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Modelling adherence behaviour for the treatment of obstructive sleep apnoea

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ABSTRACT

Continuous positive airway pressure therapy (CPAP) is known to be the most efficacious treatment for obstructive sleep apnoea (OSA). Unfortunately, poor adherence behaviour in using CPAP reduces its effectiveness and thereby also limits beneficial outcomes. In this paper, we model the dynamics and patterns of patient adherence behaviour as a basis for designing effective and economical interventions. Specifically, we define patient CPAP usage behaviour as a state and develop Markov models for diverse patient cohorts in order to examine the stochastic dynamics of CPAP usage behaviours. We also examine the impact of behavioural intervention scenarios using a Markov decision process (MDP), and suggest a guideline for designing interventions to improve CPAP adherence behaviour. Behavioural intervention policy that addresses economic aspects of treatment is imperative for translation to clinical practice, particularly in resource-constrained environments that are clinically engaged in the chronic care of OSA.

1. Introduction

1.1. Application background

Obstructive Sleep Apnoea (OSA) is a sleep disorder that afflicts an estimated 5% of the U.S. adult population; it is the second-most prevalent sleep disorder in the U.S. (NIH, 2011; Young, Peppard, & Gottlieb, 2002). OSA is characterised by repetitive nocturnal cessation of breathing, resulting in intermittent hypoxia and cortical arousals from sleep (Malhotra & White, 2002; Patil, Schneider, Schwartz, & Smith, 2007). It is well known that untreated OSA contributes to serious health-related issues, including hypertension, stroke, cardiovascular disease, metabolic disorders, and mood and cognitive impairments, and OSA increases the probability of occupational injuries and motor vehicle accidents (Billings & Kapur, 2013; Hernández-Lerma & Lasserre, 1996; Iber, Ancoli-Israel, Chesson, & Quan, 2007; Young et al., 2002). Continuous Positive Airway Pressure therapy (CPAP) is known to be a highly efficacious treatment when it is used consistently for the duration of each sleep bout (Giles et al., 2006; Guest, Helter, Morga, & Stradling, 2008; Sadatsafavi, Marra, Ayas, Stradling, & Fleetham, 2009). CPAP therapy is conducted at the patient's home and requires the patient to wear a mask connected to an air pressure pump during sleep to provide positive pneumatic pressure to the upper airway, effectively reducing airway closures and the consequences of intermittent nocturnal breathing cessation. This therapy presents numerous challenges, however, for patients. Nonadherence to CPAP therapy is reported as a common behavioural issue among an estimated 50% of patients with CPAP-treated OSA (Parthasarathy, Wendel, Haynes, Atwood, & Kuna, 2013; Sawyer et al., 2011, 2014).

A typical CPAP device automatically records the duration of usage on a daily basis, measured in hours of use per 24 hours for all intervals of use at an effective pressure for more than 20 minutes. This technology permits an objective measure of CPAP use, or adherence, and permits early recognition of nonadherence during the initial home treatment period. In order to improve CPAP adherence, several types of interventions have been proposed and preliminary tests performed. Intervention strategies reported to date include simplistic, stand-alone educational interventions, CPAP device adaptations such as heated humidification, flexible pressure and auto-adjusting positive airway pressure, cognitive behavioural interventions in both small groups and with individual patients, social

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support interventions such as peer-to-peer support (Parthasarathy et al., 2013), multi-dimensional approaches, habit-formation interventions, and self-management strategies (Sawyer et al., 2011). OSA is not a disorder that can be treated on a one-time basis; OSA requires a patient to use the device as a long-term treatment, and such chronic care necessitates cost-effective interventions. To address this challenge and implement highly effective chronic care for CPAP-treated OSA in a way that substantially reduces CPAP nonadherence, empirically-derived decision policies are needed.

1.2. Behavioural issues and Markov models

Nonadherence can be regarded as a behavioural issue that must be addressed in order to treat OSA optimally. Interestingly, such treatment adherence behaviours vary across particular sub-populations (e.g., low socioeconomic position, race) and change dynamically (Kang, Prabhu, Sawyer, & Griffin, 2013; Sawyer et al., 2014). For example, a patient may show a low level of CPAP usage during the first few days but increased usage after some time has passed, while others show a constant low level of usage. Other patients demonstrate an acceptable level of usage at the outset of treatment, but lower usage levels over time. Moreover, some patients demonstrate usage behaviours that fluctuate randomly over the entire observed treatment period. We hypothesise that such changes are due to stochastic dynamics that result from social, personal, contextual and environmental factors. Modelling such stochastic adherence behaviours can be demanding, however, given its complexity and uncertainty. The use of system dynamics has been widely suggested and utilised in understanding such complex behavioural problems (Gino & Pisano, 2008; Hämäläinen, Luoma, & Saarinen, 2013); The application of systems science approaches to complex behavioural health problems is further substantiated by agency and scientific leaders in the U.S (Grady & Daley, 2014; OBSSR, 2014). Recent studies in chronic care management have approached complex behavioural problems with a system dynamics approach (Luke & Stamatakis, 2012). One solution for dealing with these challenges is to use Markov models, which can help to predict an individual's behaviour in uncertain environments.

