Interreg CENTRAL EUROPE
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niCE-life

ONLINE SLEEP MONITORING SYSTEM

D.T2.1.5 - Finalisation and deployment

Version 1
12 2020

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1. Introduction

In the previous deliverable (D.T2.1.4), we summarized the survey and the testing phase of the project in which we presented and tested the monitoring tool with the project partners as well as the target groups. Based on the positive feedback, we re-visited and fine-tuned the online sleep monitoring tool to meet the requirements of the involved parties. We also enriched the system with some additional features to satisfy the expectation of the future users (will be described in the subsequent chapters).

In this document, we summarize the finalization of the monitoring tool based on the feedback from the project partners, target groups, and the patients themselves. The intention is to develop the system that will be easy to use (minimum requirements on the side of patients) while providing useful objective information to doctors for diagnosing, assessing, and monitoring of the sleep-related neurological disorders. We also summarize the deployment of the tool: it is publicly available and ready to be tested.

2. System finalization

To satisfy the expectation of future users, some additional features were added in the phase of the system finalization. In summary, the major required features were the following: addition of the support for sleep diary(/ies), integration of the REM sleep behavior disorder screening questionnaire (RBDSQ), and addition of the possibility to download the data. Finally, minor tweaks and bugfixes were done targeting speed and stability of the system. The newly added features will be described in more detail bellow.

2.1. Sleep diary

To identify additional correlations, actigraphy data are usually paired with sleep diary data [1, 2]. Therefore, this highly requested feature was implemented in the system. There were additional specifications requested: “The remote sleep analysis should be accompanied by sleep diaries, where the patients input approximate information about the consumption of coffee, alcoholic drinks, resting during a day, wakeups during the night, etc.”

It is possible to implement the sleep diary data collection in different ways. Firstly, data can be directly filled in by a subject via a webpage. Secondly, the sleep diary data can be written in a standardized sleep diary paper and collected with the actigraph itself. Such data could be uploaded consequently into the system by a researcher. Overall, 9 patients (5 females, 4 males; age 66.44 ± 6.02 years) at the St. Anne's University Hospital in Brno and the Central European Institute of Technology were asked about preferred variant: 22% (n=2) voted for a webpage variant, and 78% (n=7) voted for paper variant as it is easier for them to use. Eventually, to satisfy every patient, both variants were implemented into the system.

The Paper version of the sleep diary is included in Appendix. The webpage variant could be seen in Figures 1—2. It is possible to edit an entire sleep diary on the subject edit page (two diary days are displayed in Figure 1) or day by day as shown in Figure 2. Moreover, a special request was made to load the sleep diary data from Excel table. This feature is controlled by a button on the Utils page. It allows a researcher to manage all the data for different systems or scripts in a single table file.

The sleep diary data are presented on the subject detail page as a table (Figure 3) and there is information about sleep from the sleep diary for each graph with sleep prediction from the actigraphy data (see Figure 4) too. In this form, the data is easy to read and it can be compared with actigraphy data very easily. The data is presented to both groups of patients (with online and paper form of the diary). It cannot be changed on this page, therefore there is no risk of misconfiguration for patients that are not so familiar with IT.

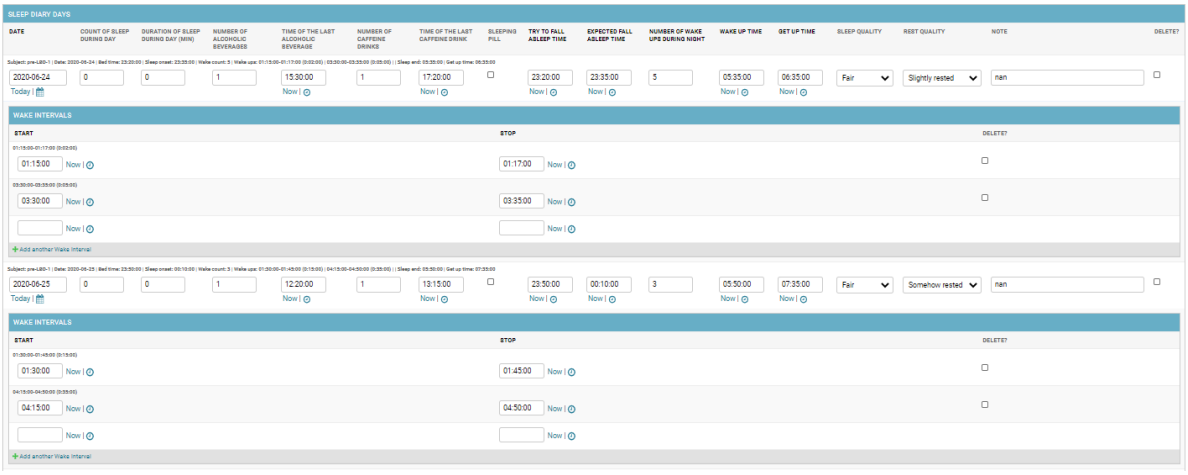

Figure 1: Sleep diary edit on the subject edit page.

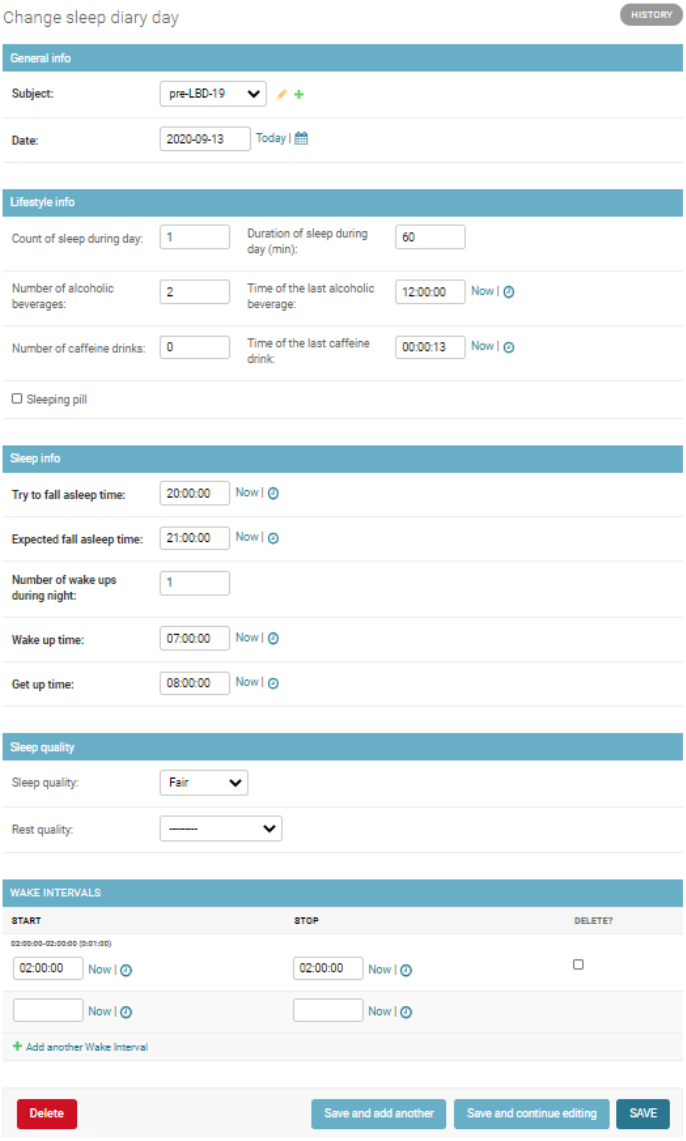

Figure 2: Sleep diary edit of a single diary day.

