The adapted model indicates when the subject starts lying down (light off) and when the subject stands up (light on). It is possible now to calculate indices as sleeping efficiency from data provided by the multi-sensor activity monitor.

The model could be used also to quickly recognise whether a subject didn't follow a "normal/regular" sleeping pattern. There are several criteria which are inherently computed or derivable within the procedure to give indicators that a biphasic model is not proper for the data. Two simple criteria for a binary setting are the following: (1) if the maximum value of the empirical probability distribution is smaller than a certain threshold (i.e. 0.7 works well for our purpose) it can be assumed that the subject had a very irregular sleep pattern within the observed analysis period; (2) if the distance between the two uncertainty peaks selected is less than two hours the subject had (on an average) too few hours of time in a lying position during the night. The output of the algorithm was qualitatively assessed by visual inspection in 132 cases randomly selected. From the visual inspection we concluded that were no major issues in the functioning of the algorithm.

5.3 Statistical analysis

Linear mixed-effect models (LMM) were used to study: (i) which factors influenced sleep quality measures, and (ii) whether and to what extent sleep quality measures were associated with subsequent daily physical activity levels and daytime sleep in patients with COPD.

To study which factors influence measures of sleep quality in people with COPD, we constructed a LMM for each sleep parameter (S_i), with GOLD and MMRC as ordinal explanatory variables; smoking status, country of origin, gender and day group (i.e. weekday vs. weekend day) as categorical explanatory variables; age and BMI as continuous explanatory variables. To account for repeated measurements, we used random effects on two levels. On the highest level, we included a random intercept per patient. The second level, within patients, had a random intercept for each day group (weekdays vs. weekends). The residuals then accounted for the differences between days within the same day group.

The model had the form:

$$S_i \sim GOLD + MMRC + Smoking\ status + \ Country + \ Gender + Day\ group + Age + BMI + \ (1\ |\ patient\ ID) + (1|\ Day\ group{:}\ patient\ ID) + \varepsilon. \ \textit{(1.1)}$$

where ε is a random error and the notations (1| patient ID) and (1| Day group: patient ID) indicate that the model accounts for by-subject and by-day group variability [109].

Next, sleep quality parameters were further categorized into quartiles to examine potential relationships with daytime measurements. Each of the physical activity (PA_i) measurements was considered the response variable of a separate LMM.

Sleep parameter quartiles (Q) and MMRC were ordinal explanatory variables; smoking status, country of origin, gender and day group were categorical explanatory variables; FEV_1, age and BMI were continuous explanatory variables of the model. Repeated measurements and day group were included as random effects.

The model had the form: