JoyStick: Measuring Vigilant Attention for Sleep Quality

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ABSTRACT

Sleep is an a priori condition for sound functioning during the day. Understanding the conditions for good sleep quality is a valuable research field. However, most sleep quality measurement devices are aimed at the lab setting. In this paper, we present JoyStick, a new sleepiness measuring device aimed at the field context. It is a self-contained, network-connected tangible measurement device that instructs users to engage in a short psychomotor vigilance test. Through experimentation, we demonstrate that the device's measurements correlate to self-reported sleepiness and that it measurements are significantly different for moments when a participant suffers sleep inertia compared to when the participant is fully awake. Unlike devices built for the lab setting, the JoyStick can be deployed in the field environment for in-situ sleep research.

KEYWORDS

Research products; sleep research; design research; tangible interaction; in-situ sampling.

INTRODUCTION

Sleep is a vital biological function. Both a sufficient sleep duration and continuity are requirements for the restoration of neurobehavioural performance capacity [2]. This makes quality sleep an apriori condition for adequate human functioning during the day. Sleep quality can be defined by '*tiredness upon waking, feeling rested, and the number of awakenings experienced during the night*' [21]. However,

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poor sleep quality results in more than solely morning tiredness [11]. A low sleep quality increases sleepiness throughout the day. It decreases mood, motivation and scores on working memory tasks [10] and impairs daytime functioning [23]. Many factors are theorized to negatively impact sleep, e.g., lower melatonin production [6], the use of electronic media [12], or substance use such as caffeine [5]. However, to be able to determine which parameters influence the quality of sleep, we first have to measure sleep quality itself. One of the most decisive effects of poor sleep quality is the degradation of attention, especially vigilant attention [19]. This degradation of vigilant attention can be measured by the psychomotor vigilance test (PVT). It measures vigilant attention by recording response times to visual or auditory stimuli that occur at random intervals. It operates on the hypothesis that when individuals have had a lower quality of sleep, their response time will be higher and they are more prone to make mistakes. It is important for sleep researchers to better understand sleep quality and which conditions influence sleep outside the lab. To measure sleep quality in the home context, a research product [16], JoyStick, was developed. JoyStick is a portable PVT device, designed to be operational under home-use circumstances, i.e., well-designed out-of-box behavior, easy operation, and few connectivity requirements. In the following, we will discuss the design considerations of the tool, the technical aspects, preliminary evaluation, and finally possibilities for deployment of the tool within clinical studies.

RELATED WORK

The quantity and quality of sleep can be measured with polysomnographic recordings (PSG); a lab based test that records brain activity (EEG) [22, 24], muscle activity (EMG) [25], and eye movement (EOG) [26]. PSG is considered to be the most accurate method of sleep assessment. But it is not practical for field studies or longitudinal studies. Currently two other methods are used in field studies to measure sleep: First, subjective sleep assessment by self-report in sleep diaries, or secondly, actigraphy, which can be done by wrist-worn activity trackers (e.g., Fitbit) that assesses when sleep takes place from the amount of physical activity detected. Both these methods have their limitations. Studies have suggested that individuals have a difficult time evaluating their sleep, especially if they are suffering from insomnia [1]. Furthermore, there are studies that suggest that gender and age of the individual plays a role in their subjective sleep assessment [18]. Activity trackers have been used in several clinical studies. However, the interpretation of the activity levels at night can be difficult. Low activity does not always mean that the individual is sleeping: the individual might be lying still but awake. On the contrary, high activity does not always mean that the individual is awake, the individual may sleep restlessly [20].

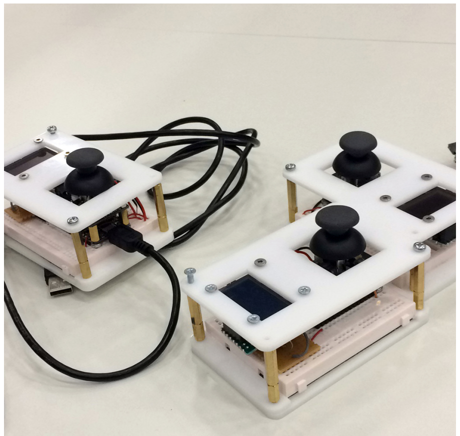
Another way to measure sleep quality is the Psychomotor Vigilance Test (PVT). This test measures an individual's vigilant attention or alertness. One of most common effects of a low sleep quality is degradation of attention [9]. The PVT-test is a variant of 'stimulus-response' method: it measures

The Stanford Sleepiness Scale (SSS) The Stanford Sleepiness Scale (SSS) is a self-report scale which is used to evaluate sleepiness in seven gradual steps [15] in research and clinical settings. We employ this scale in the evaluation of JoyStick. The SSS assesses sleepiness at a specific moment in time, unlike the the Epworth Sleepiness Scale [14], which examines general experiences of sleepiness over the course of an entire day, or the Pittsburgh Sleep Quality Index (PSQI) which assesses which sleep quality and disturbances over a 1-month time interval [4].

The SSS requires individuals to select one statement that best represents the grade of sleepiness that they perceive at the time [13].

Respondents use a scale from 1 to 7 to indicate their current level of sleepiness:

(1) Feeling active and vital; alert; wide awake.
(2) Functioning at a high level, but not at peak; able to concentrate.
(3) Relaxed; awake; not at full alertness; responsive.
(4) A little foggy; not at peak; let down.
(5) Fogginess; beginning to lose interest in remaining awake; slowed down.
(6) Sleepiness; prefer to be lying down; fighting sleep; woozy.
(7) Almost in reverie; sleep onset soon; lost struggle to remain awake.



Sidebar 1: JoyStick device

The device has a rectangular shape, similar to a small mobile phone, and it is easy to hold. The stimuli are shown on a LCD screen that resides on the upper part of the device. A joystick module with multi-directional inputs is used as input modality and it is mounted below the display to be easily accessible for the thumb. This specific choice of hardware was made due to the main requirements of the device to be a) portable (so that can be used in different user's bedrooms) and b) able to log and store the different data of the different participants in one data set remotely. Due to safety concerns the device is powered by a micro USB cable which could easily be plugged in in any wall socket or power bank.

vigilant attention by recording response times (RT) to visual or auditory stimuli. These stimuli occur at random inter-stimulus intervals. PVT based studies use different definitions for calculating PVT outcome metrics. The most common outcome metric is the number of lapses of a participant [3], defined by a RT > 500ms. A PVT test can be affected by hardware. Important in PVT measurement tools is the implementation of the input modality. These range from single buttons to a screen-based interaction with a touch screen or a laptop. The validity of these input modalities has been the key measurement in recent studies, showcasing that different devices can create accurate results [7]. However, these tools are not yet situated in the everyday setting of a participant's home but in a lab setting.

DESIGN OF JOYSTICK

With JoyStick, we focus on designing a device that can be deployed and used in the home environment. This allows for a familiar setting for the participant to measure their sleep quality in. Details on the hardware design can be found in the sidebar 1. The JoyStick was designed to establish a connection to a data collection server directly via WiFi (potentially tethered to a smart phone). This allows to operate the measurements in diverse contexts. We built JoyStick in a series of 3 devices that could be used independently by participants and that collected data segmented per participant. The input modality of our PVT-test differs from traditional PVT devices, which operate on simple RT testing (1 stimulus, 1 response). We present a choice RT test with 4 stimuli and 4 response options. It is hypothesized that this is more engaging and thus will sustain prolonged use. However, a four-choice PVT task could cause continued learning effects and strategy shifts to occur in the participants [8]. The device is used as follows: As soon as the individual wakes up, they start the device, which will also initiate the connection to the server. Then the participant gets a visual cue and by pressing down the joystick they start the test. The individuals perform a choice reaction time task with goal to respond as fast as possible to the stimuli on the screen. The stimuli are 4 directional arrows, i.e., up, down, left, right, and individuals respond to the stimuli by moving a joystick in the corresponding direction. The stimuli are shown with a random direction and a random interval to prevent individuals predicting when they have to move the joystick. The device acknowledges every response by showing 'correct' or 'wrong' on the screen for 0.3s. After a random amount of time between 0.5s and 5s a new directional arrow is shown. The length of the test and moment the test is taken can be varied depending on the design of the experiment the tool is used in.

EVALUATION

Clinical sleep studies often use protocols in which the participants are fully deprived of sleep (acute total sleep deprivation protocol) or where the sleep of the participants is restricted to a low amount (chronic partial sleep deprivation protocol) [17]. As this is out of the scope of our evaluation, both

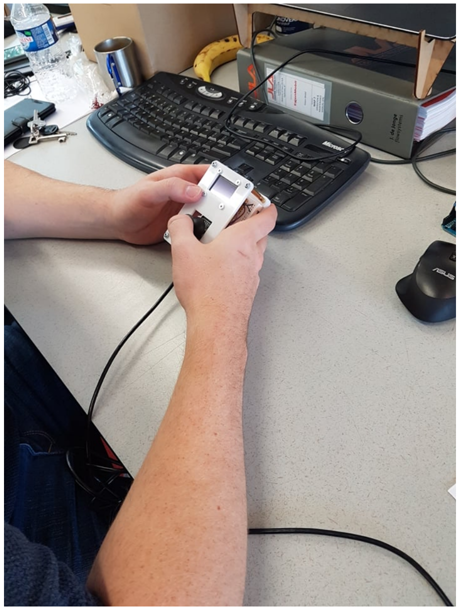


Figure 1: Participant using JoyStick in the afternoon condition

ethically and technically, we decided to simulate sleep deprivation. Behaviorally, there is a period referred to as sleep inertia following awakening from sleep. There is decreased cognition and responsiveness to stimuli compared to what is observed after several more minutes, or even hours, of wakefulness [22, 24]. To evaluate JoyStick, we aim to measure a difference in individuals number of lapses just after waking up and at noon (on the same day). We further evaluate how self-reported sleepiness correlates to the measured number of lapses.

Participants and Design

Three participants took part in this study. All participants were female and ranged in age from 24 to 25. All of them were right-handed, and controlled the input device with their thumb. Each trial lasts 6 minutes, after which the device gives the participant feedback by flashing the screen and disconnecting from the server. Participants conduct the trials in the morning, directly after they wake up (condition 1), and at noon (condition 2). The experiment lasted three days, resulting in 18 trials overall.

A repeated measures within-participant design was used. The independent variables were the time of day conditions; morning and afternoon. Dependent variables contained the participants self-reported sleepiness on the SSS and the number of lapses during a trail. A response was regarded as valid if RT was $\geq$ 100 ms and $\leq$ 1500 ms. Responses without a stimulus, RTs $<$ 100 ms or RTs $>$ 1500 ms were excluded from the analysis. Moving the joystick in the wrong direction or failing to release the joystick so it moves back to its neutral position are counted as faulty responses. Faulty responses and responses with a RT exceeding 500 ms are counted as a lapse.

Results

Sleep inertia vs wakefulness. To test the null hypothesis that alertness in the morning ($M = 117.00; SD = 49.26$) and in the afternoon ($M = 46.22; SD = 25.42$) were equal, a dependent samples t-test was performed ($N = 18$). Prior to conducting the analysis, the assumption of normally distributed difference scores was examined. The assumption was considered satisfied, as the skew and kurtosis levels were estimated between $0.57; 0.62$ and $0.72; -1.73$ respectively. The null hypothesis of equal means was rejected, $t(N) = 5.64, p < .0001$. Thus, the mean of the amount of lapses in the morning was significantly higher than the amount of lapses of participants in the afternoon.

Relationship self-report and measurement. To determine the relationship between the self-reported sleepiness on the SSS ($M = 3.50; SD = 1.47$) and the number of lapses that were measured ($M = 81.61; SD = 52.65$), we performed a simple regression analysis. Prior to conducting the analysis, the assumption of normality was analyzed. Both variables were normally distributed, $p \geq .05$. We analyzed the correlation between the two variables through Pearson's r analysis and found a strong positive correlation of $r = .84$. The regression model has an adjusted R squared value of 0.69 with a

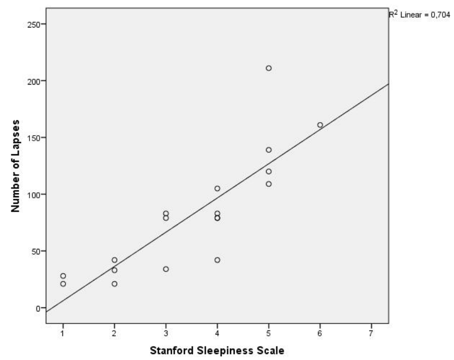


Figure 2: Simple linear regression between SSS-scores and measured lapses over 3-day testing period

$p < .001$. Thus, the self-reported sleepiness of the participants significantly predicts the number of lapses that we measure with the JoyStick. The relation can be viewed in figure 2.

DISCUSSION

Results indicate that the data coming from JoyStick devices can help distinguish between conditions in which users have lower cognitive functioning due to sleep inertia and also when they have normal cognitive function during the day. Furthermore, the sleep quality metrics that the devices collect are correlated to self-reported sleepiness. However, the measurements are preliminary with a low sample size over a short time period. Also our experimental method warrants some discussion: individuals have different personal baselines for sleepiness, which makes interpretation of sleepiness scale results difficult. Unlike previously described sleep quality measuring techniques which are either subjective measurements or lab-based quantitative measurements oriented, JoyStick can be used to quantitatively measure sleep quality in the home environment of the user, which allows to extend JoyStick's scope beyond scientific studies towards, e.g., quantified self applications.

CONCLUSION

In this paper, we present the JoyStick, a new sleepiness measuring device targeting field settings. It is a self-contained, network-connected tangible measurement device that instructs users to engage in a short psychomotor vigilance test. The outcomes of this test, metrics of speed and correctness, can indicate vigilant attention and thereby approximate sleep quality. Through experimentation, we have demonstrated that the device's measurements correlate to self-reported sleepiness and that its measurements are significantly different for moments when a participant suffers sleep inertia compared to when the participant is fully awake. Unlike many previously described devices built for the lab setting, the JoyStick can be deployed in the field for in-situ sleep research.

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