SLEEP DIARY

Date	Day sleep nr.	Day sleep time	Alcohol nr.	Alcohol time	Caffeine nr.	Caffeine time	Sleeping pill	Bed time	Sleep time	Wake ups nr.	Awake time	Get up time	Sleep quality	Rest quality
Aug. 27, 2020	1	0	0	midnight	2	4 p.m.	False	10:15 p.m.	10:30 p.m.	4	5:15 a.m.	6:45 a.m.	Poor	Slightly rested
Aug. 28, 2020	0	0	1	6:30 p.m.	1	3 p.m.	False	11 p.m.	11:30 p.m.	3	6:30 a.m.	6:30 a.m.	Fair	Somehow rested
Aug. 29, 2020	1	10	0	midnight	1	4 p.m.	False	10:15 p.m.	11 p.m.	3	5:40 a.m.	6:40 a.m.	Fair	Somehow rested
Aug. 30, 2020	1	15	0	1 p.m.	2	3 p.m.	False	10 p.m.	10:10 p.m.	3	5:10 a.m.	5:10 a.m.	Fair	Somehow rested
Aug. 31, 2020	1	10	0	midnight	1	10 a.m.	False	11 p.m.	11:05 p.m.	2	5:15 a.m.	6:45 a.m.	Fair	Somehow rested
Sept. 1, 2020	1	30	0	midnight	2	3 p.m.	False	11 p.m.	11:10 p.m.	3	6:15 a.m.	7:15 a.m.	Good	Somehow rested
Sept. 2, 2020	0	0	0	midnight	3	3 p.m.	False	10:50 p.m.	11:10 p.m.	2	5:30 a.m.	8 a.m.	Poor	Slightly rested

Figure 3: Sleep diary as a table on the subject detail page.

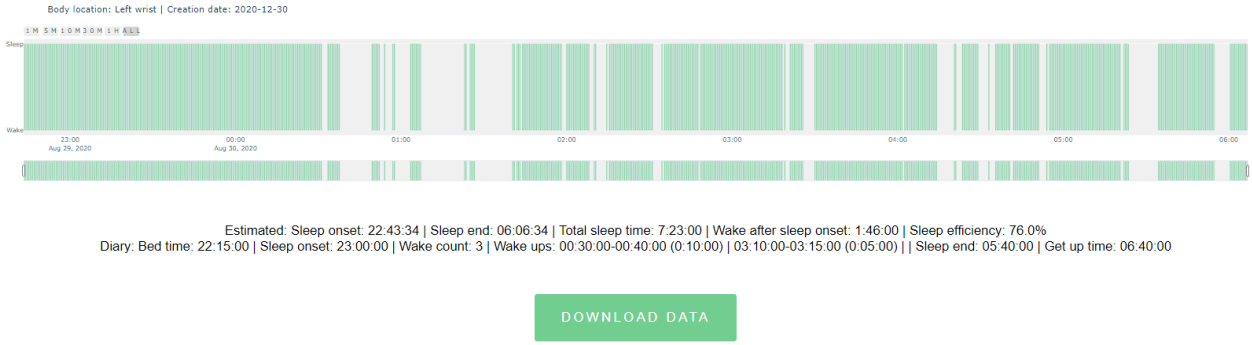

Figure 4: Sleep estimation with the sleep diary data.

2.2. RBDSQ

Idiopathic rapid eye movement sleep behavior disorder (RBD) affects 1—2% of people over 60 years of age, and presents a high risk of developing a neurodegenerative disorder from the group of synucleinopathies, such as Parkinson's disease, dementia with Lewy bodies and multiple system atrophy [3]. REM sleep behavior disorder screening questionnaire (RBDSQ) helps to identify symptoms typical for RBD. It monitors the occurrence of unpleasant dreams (2 items), history of dream enactment (1 item), self-awareness of limb movements in sleep (1 item), presence of unusual and/or harmful behaviour during sleep (5 items), sleep disturbance related to dream mentation (2 items), and coherent recollection of dream content (1 item) [4].

