COPD patient begins the level test on an ergometer with a low initial performance (e.g. 5 watts). The performance is increased by 5 or 10 watts every minute until the patient is properly exhausted and can no longer exercise. The data of performance, HR and time are recorded during the test. The HR which corresponds to the maximum performance is the personal maximum HR. The following different training intensities are defined based on the personal maximum HR according to [20].

A-intensity: 65-72% of maximum HR
B-intensity: 72-80% of maximum HR
C-intensity: 80-86% of maximum HR
D-intensity: 86-97% of maximum HR

Please note that these recommendations are originally intended for patients who are affected by coronary artery disease (CAD). They still have to be validated for COPD patients.

Training intensity is assessed by measuring HR. Using the set of performance-HR-time data, training intensity can also be assessed by performance.

2) Endurance test

Target performance is identified by using endurance test. At first, C-intensity is employed for a COPD patient. During an endurance test, the patient performs 20 minutes training with a performance which corresponds to 80% of the maximum HR. If the patients' HR is below 86% of the maximum HR, training performance is suitable as the target performance. If not, a lower intensity is recommended.

D. System implementation

We used a three-tier client server architecture for the software implementation (Figure 1). A plug-in for the open source software "Media Portal" was used as GUI [21]. The open source software JBoss Drools was used as the foundation of our DSS [16]. JBoss Drools is a business rule management system. It contains its own complete language, editor and compiler. The GUI and the DSS are connected by a web service.

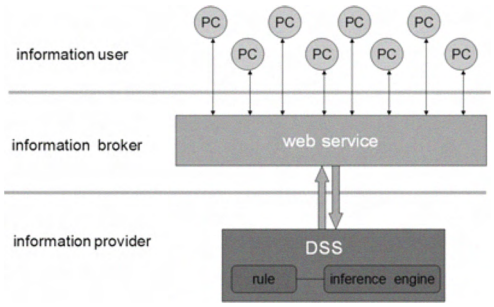

Figure 1. Three-tier client server architecture in CAT

IV. RESULTS

A. Knowledge base

HR, BP and SO_2 have been chosen as parameters for the supervision of COPD patients. HR and SO_2 are measured every minute, BP every three minutes. Through the literature review and the expert interviews, a list of rules for controlling the training of COPD patients has been identified. The rules used in our DSS are listed in Table II.

B. The software CAT

We developed a software called "COPD patients' assistant for physical training" (CAT) including a DSS. CAT autonomously controls the training on a bicycle ergometer according to the patient's physical status. CAT has a server program that contains the DSS and a client program. The server program is responsible for the regulation of the training intensity, fault-tolerance and writing protocol. If the server program receives an error value from the sensors, this error value is dropped and the previous correct value is used as the current value. All correctly measured values and all of the

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fired rules are recorded into a CSV file for tracking the training. The client programm interacts with the SO_2 sensor (Nonin Avant 4000), HR sensor (Corscience BT 12), ergometer (Daum Electronic ergo_bike premium8) and the GUI. Web services enable teletraining of COPD patients.

TABLE II
KNOWLEDGE BASE IN THE DSS

ID	rules
1	If: SO2 < 90% Then: reduce performance by 15%
2	If: SO2 < 80% Then: stop training
3	If: HR > maximum HR Then: stop training
4	If: HR increase > 5 beats in the last 5 minutes Then: reduce performance by 15% (This rule should be checked from the 4th minutes)
5	If: HR > coefficient * maximum HR Then: reduce performance by 15% (coefficient = 72% for A-Intensity, coefficient = 80% for B-Intensity, coefficient = 86% for C-Intensity)
6	If: Systolic BP > 220 mmHg or Diastolic BP > 180 mmHg Then: stop training
7	If: Systolic BP increase > 5mmHg in the last 3 measurements Then: reduce performance by 15% (This rule should be checked from the 2nd measurement)
8	If: Systolic BP > 180 mmHg Then: reduce performance by 15%
9	If: HR < 65% of the maximum HR Then: increase performance by 10% (This rule should be checked from the 8th minutes)

CAT's architecture is demonstrated using the three-layer graph-based meta model (Figure 2) [22]. This meta model has been chosen because it is widely used in the domain of health information system architecture design.

