Decision Making Concepts for the Remote, Personalized Evaluation of COPD Patients' Health Status

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Summary

Introduction: This article is part of the Focus Theme of *Methods of Information in Medicine* on "Biosignal Interpretation: Advanced Methods for Neural Signals and Images".

Objectives: This paper presents the main concepts of a decision making approach for the remote management of COPD patients based on the early detection of disease exacerbation episodes.

Methods: An e-diary card is defined to evaluate a number of physiological variables and clinical parameters acquired remotely by means of wearable and environmental sensors deployed in patients' long-stay settings. The automatic evaluation of the card results in a so-called *Chronic Status Index* (CSI) whose computation is tailored to patients' specific manifestation of the disease (i.e., patient's *phenotype*). The decision support method relies on a parameterized analysis of CSI variations so as to early detect worsening changes, identify exacerbation severity and track the patterns of recovery.

Results: A preliminary study, carried out in real settings with 30 COPD patients monitored at home, has shown the validity and sensitivity of the method proposed, which was effectively able to timely and correctly identify patients' critical situation.

Conclusion: The preliminary results showed that the proposed e-diary card, which presents several novel features with respect to other solutions presented in the literature, can be practically used to remotely monitor COPD patients.

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1. Introduction

Dedicated health programmes are more and more being studied to monitor remotely Chronic Obstructive Pulmonary Disease (COPD) patients, so as to provide a long-term care option able to reduce disease's impairment and exacerbation episodes. Recent trials have demonstrated the real advantages of patients' telemonitoring based on teleassistance via phone calls of qualified nurses [1, 2]. In the most advanced settings, patient's monitoring relies on the deployment of a dedicated sensorized infrastructure to continuously acquire key health indicators about patients' conditions. In these settings, there is the strong demand for intelligent applications able to support clinical professionals to analyze and correlate the multi-parametric sensed data. Being this an emerging clinical problem, some attempts to tackle the automatic interpretation of telemonitoring data have been so far reported in the literature with different levels of automation [3, 4], as discussed in more detail in the next section.

This paper presents a decision making approach (developed within the EU FP7 funded project CHRONIOUS), which is able to assess COPD patients' health status by interpreting physiological variables acquired remotely. The approach is based on the definition of an *e-diary card*, i.e., a list of items corresponding to a quantification of patients' signs and symptoms. These are obtained at patient's home remotely, on a periodical basis, either by the patients themselves or by their relatives or automatically acquired by some sensor devices and transmitted to a clinical centre. The e-diary card here presented is defined to assess patients' clinical signs, their degree of disability, their real behaviour and activity, and contextual environmental conditions. The automatic evaluation of the card results in a so-called *Chronic Status Index* (CSI), whose computation is tailored to patients' specific manifestation of the disease. A parameterized analysis of the CSI value and its variations permits to early detect worsening changes in patients' clinical conditions, identify exacerbation severity and track the patterns of recovery.

2. Related Works

COPD is among the most serious and disabling pathologies that affect the middle-aged and elderly population in the industrialized countries [5]. COPD cannot be fully cured according to current medical standards and patients' conditions progressively deteriorate due to the occurrence of exacerbation events, which are periodic acute events that worsen symptoms and lung function. Acute exacerbations cause a

decline in patients' health status and may increase health system expenditures due to patients' hospitalization. An important research line has focused on symptom definition and characterization of these exacerbation events [6, 7]. In this frame, diary cards filled in by patients have been defined as direct measures of the signs or symptoms of exacerbation to provide researchers with means to assess frequency, severity, and duration of exacerbations. To date, diary cards have varied in content (i.e., different number of items, usually corresponding to self-evaluated symptoms, no measured signs) and scoring (i.e., ratings of symptoms or improving/worsening patterns) [2, 8–10].

In recent years, the goal of improving COPD quality of life and reduce medical care costs has fuelled the development of remote disease management programmes to early detect exacerbation events. Indeed, the quest for telehealth/telemedicine/ehealth solutions dates back to the first attempts in 1990s (for systematic reviews, please refer to [1] and [11]). The applications presented over the last decades are generally characterized by different level of automation of patients' telemonitoring. Indeed, early solutions mainly relied on telecommunication of data (e.g., pulse-oximetry data sent via phone [12]) or via teleconferences between nurses and physicians [13] or patients and clinical stakeholders [2]. Recently, technological advances and the diffusion of mobile technologies have promoted the development of more sophisticated monitoring infrastructures and higher level of automation in data interpretation. The solutions presented differ in relation to

- *the type of physiological data collected:* many works consider the main signs and symptoms (e.g., sputum, sputum colour, dyspnoea, …) self-evaluated by the patients and reported as answers to validated or ad hoc questionnaire [14 –16]; while other studies comprise also the deployment of some sensors, such as a pulse-oximeter, a spirometer [17] or ad hoc monitor devices [4];
- *the level of automation of data collection*: the self-evaluated and measured parameters can be either reported manually by the patients [14–16] or automatically collected by a monitoring device, either a smart phone [17] or ad-hoc devices [4], and transmitted to a central processing unit, usually deployed in a clinical structure;
- *the monitoring task faced*: in some cases, the data remotely collected are used to support the general care of COPD patients [4, 14, 16], while, in others, to face specific tasks, such as teletraining [18] or the detection of exacerbation events [17];
- *the level of automation of data interpretation*: in some cases, the data are just recorded on the clinical side to be shown to physicians who assess disease progresses [16]. In the most advanced settings, automatic methods interpret the data collected and provide suggestions [4, 17, 18].

In this work, we merged the diary card approach with the most advanced telemonitoring settings, defining an *e-diary* card: the items considered comprise self-evaluated symptoms, reported as answers to questionnaires, plus parameters measured with personal sensors. A dedicated sensing infrastructure was deployed to this aim, as discussed in the next section, to include also contextual environmental information as well as data on patients' quality of life. Data are automatically transmitted to a clinical centre, where they are automatically evaluated to track disease evolution, detect patients' early signs of exacerbation onset and promptly alert clinicians. Additional innovative features were given to the e-diary card: i) the personalization of its evaluation, i.e., based on patients' phenotype, and ii) the typology of employment, i.e., not only for the detection of patients' exacerbation but also for tracking the recovery patterns.

The card definition has required a strict cooperation among biomedical engineers, computer scientists and physicians with specific experience in telemedicine programmes for COPD telehealth.

3. Methods

To monitor COPD patients in their long-stay settings, a smart and complex platform was conceived, based on multi-parametric sensor data processing and fusion[a]. The platform includes a sensing infrastructure composed by:

- a sensorized vest able to measure electrocardiographic and respiratory activities; arterial oxygen saturation; skin temperature; cough and snoring; motion activity and falls;
- Bluetooth devices able to measure body weight, blood pressure and blood glucose;
- an environmental device installed in patients' living room for acquiring information about ambient light, and the presence of carbon monoxide, volatile organic compound and air particle;
- a touch-screen workstation for collecting patients' answers to questionnaires about their lifestyle, food and drug intake, and psychological conditions.

According to an agreed data acquisition schedule, the patient is reminded to perform measurements and, then, wears the vest, takes measures with the wireless sensors and answers the questionnaire on the touch-screen. Environmental data are acquired automatically in concurrence, on a regular basis. Signals collected by the vest are locally processed by a data acquisition system based on a microcontroller, called *data handler*, connected to the vest, which extracts some summary parameters. These are then automatically transmitted to the *data collector* on the touch-screen workstation[b], which receives via Bluetooth all the data and moves them to the clinical centre via Internet. Data transfer is accomplished via a home ADSL connection through a two-way authenticated web service. At the clinical centre, data are mapped on the e-diary card items and used to compute the CSI according to a *scoring* pattern. The idea behind the definition of the CSI is to use a single measure to detect potential COPD exacerbations. Indeed, a single value, when

a Please refer to [19] for additional details
b Originally, the sensing infrastructure included a PDA to collect the sensed data and transmit them to the central server. This solution has been updated during the first experimentation phase to improve the usability of the system from the patients' point of view.