As requested, the RBDSQ was implemented into the system as well. As displayed in Figure 5, the questionnaire can be answered on the subject edit page, where more instances of the questionnaire can be created for each subject, etc. The overall score of the last RBDSQ is displayed on the subject detail page.

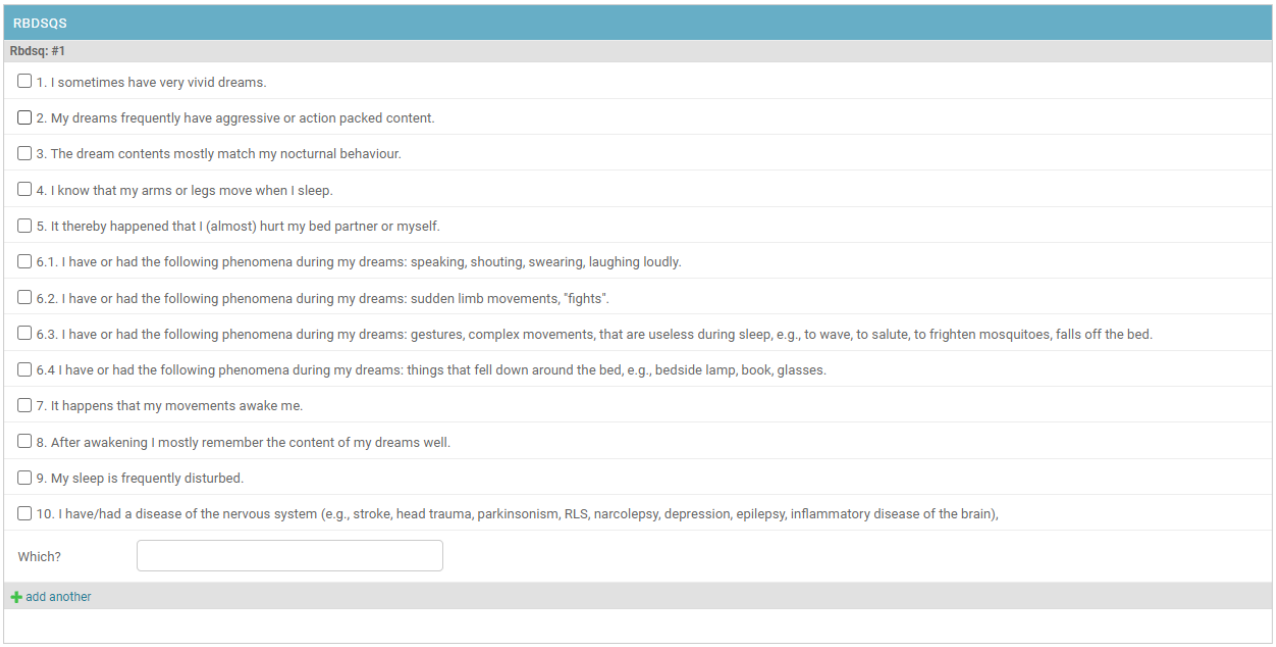

Figure 5: RBDSQ on the subject edit page.

2.3. Data downloading

An authenticated user is able to download the sleep prediction data from the server. Task can be performed via the Download Data button under each graph on the subject detail page. An Excel spreadsheet was determined to be most preferred format for the downloaded data. Exported data format depends on the subject type. Format for the sleep prediction data is presented in Table 1. The first column contains timestamps, the second column holds the sleep predictions, where value **W** means wake and **S** stands for sleep. The File contains only this data to protect real patients in case someone gains unauthorized access, i.e. the data does not contain any vulnerable, private, or protected information.

Table 1: Format of the downloaded data.

