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Evaluation of Substituting a Sleep Diary by Smartwatch Measurement

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Abstract. The importance of sleep for human life is enormous. It affects physical, mental, and psychological health. Therefore, it is vital to recognise sleep disorders in a timely manner in order to be able to initiate therapy. There are two methods for measuring sleep-related parameters - objective and subjective. Whether the substitution of a subjective method for an objective one is possible is investigated in this paper. Such replacement may bring several advantages, including increased comfort for the user. To answer this research question, a study was conducted in which 75 overnight recordings were evaluated. The primary purpose of this study was to compare both ways of measurement for total sleep time and sleep efficiency, which are essential parameters for, e.g., insomnia diagnosis and treatment. The evaluation results demonstrated that, on average, there are 32 minutes of difference between the two measurement methods when total sleep time is analysed. In contrast, on average, both measurement methods differ by 7.5% for sleep efficiency measurement. It should also be noted that people typically overestimate total sleep time and efficiency with the subjective method, where the perceived values are measured.

Keywords -- Objective Sleep Measurement, Sleep Diary, Sleep Efficiency, Sleep Study, Wearables.

I. Introduction

Sleep is essential for human life and well-being. The fact that humans spend, on average, about a third of everyday sleeping emphasises its influence on our life, as human evolution has led to this significant amount of the needed rest time based on its importance [1].

Considering the relevance of sleep for human health, it is crucial to keep its quality high. For that, possible sleep disorders should be identified at the early stage to apply timely and appropriate therapy. Different parameters can be measured and analysed depending on a particular sleep disorder to facilitate diagnosis. In the case of sleep insomnia, one of the standard methods for diagnosis and therapy monitoring is based on using sleep diaries to obtain relevant sleep characteristics. The consensus sleep diary is one of the established tools being applied [2].

A sleep diary can be classified into the category of subjective sleep measurement [3]. This kind of measurement is based on the human perception of sleep and therefore is individual-related [4]. Another sleep measurement approach is called objective and relies on recording sleep-relevant characteristics /physiological parameters with the help of specialised devices [5].

Both measurement methods are used in sleep medicine to diagnose various disorders, and a combination of them might provide a comprehensive sleep analysis [6]. Nevertheless, the question if a substitution of a subjective approach through the objective one could be possible is arising, as the objective method could provide more convenience for a user due to automatical measurement without the necessity of daily filling out the documents as it must be done in case of sleep measurement with a sleep diary [7]. The comparison of these measurement approaches was reported in several publications, e.g., [8] or [9]. However, a particular device should be compared with a subjective measurement recording parameters of interest to provide a reliable conclusion on the possibility of such substitution.

This article aims to evaluate the possibility of substituting a sleep diary with a smartwatch Samsung Galaxy Watch 4 for the measurement of Total Sleep Time (TST) and Sleep Efficiency (SE), being significant characteristics in sleep medicine [10] and correlating with human health [11] and performance [12].

II. Methods

A sleep diary is a commonly used method for the subjective assessment of sleep. Several versions exist, and for the presented in this manuscript study, the German version recommended by the German Society for Sleep Research and Sleep Medicine was used [13].

Various devices for measuring sleep parameters can be used for objective measurement. To ensure comfortable use, the device should disturb the user as little as possible during sleep. A widely used approach is the use of wearables. The choice of the Samsung Galaxy Watch 4, in particular, is based on several reasons:

- The previous models of the Samsung Watch were evaluated for measuring physiological parameters with acceptable results [14].
- The relevant sleep parameters, such as TST and SE,

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can be measured with this device.

- The measurement results can be accessed via a mobile app or downloaded from a user account.
- All settings can be made in advance via the mobile app, and the measurement is fully automatic.
- The watch can ensure a battery life of about 30-40 hours.

TST and SE were chosen for the evaluation because of their significance and informative value. According to [15], there are several ways of determining SE. In the presented evaluation, we used the following Formula 1:

$$SE = TST(Wake\ up\ Time - Time\ trying\ go\ to\ Sleep) * 100\% \quad (1)$$

To perform the evaluation, the field study was planned and executed. Five participants from the age group 20-40 years old were included in the study, and no significant health disorders were known to be present. Before starting the study, the aim and process of the experiment were explained, and all questions were addressed.

The smartwatch and sleep diary were presented and explained to participants on the first day of the study. They had to wear them during the day or at least put them on 20 minutes before going to bed and take them off not earlier than 20 minutes after getting out of bed. Always when the battery state was lower than 35%, the smartwatch had to be charged. A sleep diary was to be filled out directly after going to bed and immediately after waking up to ensure accurate data recording.

III. Results

After performing the study, a set of 75 overnight recordings by a smartwatch and a sleep diary was collected and analysed. The average differences between the subjective and objective measurement approaches were calculated for TST and SE parameters, and following Table 1 demonstrates the obtained statistical values for both characteristics.