Table 1 The table reports all the items included in the e-diary card, specifying for each of them the scoring pattern, the frequency rate of acquisition, the reference supporting the importance (CLIN stands for "suggested by the expert clinicians involved in the study"), and the source: i.e., Q = Questionnaire;

CHRONIOUS COPD CARD SCORES	0	1	2
Dyspnoea	Under strong activity	Speed walk or climb	Moderate activity with stops
Cough	Spontaneous and strong	Weak, not productive	Strong but extremely productive
Sputum	No need for sputum	Moderate	Copious
Sputum Colour	No sputum	White	Yellow
Wheeze	Never	Occasional	Under strong efforts
Neurological Status	Normal, wakeful	Slow but answering	Confused, diurnal drowsiness
Ventilator Interaction	No troubles or no ventilator	Occasional alarms on ventilator	Alarms and need for suction, or mask discomfort
Walk	Autonomous	Walk with stops, no dispnoea	Walk with stick and dyspnoea
Body temperature (T)	Normal	>37°C and <37.5°C without antipiretic	>37°C and < 38°C with antipiretic
Weight	Stable weight, no ankle oedema	Increase of < 2 Kg in 2 days	2– 4 Kg in 2 days
Heart Rate (HR)	<90 BPM	90 –100 BPM	100 –110 BPM
ECG	regular	extrasystols	atrial fibrillations
Arterial Pressure (systolic)	120	120 –140	140–160
Arterial Pressure (diastolic)	70	70–90	90–100
SpO_2	>92% with room air and O_2	91% with air and 90–92% with O_2	<90% with room air
Respiratory Frequency (f)	<14	14–16	16–20
Inspiratory Time (Ti)	1.6–1.8	< 1.6 > 1.20	< 1.2 > 1.0
Expiratory Time (Te)	3.0–3.4	< 3 > 2.5	< 2.5 > 2.0
Respiration Asinchrony (LBI mean value in the last 30mins)	1.0	1.2	1.4
(Resp. Freq.)/(tidal volume) = f/Vt	<80	80–95	95–110
Minute Ventilation (Ve)	<12 > 10	< 10	< 8
Patient Activity (steps num. per day)	> 2000	< 2000 > 1800	< 1800 > 1000
Coughs Counter (n/min)	0	<2 24–	<10 26–
Ambient Temperature	22°C	26°C	28°C
Ambient Humidity	50%	40% or 60%	30% or 70%
Patient Position (supine) h	< 8	> 8 < 10	> 10 <15
Sleep Quality (N° position changes/h)	<10	> 10 < 15	> 15 < 25
Sleep quality (questionnaire)	optimal	good	sufficient
Do you feel tired? (asthenia)	never	occasionally	after light activity
Age	<55	>55 and <60	>60 and <70
Depressive Phenotype (HAD)	never	sometimes	frequent

standardized and validated, can ease the understanding of the disease and its treatment and foster the comparison and aggregation of results across different studies [8].

3.1 e-Diary Card Definition

The definition of the card relied on four important issues: i) the definition of a patients' *phenotyping* schema to take into account different possible manifestations of the disease; ii) the selection of the relevant parameters (*items*) to be evaluated; iii) the quantization of items' values according to a scoring pattern; iv) the customization of CSI evaluation to patients' phenotype. All these issues were tackled according to a review of well-established and up-to-date literature [20, 22 –30] and to previous experience in COPD teleassistance programmes [2].

3.1.1 Patient's Phenotyping

COPD phenotyping is still an open and hot topic [20]. A phenotyping schema was defined taking into account the most valuable

WS = Wearable sensors; WD = Wireless devices; ES = Environmental sensor; CE = Clinical evaluation. The depressive phenotype is measured according to the Hospital Anxiety and Depression (HAD) scale [31].

	3	4	Time Frame	Ref.	Source
	Light activity, stop after few steps	At rest during daily activities	once a day	[2]	Q
	Weak, productive, frequent	No spontaneous cough; need for suctions	once a day	[2]	Q
	Very copious	Unbearable	once a day	[2]	Q
	Yellow/green	Green/brown or with blood	once a day	[2]	Q
	Under moderate efforts	At rest	once a day	[2]	Q
	Difficult posture and verbal answer	No answer to manual stimulus	once a day	[2]	Q
	Alarms, occasional contrasts and dyspnoea under ventilator	Ventilator break; alarms and fighting against ventilator	once a day	[2]	Q
	Assisted walk, few steps, armchair use	No deambulation, bedridden	3 times a week	[2]	Q
	>38°C with antipiretic and antibiotic for 1 day	>38°C with antibiotic for 3 days	3 times a week	[2]	WS
	2– 4 Kg in 1 day	> 4 Kg in 1 day	once a day	[2]	WD
	110–120 BPM	>120 BPM	3 times a week	[2]	WS
	atrial flutter	ventricular arrhythmia	3 times a week	[22]	WS
	140 –160	>190	3 times a week	[22]	WD
	100 –110	>110	3 times a week	[22]	WD
	<90% with O_2	<80% with O_2	3 times a week	[2]	WS
	20–25	>25	3 times a week	[23–25]	WS
	> 0.80 < 1.0	<0.80	3 times a week	[23–25]	WS
	< 2.0 > 1.60	e	3 times a week	[23–25]	WS
	1.6	1.8	3 times a week	[23–25]	WS
	110 –120	> 120	3 times a week	[23–25]	WS
	< 7	< 6	3 times a week	[23–25]	WS
	< 1000 > 500	<500	3 times a week	[26–28]	WS
	<15	>15	3 times a week	[CLIN]	WS
	28 –30°C	>30°C	once a day	[CLIN]	ES
	20% or 80%	<20% or >80%	once a day	[CLIN]	ES
	>15 <18	> 18	once a week	[CLIN]	WS
	25–30	> 30	once a week	[CLIN]	WS
	bad	very bad	once a day	[CLIN]	Q
	after heavy activity	for the most part of the day	once a day	[CLIN]	Q
	>70 and <75	>75		[CLIN]	CE
	very frequent	pathological	twice a year	[20–30]	CE