	PREDICTION
2020-06-18 22:33:42	W
2020-06-18 22:34:12	W
2020-06-18 22:34:42	W
2020-06-18 22:35:12	W
2020-06-18 22:35:42	S
2020-06-18 22:36:12	S
2020-06-18 22:36:42	S

Data of subjects from an open-source dataset, that were used as training data for the machine learning algorithm and that contains polysomnography data as well, allows to download extended data format. Extended format contains timestamp index column followed by 90 columns of features used by machine learning algorithm XGBoost, penultimate column contains sleep prediction by XGBoost, where 0 stand for wake and 1 for sleep, and the last column holds polysomnography data considered as ground truth. Some examples of data can be downloaded from https://linda.utko.feec.vutbr.cz.

3. System deployment

System was deployed to be publicly available at the following URL: https://linda.utko.feec.vutbr.cz. In the subsequent subchapters, the deployment process is described in detail.

3.1. Database

SQLite database was used in the development phase for the reason that it is a default database used by the Django framework. However, it is suitable for the development use case only as it is easy to work with and it has no special requirements on the environment [5]. Nevertheless, it is not recommended to be used in the production environment with very large datasets and high concurrency [6] as it is a file-based database only, so it can be easily corrupted or obtained by an unauthorized user. It was decided to use MySQL database instead, owing to the fact that it was already installed on the server and it is one of the recommended options by Django Software Foundation [5].

MySQL database is managed by MySQL server implementation and it works in client-server mode. From the system point of view, a connection to the database must be established. Therefore, *mysqlconnector* library was installed and appropriate changes were done in the Django application settings.

A password needs to be passed to the Django application settings to establish the connection with the database. It must remain secret, however. On that account, it cannot be published in the open source code. I.e., the database password as well as the secret key for CSRF tokens are stored in the secret JSON file, which is not publically available[1]. These settings meet the best deployment practices listed by Django Software Foundation [7].

3.2. Django deployment checklist

Django deployment checklist is a set of advices and recommendations, which should be met before deploying the Django application into production. Automatic audit of some of the settings could be done via the script. This script reported some advices, e.g. additional security settings to protect CSRF and SESSION cookie, disable of DEBUG mode etc. Those changes were implemented and the script validated the application as production-ready. Additional advices of the Django deployment checklist and best practices collected on the internet were implemented to make the application fast, stable, and secure [7, 8, 9].

[1] Changes made in the source code to meet the deployment requirements can be referred to on the source code repository in the development branch: https://gitlab.com/MarekMikulec/geneactiv-processing-data/-/tree/deploy or in the following link: https://github.com/BDALab/sleep-analysis-system/tree/deploy.

3.3. Deployment via WSGI application on the web server

The online sleep monitoring system was created as a Django application. Django currently supports two standard interfaces to communicate with a Web server: WSGI and ASGI.

- WSGI is the main standard to communicate with a Web server. It supports only synchronous code. An example of WSGI interface implementation are libraries such as *Gunicorn*, *mod_wsgi*, etc.
- ASGI is the asynchronous-friendly standard. It must be used to support asynchronous features as they were designed [10].

The system does not use asynchronous features; therefore, it can be deployed via the WSGI standard. In future development, re-implementation of long-running tasks like machine learning model training should be implemented as asynchronous operations and they should inform user about the progress. However, all long-running tasks are restricted to be used only by a System Administrator, who can access live console logs and monitor the progress in detail from here. Therefore, ASGI standard is not needed and most likely will not be used in the future.

A standard combination of Django-mod_wsgi-Apache Web server was attempted to be used. Anaconda virtual environment is usually not used and recommended for deployment. Firstly, the requirements were collected from Anaconda virtual environment, then the system was migrated into Python virtualenv[2]. Secondly, the requirements were installed into virtualenv. Then, mod_wsgi and Apache Web server were installed, and set-up as described in the documentation and in the following tutorials [8, 9, 10, 11]. Unfortunately, configuration was not able to work properly, as it is targeted primary on Linux-based operating systems not on Windows server as used to deploy the application.