Most behavioural intervention studies assume that patients, regardless of their behavioural patterns, will react similarly to interventions. In reality, however, some patients exposed to a behavioural intervention may demonstrate a ceiling effect for the primary outcome; this results in varying degrees of behavioural intervention effectiveness among different patients. Recent research suggests that interventions for improving CPAP usage can be less effective for patients showing moderate adherence compared to the patient group with low adherence (Wozniak, Lasserson, & Smith, 2014). Such bias between assumed and actual effectiveness should be considered when evaluating cost-effectiveness of the corresponding interventions. To decrease this bias, intervention designers can consider adaptive strategies that are applicable to different patient groups showing different behaviours. From this perspective, we consider multiple Markov models for each available intervention and formulate as a stochastic decision problem—namely, the Markov decision process (MDP)—that can optimise the intervention strategy for behavioural changes depending on the individual's current behaviour.

In this paper, we suggest using Markov models to capture the stochastic dynamics of adherence behaviours and MDP to explore the optimal strategy for improving a patient's adherence, a behavioural issue, during OSA treatment. From the estimated models, we reveal some notable behavioural trends in CPAP usage and address cost-effectiveness issues relative to intervening in all patients. By examining the impact of intervention scenarios using the MDP, we further suggest a guideline for designing interventions, dependent on an individual patient's current behaviour (i.e., adherence), to effectively improve the target behaviour.

The structure of the paper is as follows. In the next section we define Markov models for CPAP adherence behaviour and estimate transition probabilities using data obtained from a recent prospective cohort study (Sawyer et al., 2014). In Section 3, we develop MDP models to determine cost-effective intervention policies, along with some structural properties. Then, in Section 4, we illustrate the predicted optimal policy patterns using MDP models for probable intervention cases in a chronic care scenario. In particular, we use the result of the Markov model estimated in Section 2 and derive from our own recent research as the basis for design of the MDP model discussed in Section 3, and the baseline transition probabilities (as a 'Do nothing' action) for our MDP model in Section 4. Additionally, we validate the cost-effectiveness of two clinical interventions using Markov models in Section 4. Conclusions, limitations, and future work are described in Section 5.

2. Markov model for CPAP adherence behaviours

In this Section, we discuss the development of a Markov model for CPAP adherence and explain how we characterise the dynamics underlying CPAP usage behavioural trends.

2.1. Data description

We examined the first month of CPAP usage data from a prospective single cohort study that included 97 patients with moderate to severe OSA (Sawyer et al., 2014). The goal of the primary study was to examine the predictive utility of a risk screening questionnaire to prospectively identify patients with OSA who were at high risk for CPAP nonadherence at the outset of the treatment period. Participants were recruited at an academic sleep centre after OSA diagnosis was established during an overnight sleep study, i.e., polysomnogram. OSA severity was determined by the apnoea–hypopnoea index (AHI), or apnoeas plus hypopnoeas divided by hours of sleep during polysomnogram (AASM, 2005). OSA severity is categorised as mild, ≥ 5 and < 15 events/hour, moderate, ≥ 15 and < 30 events/hour, or severe, ≥ 30 events (Epstein et al., 2009).

For the primary study, the inclusion criteria for newly-diagnosed OSA patients were: (1) an apnoea–hypopnoea index (AHI) greater than or equal to 5 events/hour on an in-laboratory polysomnogram, conducted and scored in accordance with standard criteria (Iber et al., 2007); (2) referral to CPAP titration polysomnogram, i.e., an in-laboratory, single night sleep study during which CPAP pressure is titrated to reduce/eliminate apnoeas and hypopnoeas and normalise oxygenation during sleep; and (3) ability to speak and read English. Participants had no previous experience with CPAP prior to study enrolment. After informed consent, the participants' demographic and OSA features were collected, and an in-laboratory CPAP titration polysomnogram was performed. Thereafter, participants received home CPAP treatment for 30 days and objective CPAP usage data were collected at study termination. Such usage data were recorded sequentially at a daily basis for 30 days.

We pre-processed the data by excluding patient outcomes with erroneous or missing values; 92 patients remained for the final analysis. Table 1 shows summary statistics for the included patients.

2.2. State definition

A patient's adherence behaviour can be quantified by observing his or her usage behaviour. From this perspective, we define the amount of a patient's CPAP usage as a state of the Markov model, which we define in discrete units as shown in Table 2. Generally, standard, commercially available CPAP machines record usage in time, so a patient's CPAP usage value can be regarded as continuous. In order to avoid computational issues, however, we define this continuous state as discrete in this paper by grouping the continuous