and predictive parameters for prognosis. In particular, the BODE[c] index [21] appeared a fundamental parameter to characterize patients, being it currently used to evaluate patient's life expectancy. It can assume values in the range 0 –10 and is computed on the results of tests on: i) predicted amount as a percentage of the forced expiratory lung volume in one second, ii) six-minute walking distance, iii) modified Medical Research Council dyspnoea scale; and iv) body mass index. Other variables were added to the BODE index to consider smoking habits, patient's attitude to develop exacerbations and physical activity performed regularly. The values of all the considered variables are as follows:

- BODE Index: 0–2, 3–4, 5–6, 7–10
- smoking addiction: yes, no
- exacerbations per year: two or less, more than two
- number of steps per day: more than 500 (active), less than 500 (sedentary).

a Please, visit http://www.pulmonaryrehab.com.au/pdfs/BodeIndexForCOPD.pdf for a complete definition of the BODE index

Through the professional assistance of clinical personnel with experience in telemedicine, and based on bibliography evaluation, the ranges of variables' values were defined and used in combination in order to define 32 different phenotypes: e.g., phenotype 1 corresponds to patients with BODE index 0–2, who smoke, experienced 2 or less exacerbations in the last year and are active; whilst phenotype 32 comprises patients that have BODE index 7–10, do not smoke, experienced more than two exacerbations per year and are sedentary.

3.1.2 Card Items

A professional clinical evaluation board defined a set of variables that needed to be taken into consideration for proper remote monitoring of patients. A sub-set of 31 variables were considered relevant among those parameters acquired by the sensing infrastructure and data pertaining to patients' clinical history and demographic data (Table 1). The suggestions of experts in COPD telemedicine and bibliography evaluation [2] guided the selection of these variables. Some of these variables were automatically measured, on a daily basis, by body or environmental sensors, while others were obtained through periodic questionnaires answered by patients themselves or their relatives. Table 1 reports the complete list of items, and specifies the acquisition rate and modality (i.e. source) for each of them.

3.1.3 Scoring Pattern

The continuous or qualitative values of the card items were quantized to obtain a fix number of scores. Starting from the work in [2], a five-point ordinal scale (i.e., values from 0 to 4) was defined to yield a total sum in the range 0–120, with higher values corresponding to more severe health status. Table 1 reports the scores defined for each card item.

3.1.4 CSI Tailored Evaluation

CSI computation was tailored to patients' characteristics by defining a weighting schema that ensures different importance to the card items according to patient's phenotype. More precisely, a vector of weights (one for each card item), developed through clinical experts counselling and previous findings evaluation [2], was assigned to each of the 32 phenotypes. Weight values vary in the range [0, 1], thus reducing or increasing the relevance of the different parameters considered.