Finally, combination of Django-Werkzeug WSGI-WhiteNoise was used. All libraries are written in Python and cooperates together with not problems. Werkzeug WSGI is directly integrated in django-extensions library, therefore the deployment is simplified. WhiteNoise works as a Web server and serves static files instead of Apache Web server from the previous configuration. It is not so efficient in implementation, i.e. serving a request could take longer, however it is still suitable for public testing. Huge advantage of this configuration is its sufficiency for automation [12, 13]. Therefore, an entire redeployment could be done really fast and possibly automatically, in case of the server failure, etc.

3.4. Hyper Transfer Protocol Secure

Hyper Transfer Protocol Secure (HTTPS), an essential step to secure any website which allows user to log in, was enforced site-wide. It creates an encrypted communication channel and allows user to transmit secret information securely over Internet.

HTTPS requires a certificate to identify the server and to secure the connection. In the testing phase, self-signed certificate was used. During last phase of the deployment, certificates signed by a certification authority was obtained via https://zerossl.com/. ZeroSSL is a trusted certification authority, which provides certificates for example to Uber, Lenovo, or Slack.

Together with the previously mentioned security mechanisms, like access control, cross site scripting protection and much more, the system is secure and sustainable for the public testing. However, to extend the security even beyond the borders of the software security field, all data of the real patients are pseudonymized. Subjects are identified by unique identifier only, and the real person identity remains anonymous.

[2] Both build-in virtualenv and virtualenvwrapper-win were tested, finally build-in implementation was used as it worked as expected and it does not need special installation.

4. Conclusion

In this document, we summarized the finalization of the monitoring tool based on the feedback and we described the deployment stage. All of the requested features were implemented and the system was deployed successfully on https://linda.utko.feec.vutbr.cz. To test the system from subjects' point of view, it is possible to use the testing account with the following username: **TestSubject** and with the password: **SubjectToDemonstatePatientUsage** (go to Dashboard and select subject with CODE: TESTSUBJECT). **The testing account for researcher role or administrator role cannot be provided directly in this document due to security reason, they can be created on request.** Moreover, our team is currently working on video(s) documentation of the system, that will be available on url: https://drive.google.com/drive/folders/1qmAzPeO-6zColWkW9pCFYtzFeX067T5M?usp=sharing.

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6. Appendix

6.1. Sleep diary

This document was created for patients at the St. Anne's University Hospital in Brno and the Central European Institute of Technology. It is a standardized sleep diary. It matches its webpage version and the data can be transferred there accordingly. The diary is in the Czech language.

Spánkový deník (ver. 2020/05/06)

Jméno a příjmení:
Datum narození:
ID:

	Příklad							
Datum	2.5.2020							
vyplnit před spaním: 1a. Kolikrát jste si šel/šla během dne lehnout? 1b. Kolik minut jste během dne prospal/a?	2x 40 min.							
vyplnit před spaním: 2a. Kolik alkoholických nápojů jste přes den vypil/a? 2b. V kolik hodin jste vypil/a poslední?	1 20:15							
vyplnit před spaním: 3a. Kolik nápojů s kofeinem (kafe, čaj, energy drinků) jste přes den vypil/a? 3b. V kolik hodin jste vypil/a poslední?	3 17:32							
vyplnit před spaním: 4. Užil/a jste lék na spaní? (pokud ano jaký, kolik a v jaký čas)								
vyplnit ráno (do 1 hod. po opuštění postele): 5. V kolik hodin jste ulehl/a do postele?	22:35							
vyplnit ráno (do 1 hod. po opuštění postele): 6. V kolik hodin jste se snažil/a usnout?	22:50							
vyplnit ráno (do 1 hod. po opuštění postele): 7. Jak dlouho vám přibližně trvalo usnout? (nesledujte při usínání hodiny)	10 min.							
vyplnit ráno (do 1 hod. po opuštění postele): 8. Probuzení během noci (pro každé probuzení: přibližně od kdy – do kdy)	1:12 – 1:17 3:45 – 3:58							
vyplnit ráno (do 1 hod. po opuštění postele): 9. V kolik hodin jste se probudil/a?	7:12							
vyplnit ráno (do 1 hod. po opuštění postele): 10. V kolik hodin jste opustil/a postel?	7:20							
vyplnit ráno (do 1 hod. po opuštění postele): 11. Jak dobře jste se vyspal/a? (1–5, viz legenda pod tabulkou)	2							
vyplnit ráno (do 1 hod. po opuštění postele): 12. Jak svěže jste se po probuzení cítil/a? (1–5, viz legenda pod tabulkou)	3							
vyplnit ráno (do 1 hod. po opuštění postele): 13. Komentář (nepovinné)	nachlazení							