TABLE I. STATISTICAL VALUES REPRESENTING THE DIFFERENCES BETWEEN OBJECTIVE AND SUBJECTIVE MEASUREMENT FOR 75 OVERNIGHT RECORDINGS

Characteristic	Mean	Median	SD
Total sleep time	00:32	00:28	00:19
Sleep efficiency	7,50%	7,06%	3,28%

Analysing the findings, one can see that the difference between the two measurement methods is, on average, more than 30 minutes for TST. If this difference can be acceptable for a substitution depends on the particular aim of the sleep characteristics analysis.

In the case of SE measurement, a 7,5% difference appears to be relatively low, which leads to the conclusion that a substitution may be reasonable for this sleep characteristic.

To facilitate a comprehensive and comprehensible representation of the obtained evaluation results, box plots for TST and SE were generated and presented in Figure 1 and Figure 2.

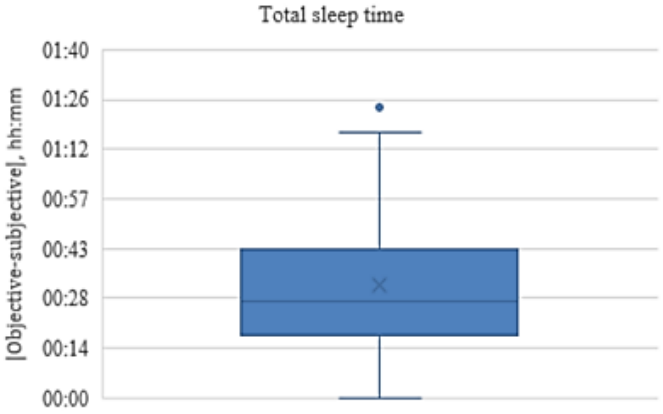

Fig. 1. Box-plot visualising the differences between the objective and subjective measurement of total sleep time for 75 overnight recordings.

Analysing Figure 1, it can be observed that outliers may reach up to 1 hour and 25 minutes of difference for a single night. This leads to the assumption that an exchange of measurement methods cannot be recommended if an accurate measurement is necessary for particular nights.

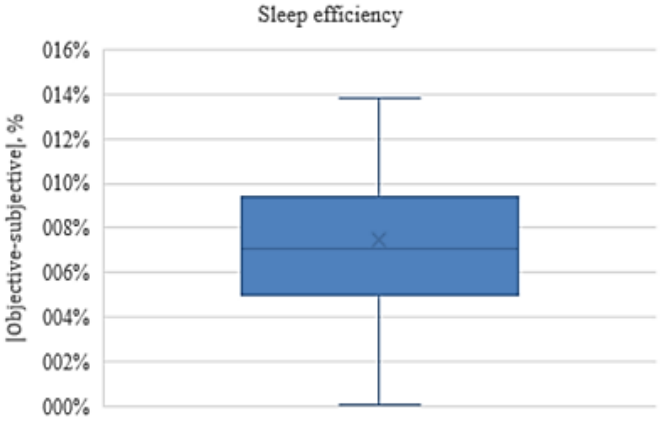

Fig. 2. Box-plot visualising the differences between the objective and subjective measurement of sleep efficiency for 75 overnight recordings.

When analysing Figure 2, it can be seen that the differences between measurement approaches are between 0% and 14%, meaning that the highest reliability of the results in the case of substitution can be achieved by a long-term observation of the SE parameter.

IV. Conclusion and Future Work

Since an automatic measurement of sleep characteristics could increase the convenience for the users and reduce potential missing data, as the measurement could be done fully automatically, the evaluation of the possibility of replacing the sleep diary with an electronic device seems reasonable.

In the work presented in this article, the Samsung Galaxy Watch 4, one of the state-of-the-art smartwatches, was chosen for the objective measurement. It is essential to mention that the findings and conclusions obtained refer to this particular smartwatch and cannot be directly transferred to other hardware devices. To summarise the results, the following statements can be presented as the main conclusions:

- The evaluation of the TST as one of the meaningful

sleep characteristics led us to the conclusion that the substitution of the subjective measurement by the objective one and vice versa is unreliable when a high level of accuracy is required. One of the reasons is a substantial underestimation of awake time during the night in the case of the subjective measurement, which leads to an overestimation of TST. This also coincides with other reported findings in this area [16].

- Another parameter that was analysed - SE - seems to be suitable for replacing a sleep diary as a measurement method with a Samsung Galaxy Watch in the case of long-term observation, as the difference between the two approaches is 7.5% on average.

The performed analysis of the findings has allowed us to determine the following steps to be performed within the research line:

- Extension of the number of recordings, as well as the increase of participants number, is one of the main aims. This would allow us to enlarge the significance of the outcome.
- A broader set of parameters might be included in the evaluation, e.g., Time of Falling Asleep or Wakeup Time.
- Other devices might also be introduced in the evaluation, allowing for a certain generalisation of the outcomes. It is known that different measurement and analysis approaches, including algorithms using signals that may be measured in a non-obtrusive way [17-19], are available and can be applied to various devices. Therefore the extension of the set of devices appears to be reasonable.

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