The CSI is, then, computed as the weighted sum of the card item scores: considering a patient P that belongs to phenotype $<l$; the vector $\boldsymbol{\omega}^{<l}$ of weights assigned to phenotype $<l$:

$$\boldsymbol{\omega}^{<l} = [\omega_1^{<l}, \ldots, \omega_n^{<l}]$$

and the e-diary card vector $\boldsymbol{\sigma}$ of $n = 32$ scores

$$\boldsymbol{\sigma} = [\sigma_1, \ldots, \sigma_n]$$

the CSI is computed as follows:

$$CSI = \Lambda_{i=1,\ldots,n}\, \omega_i^{<l} \xi\, \sigma i \qquad (1)$$

3.1.5 Identification of Exacerbations

The decision support method relies on the analysis of the CSI trend. In particular, the detection of a potential exacerbation is carried out by comparing the current value of CSI and its *baseline* value: whenever it is detected a significant increase of the CSI, a specific alert is sent to clinicians. The baseline value is firstly computed at time zero, i.e. at patient's enrolment in the monitoring programme; then it is re-assessed each time the patient recovers a stable condition after an exacerbation. Previous experience of clinical experts and bibliography evaluation allowed us to define a parameterized schema to generically define the outcomes of the decision method. In particular, to different increases of the current value at time t of CSI (CSI_t) w.r.t. the baseline value (CSI_0) correspond an action of the decision method, an advice to be reported, and an alert colour. Increasing degrees of severity are to be individuated with increasing values of the parameter δ_i (i.e., $\delta_a < \delta_b < \delta_c$), which expresses the level of needed clinical attention as follows:

- $CSI_t \geq CSI_0 + 8_a$, action: Alert clinicians and highlight the worsened patient's parameters, alert colour: Yellow
- $CSI_t \geq CSI_0 + 8_b$, action: Alert clinicians and signal a severe situation, alert colour: Orange
- $CSI_t \geq CSI_0 + 8_c$, action: Alert clinicians and suggest patient's hospitalization, alert colour: Red.

The delta values have been introduced in the general definition of the e-diary card, with the main idea to define their values in accordance with experimental results obtained in a validation study.

4. Preliminary Study and Results

To date, there are neither clinical guidelines nor assessed clinical evidences that evaluate all the items here considered and suggest precise values for the weights and for the CSI delta values. Hence, preliminary values were defined according to direct experiences in COPD telecare of clinicians involved in the study [2], so as to assess the reliability of the proposed method.

The decision support method was implemented as a web-based application, included into a platform of services developed within the CHRONIOUS project. Such an application is able to automatically acquire the remotely sensed data, compute the CSI, and evaluate patient's health status according to the index trend.

A first usability study was carried out to verify the appropriateness and manageability of the sensor equipment. Then a preliminary study was carried out to verify the feasibility and sensitivity of the e-diary card. A group of 26 COPD patients (18M/8F) (patients were originally 30; we registered 3 dropouts due to study participation refusal, and 1 patient had almost no data due to technical problems) was recruited at two clinical sites: 16 in Firenze, at Azienda Ospedaliero-Universitaria Careggi, and 10 in Barcelona, at Hospital Clinic de Barcelona[d]. Patients were provided with the sensorized infrastructure and remotely

a The protocol of the study was approved by the local Ethical Committee of each clinical site. The patients signed an informed consent and were firstly trained to use the equipment.

monitored for a mean period of 115 ± 40 days in the period March– August.

4.1 Patients and Evaluation Method

COPD patients were selected by clinicians working in the two clinical validation sites. A patient was considered eligible for inclusion if all of the following criteria were met: Male or female, 45 ≤ age ≤ 85 years, 18 ≤ BMI ≤ 35, no deformity of the chest wall, stable status at recruitment, ex or current smokers, COPD stage III– IV, according to GOLD guidelines. Patients were excluded if met at least one of the following criteria: psychiatric disorders, other severe comorbidities with compromised life expectancy in the study period, illiteracy, refusal, or residence in a nursing home. Patients were equipped with the CHRONIOUS system and remotely monitored on a time basis depending on the acquired signals (Table 1). They were also periodically examined – every 2– 4 weeks – by clinicians, who were blind to the partial results of the e-diary card. The main goal of the preliminary study was to verify that the CSI computed by the e-diary card was sensitive enough to detect patient's worsening symptoms and that the index behaviour correctly corresponds to the trend of the disease. Patients were followed during the study, and they were offered a phone direct contact with the specialist so as to raise also their confidence to the study.

4.2 Analysis of Results

Patients characteristics were the following: age 70 ± 8 y, BMI 27 ± 5, COPD Stage 15 III, 11 IV, FEV1%pred 38 ± 10%, VC%pred 70 ± 19, FEV1/VC%pred 43 ± 11.