Hodnocení: 1 = velmi dobře, 2 = dobře, 3 = průměrně, 4 = špatně, 5 = velmi špatně

Instrukce k deníku a jeho položkám

Jak často deník vyplňovat? Prosím vyplňujte denně před i po spánku dle vyznačených polí v deníku.

Co dělat, když vynechám den? Snažte se vyplňovat 7 dní v kuse. Pokud vynecháte, nic nevyplňujte a pokračujte dalším dnem. Musí být 7 záznamů.

Co dělat, když něco nestandardního (třeba nachlazení/chřipka) ovlivní můj spánek? Informujte o tomto v poli č. 13.

Jak přesné musí být uvedené časy? Uvádějte přibližné odhady, nesledujte zbytečně hodiny (např. při usínání).

2a. Kolik alkoholických nápojů jste přes den vypil/a? Za 1 alkoholický nápoj se považuje 0,5l piva, 2dl vína, nebo 1 panák tvrdého alkoholu.

5. V kolik hodin jste ulehl/a do postele? Toto nemusí být čas, kdy se začnete snažit spát. Např. si budete ještě číst.

6. V kolik hodin jste se snažil/a usnout? Toto je opravdu čas, kdy jste se odebrali ke spánku.

9. V kolik hodin jste se probudil/a? Uveďte čas posledního probuzení, po kterém jste ráno již neusnul/a.

10. V kolik hodin jste opustil/a postel? Mezi časem probuzení a tímto časem jste mohli např. jen polehávat, brouzdat na telefonu atd.

11. Jak dobře jste se vyspal/a? Zhodnoťte, jestli byl váš spánek dobrý, špatný…

12. Jak svěže jste se po probuzení cítil/a? Jak jste se cítil/a během pár minut po probuzení?

Instrukce k náramku (aktigrafu)

Náramek bude zaznamenávat Váš pohyb nedominantní ruky, teplotu a míru okolního osvětlení. Žádné další informace nejsou zaznamenávány.

Náramek se nenabíjí. Než Vám byl předán, byl dostatečně nabit.

Nenamáčejte náramek do vody.

Náramek se nasazuje na nedominantní ruku. Pokud jste pravák/pravačka, dejte si náramek na ruku levou. Pokud jste levák/levačka, dejte si náramek na ruku pravou.

Náramek si na nedominantní ruku nasaďte vždy před tím, něž ulehnete do postele. Sundejte ho hned po tom, co ráno postel opustíte.

Náramek si upevněte tak, aby vás příliš nestahoval, ale **aby také nebyl na ruce příliš volný**.

Kontakt pro dotazy a řešení technických potíží

MUDr. Ivona Morávková, +420 XXX XXX XXX

Děkujeme Vám za spolupráci. Vaše trpělivost při vyplňování deníku a nošení náramku pomůže při výzkumu a vývoji nové metody diagnózy onemocnění s Lewyho tělísky v raném stádiu. Ta mj. umožní zvýšit kvalitu života pacientů s těmito onemocněními.