The task "training control" and the object "training information" are shown at the domain layer. The task interprets and edits the object. The application components "DSS", "CAT GUI" and "web service" are shown at the logical tool layer. The "DSS" communicates with "CAT GUI" by the "web service". The association between the domain layer and the logical tool layer shows that the task "training control" is supported by the application component "DSS". The physical components "server", "net", "client", "sensor" and "ergometer" are shown at the physical tool layer. The associations between the logical tool layer and the physical tool layer show which components are realized by which tools.

C. Online test

To test the functionality of the software including the DSS, an online test with a healthy volunteer (maximum HR: 191 beats per minute, suitable training intensity: C, target performance: 140 watts) was carried out (Figure 3). In this test, HR and SO_2 were measured by sensors. BP was set with fixed values (120/80 mmHg), because our sphygmomanometer cannot continuously measure BP.

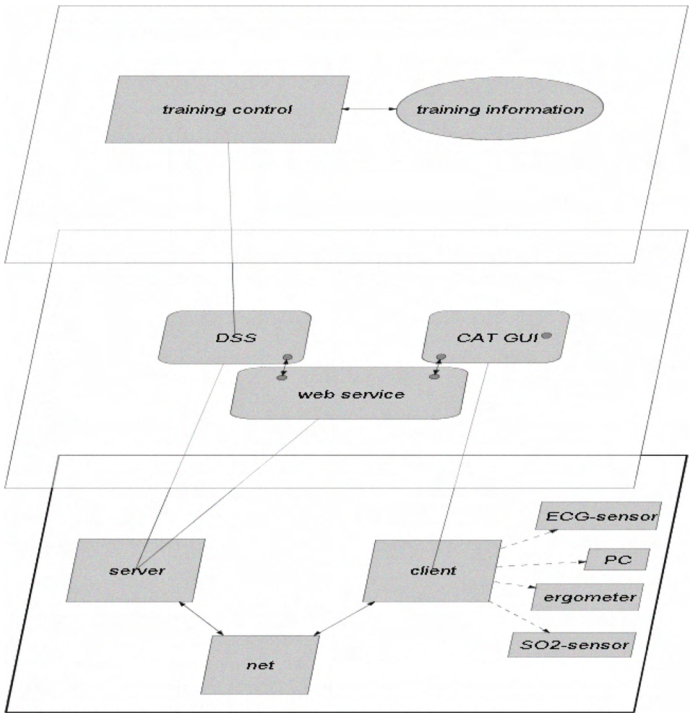

Figure 2. The three-layer graph-based meta model of CAT (On top is the domain layer, in the middle is the application tool layer, the bottom is the physical tool layer)

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Figure 3. Online test (The volunteer and the ergometer are on the left side, the GUI is shown on a digital TV set, sensors are on the body of the volunteer.)

The training performance was 70 watts in the initial phase (the first two minutes). The performance was 140 watts from the 3rd minute to the 7th minute. The performance was reduced by 15% in the 7th minute, because the HR reached the upper threshold (164 beats per minute). The performance was increased by 10% in the 9th minute, because the HR reached the lower threshold (124 beats per minute). The training had to be stopped in the 10th minute, because the HR was beyond the maximum HR (191 beats per minute). Please note that this heart rate excess was provoked intentionally in order to test the system. Three rules were fired during this online test. A complete training protocol can be found in Table III.

TABLE III
TRAINING PROTOCOL (UNDERLINED SENTENCES DEMOTE THE FIRING RULES)

New exercise begin at 2008/07/03 17:48:19									
ID	**HR**	**SO_2**	**SB**	**DB**	**P**	**RH**	**RB**	**MH**	**T**
1	**82**	98	120	80	**70**	-	120	191	3
2	**82**	98	120	80	**70**	-	120	191	3
3	**130**	98	120	80	**140**	-	120	191	3
4	**125**	98	120	80	**140**	-	120	191	3
5	**92**	97	120	80	**140**	-	120	191	3
6	**91**	98	120	80	**140**	82	120	191	3
7	**178**	98	120	80	**140**	82	120	191	3
The performance was reduced by 15%. (HR reached the upper-threshold)									
8	**140**	98	120	80	**119**	130	120	191	3
9	**122**	98	120	80	**119**	125	120	191	3
The performance was increased by 10%. (HR reached the lower-threshold)									
10	**207**	98	120	80	**131**	92	120	191	3
The exercise had to be stopped. (HR reached the stop-threshold, intentionally provoked heart rate excess to test the system)									
11	**-**	**-**	**-**	**-**	**0**	**-**	**-**	**-**	**-**

SB: systolic blood pressure. DB: diastolic blood pressure. P: performance. RH: reference heart rate. RB: reference systolic blood pressure. MH: maximum heart rate. T: type.