The study was carried out to compare the values of the CSI with the periodic evaluation of clinicians who visited the patients at home. At each visit, the clinician on duty filled in an evaluation form comprising the results of the COPD Assessment Test™ (CAT)[e] questionnaire plus other measured parameters (FEV1, FEV1%, VC, VC%, FEV1/VC%). The clinician also summarized patient's status with a classification score, stating if the patient was stable (score 1), had a mild exacerbation (score 2), had a moderate-severe exacerbation (score 3), or had an extremely severe exacerbation (score 4).

In most of the cases, the patients were stable and did not show any significant

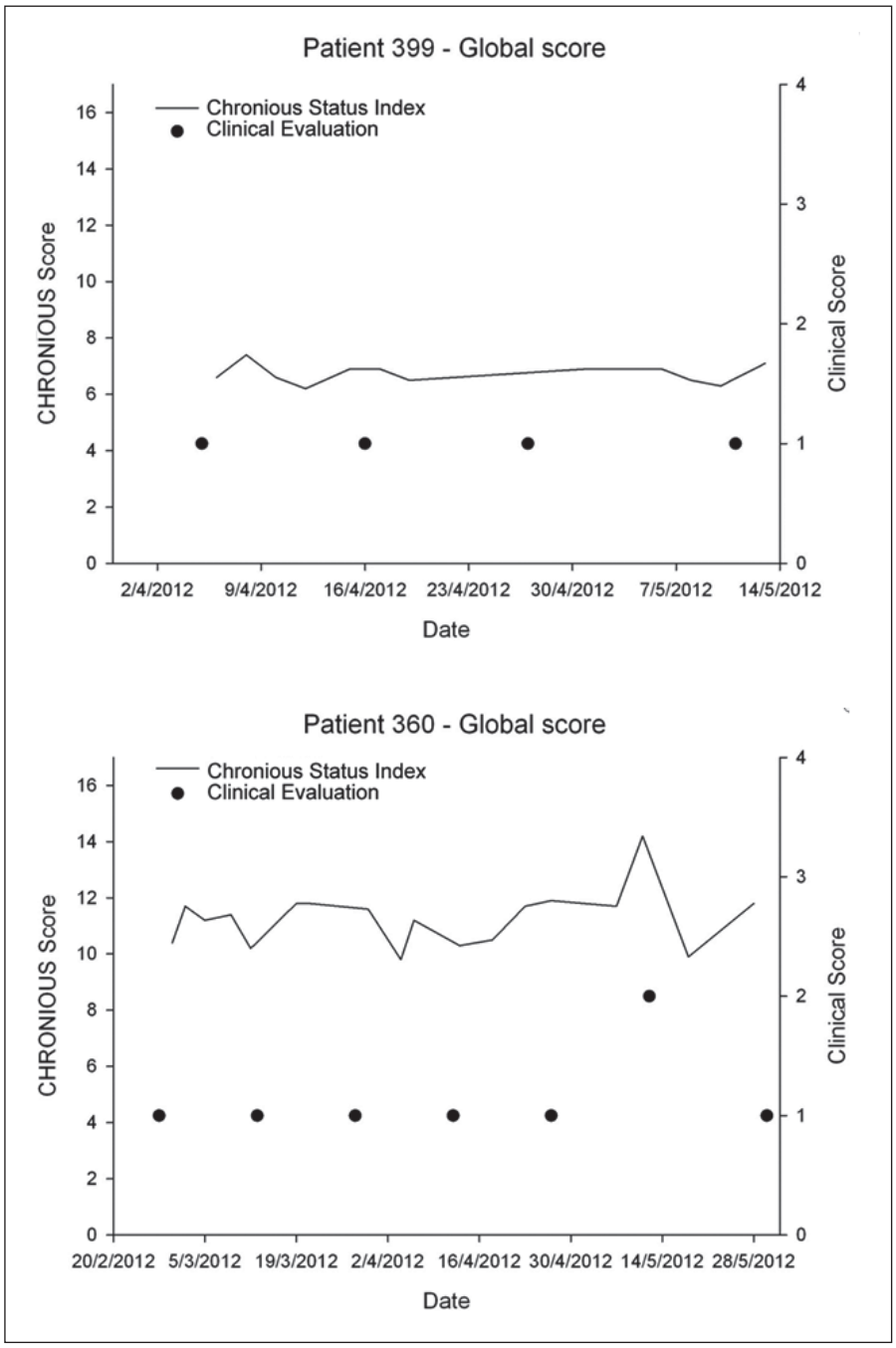

Figure 1 Comparison between the CSI and the clinical evaluation. The ordinate axis on the left reports the CHRONIOUS CSI, the ordinate axis on the right reports the score assigned by clinicians during their periodic evaluation (1–4 score, see the text for the description of these values). On the top, a stable patient (male, 75 years old, belonging to phenotype number 16). Below, a patient (male, 74 years old, belonging to phenotype 20) who experienced a worsening event, correctly detected by the CSI evaluation.

e http.// www.catestonline.org/images/pdfs/CATest.pdf

change neither in CHRONIOUS score nor in the clinical evaluation (CAT score at recruitment 15.6 ± 8, CAT score at the end 15 ± 7)[f]. Indeed, no phone calls were recorded to signal acute events.

A case of patient's condition mild worsening was reported by the clinical personnel and correctly identified by CHRONIOUS e-diary card, as shown in Figure 1 (bottom panel).

The offline comparison between the card's results and clinicians' evaluation demonstrated that the decision support method was effectively able to detect patient's exacerbation when occurring. Actually, the tracked evolution of the CSI was stable for stable patients (i.e., its variation was on average <± 1 for the 25 stable patients), while increased when patients' status worsened, as shown in Figure 1: the graph on the top shows the stable trend of the CSI, which corresponds to patient's stability recorded also by clinicians; the graph on the bottom shows that the CSI increased when the patient's conditions worsened.

4. Discussion and Conclusions

The preliminary study carried out demonstrated the good sensitivity of the e-diary card: the card correctly detected both the worsening event and the stable conditions of the disease (i.e., CSI was stable for stable patients, while increased when patients' status worsened).

Since only one worsening event was detected, the data collected during the preliminary study did not allow to define precisely the δ_i values. This task will require a more throughout study with a higher number of subjects and a longer duration.

At any rate, the results obtained are promising, considering that such a card presents several properties that prove its novelty with respect to similar solutions based on diary card [8, 9]. In particular, noteworthy features are:

- the heterogeneity of card items: the card considers not only disease signs and symptoms, but also patient's disability, patient's mood and frailty, patient's real activity, and environmental conditions;
- the innovation of card recording: most of the card items are automatically measured by the sensors;
- automatic alerting mechanism: the card evaluation is embedded into an application able to automatically alert clinicians via SMS;
- the personalized computation of the CSI: different disease's manifestations are considered via a patient's phenotyping schema, and this drives a weighting mechanism that adjusts the relevance of the different card items.

To date, no other solutions presented in the literature supplies contemporary all these features, as discussed in the related work sections. Actually, compared to other works on COPD exacerbations with similar features in terms of sensorized data collection and automated data interpretation [4, 17], our method introduces the idea of patient's phenotyping to personalize data interpretation.

As far as the results of the preliminary study are concerned, it is worthy to observe that usually the works carried out on COPD patients' telemonitoring based on ICT innovative sensor technologies are related to research projects which comprise just a validation phase at the end. Pilot studies presented in the literature have just few parameters monitored and, generally, do not employ automatic data interpretation facilities [1, 2, 32].

Indeed, the other two works similar to ours, i.e. [4] and [17], present similar type of results. In particular, the solution reported in [17] is based on a Bayesian Network for data interpretation whose parameters have been defined mainly in accordance with the suggestions of expert clinicians. Only partially have the network parameters been induced by data, and data used to this purpose were, in reality, acquired by another study and collected only by questionnaires and not sensors. Moreover, the system described has undergone just a technical feasibility and usability pilot study with five stable patients. Hence results are missing on exacerbation events detected with the system in real-life settings[g].

The solution described in [4] relies on a knowledge-based Decision Support System (DSS), whose production rules have been elicited from expert clinicians. The authors report only one case to illustrate the potential and rationale of applying DSS to the analysis of telehealth data.

Our work comprises a preliminary study in real settings which revealed the correct functioning of the method we propose. Further works will aim at monitoring patients for longer periods, so as to have the possibility to detect a higher rate of exacerbations and classify them in accordance with the δ_i-values pattern. Moreover, a further research idea is to use the CSI evolution to understand how the tracked CSI values might be used also to identify patients' recovery patterns.

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f This is probably due to the seasonal trends of COPD: the project needs required to monitor patients in the period spring-summer.

g Authors report the results of the application of the Bayesian network on data collected by the pilot described in [32].

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