V. DISCUSSION

A. Rule based training control

The COPD patients perform physical training using the prepared training plan. During the training, sensors measure vital parameters. Based on the measured data, a standardized rule base is used to control training performance. This mechanism may make the training of COPD patients safer and more efficient.

Level test and endurance test are used to create the personal training plan. Compared with other, more general methods such as the formula proposed in [23], our test-based method is more complex but more accurate, because the individual physical fitness is fully taken into account. The two tests should be made on two different days, so that they do not interfere with each other.

To supervise the physical status of COPD patients, HR, SO_2 and BP are used as parameters. Other parameters such as breath rate are reported for pre-training and post-training measurement in literature [10]. Breath rate could also be used as a supervision parameter during training. More research should be done in this area. In addition, lactate can also be used as a supervision parameter, at present, there is no lactate meter available, which is non-invasive and measures continually.

We use nine rules to control the training of COPD patients. Three rules abort the training when the patients are in danger. Five rules reduce the training performance by 15% if the patient is overloading. One rule increases training performance by 10% if the patient is light loading. The thresholds used in these rules are, for security reasons, "conservative" values. With these nine rules, training of COPD patients can be controlled by DSS at home, but this knowledge base still needs to be validated by different independent experts, because seven of our nine rules come from one expert. In addition, our knowledge base needs further refinement. On the one hand, it may be expanded by using other supervision parameters e.g. breath rate; on the other hand, the expansion can be achieved through the refinement of existing rules.

The rules are standardized using the Drools rule language and the Arden Syntax for Medical Logic Modules. Using Drools to standardize the rules has three advantages: firstly, the standardized rule has a simple structure and does not have redundant information. Secondly, Drools has a complete development environment including a rule editor and a rule compiler. Thirdly, the Drools compiler uses the Rete algorithm to speed up rule matching. But Drools is a business rule management system. The rules, which are encoded by Drools may not be accepted by a health provider. MLMs, in turn, have two advantages: firstly, the Arden Syntax is a part of the HL7 standard family. Secondly, it is well known by many healthcare providers. However, so far there is no standardized Arden compiler and Arden editor available. In addition, due to an issue known as the "curly braces" problem for MLM [24], it is hard to deploy and transfer a DSS including MLMs.

B. The architecture of CAT

A three-tier client server architecture is used in the software CAT for supporting teletraining. The

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broker layer web service communicates with the client layer and the server layer. Web services are very suitable for home care software, because they use HTTP and thus can pass through a variety of firewalls. But poor security is its disadvantage. Web services use non-encrypted XML as communication messages. These messages cannot protect the patient's privacy. WS-security is a method to improve the safety of CAT.

C. Limitations and future work

There are some limitations that have to be mentioned with regard to our results:

1) Knowledge base

Simple production rules are used in our knowledge base. The thresholds used in the rules can roughly control the physical training of COPD patients. But these rules are not adaptive for individual COPD patients. Fuzzy rules with an adaptive threshold might work better for the individual controlling.

For COPD patients who have extreme values for vital sign parameters already when resting, e.g. a low blood oxygen saturation ($SO_2 < 90\%$) or a high BP (systolic BP > 180 mmHg), our fixed rules may not be appropriate to control a training session as they would continuously reduce performance. For safety reasons, these patients should be monitored by a physician.

2) Evaluation

The correct functions of the software CAT including the DSS have been confirmed in laboratory environment tests. But the effects of its use for COPD patients' rehabilitation and their quality of life must be evaluated in a sound study. If CAT shows medical benefits, it should be integrated as part of a sensor-enhanced health information system and put into use [25, 26].

VI. CONCLUSION

Our knowledge base and prototype implementtation demonstrate the feasibility of telemedical decision support for physical training of COPD patients. The use of a standardized representation of the knowledge base, Drools, facilitates knowledge sharing and visualization. Our future work will focus on the evaluation of the software including the knowledge base.

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