Estimation of elapsed time after spontaneous wake-up from sleep in home setting

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Time estimation after wake-up from sleep has in earlier studies been shown to correlate with relative amount of slow-wave sleep. The aim of this study was to investigate if this effect could be found with subjects sleeping until spontaneous wake-up. Twenty-six women who slept alone at home, equipped with an actigraph and a questionnaire, participated in the study. The result showed that there was a positive correlation between time in bed, which was assumed to reflect relative amount of slow-wave sleep, and subjective time in relation to objective time. However, there also was a positive correlation between predicted wake-up time before going to sleep and subjective time in relation to objective time. This suggest that the former correlation might have been a result of pure intellectual guesses. Further studies, using more participants or different research designs, are needed to investigate or reject this eventual relationship.

Time estimation ability in humans can be divided into three different areas; millisecond timing, interval timing and circadian timing (Buhusi & Meck, 2005). Millisecond timing is necessary for things like motor control, speech recognition and speech production. Circadian timing on the other hand is responsible for things like the sleep-wake cycle and the regulation of appetite. Interval timing falls somewhere in between with its emphasis on aiding conscious time estimation tasks in the second to minute to hour range. The system underlying conscious time estimation has primarily been investigated through experiments with subjects in waking states but less is known how it operates during sleep.

During sleep, humans and other mammals usually go back and fourth through several different sleep stages, characterized mainly by their frequency on an EEG reading and by their different activation and deactivation of separate brain areas (Silber et al., 2007). Slow-wave sleep, the deepest of all sleep stages, has the lowest frequency whereas REM sleep, the stage when most of the dreaming takes place, has the highest. Further, slow-wave sleep occurs in greater amounts in the earlier parts of sleep than in the later, when REM sleep is more dominant.

Human estimation of elapsed time after wake-up from sleep has first and foremost been studied in the clinical research field (e.g. Edinger & Fins, 1995; Means, Edinger, Glenn & Fins, 2003; Pinto et al., 2009; Tang & Harvey, 2005). Focus has been on patients with insomnia and paradoxical insomnia where the latter condition is characterized by a constant underestimation of how long one has slept and how long it takes until falling asleep, even though the patient can show otherwise normal sleep measures (Merzeer, Bootzin & Lack, 2003). No problems with time estimation during wakefulness have been found in people with this condition (Rioux, Tremblay & Bastien, 2006). However, a behavioral experiment have shown that the problem in estimating how long one lays awake before falling asleep can be partly corrected by presenting gathered sleep data to the subject, thereby objectively confirming his or hers misperception (Tang & Harvey, 2004). The same experiment could not correct the misperception of total sleep time though.

Aritake-Okada et al. has in a recent study (2009) looked into healthy young males' time estimation ability regarding elapsed time spent in sleep. In this study, the participants were woken up 6 times during the 9 hour long experimental phase to give a subjective estimation of the elapsed time since their last wake-up trial. The result showed a positive correlation between relative amount of slow-wave sleep and time estimation ratio (TER), where the latter measure was computed through dividing subjective elapsed time with the actual time interval. Since slow-wave sleep is more frequently occurring in the beginning of sleep, subjects tended to show a lower time estimation ratio in the latter trials than the former. Also, no difference was found between a group that slept during the day and a group that slept during the night even though the two groups' circadian rhythm was in phase with each other. These results differ from time estimation experiments with waking subjects where circadian rhythm alters time perception by creating an underestimation of the elapsed time during nighttime (Kuriyama et al., 2005) suggesting that perhaps different time measuring systems in the brain are used during wake and sleep. Aritake-Okada et al. (2009) surmises that the general effect of overestimating time when exposed to more relative amount of slow-wave sleep is due to the inactivation of the frontal lobes, characteristic of this state (Kajimura et al., 1999). Since the frontal lobes has been shown to be a vital part in time estimation (Buhusi & Meck, 2005), inactivation of them may very well result in disturbed time perception.

One could pose the question if the results from Aritake-Okada et al.'s (2009) study could be generalized to more ecologically valid situations. For once, it is possible that the reoccurring awakening trials altered the subjects normal sleep patterns or their subjective time estimation in some way. Also, there could be a difference between being deliberately woken up and being allowed to sleep until spontaneous wake-up regarding time estimation. Therefore, the aim of this study was to look for the effects in a less artificial situation allowing the participants to sleep at home without setting no alarm clock.

Further, the aim in this study was to investigate healthy subjects, just as in Aritake-Okada et al.'s. Therefore, only people without any current or earlier medical diagnosis of any sleep disturbances were allowed to participate. While this filtering process probably excluded some unfit participants, it can not be said to have been rigorous enough to guarantee that no subjects with sleep disturbances participated. Earlier studies have shown that the difference in time estimations after sleep between healthy women and women with insomnia is lesser than between the same groups for men (Voderholzer, Al-Shailawi, Weske, Feige & Riemann, 2003). With respect to this, a randomly assigned group of women should give time estimations closer to the population of healthy subjects than a randomly assigned group of men. All this, in combination with the fact that Aritake-Okada et al. (2009) only included men in their study, drove the decision to target only women in this one, since an eventual positive result, in combination with Aritake-Okada et al.'s work, should be easier to generalize to both genders.

The expected result was that the longer the subjects slept, the lesser they would overestimate the actual time interval since they would get less relative amount of slow-wave sleep. The participants were therefor equipped with actigraphs (a wrist-worn device with an internal clock and a piezoelectric sensor which registers movements of the arm) to ensure that they actually slept and did not lay awake. Further, to control that the participants did not just guess the time using their own experience of how long one usually sleep when setting no alarm clock, a scenario that could have given data in concordance with the expected results, two different groups were used. The first group, which consisted of half of the subjects, was prompted to guess at which time they would wake-up before going to sleep, while the second one, which consisted of the other half, received no such instructions. The expected result was that this measure would not contribute to explain an eventual correlation between objectively elapsed time and TER.

Method

Participants

26 female psychology students from Stockholm University participated in the study. They were between 19 and 33 years old (M=24.5, SD=3.8). For their participation they received course credits. None of them had any prior or current medical diagnosis of sleep disturbances.

Procedure

All participants received a questionnaire and an actigraph to bring home. They received both verbal and written instructions on how to conduct the study. In these instructions, the participants were instructed to read through the whole questionnaire before beginning the study. The subjects were told to choose a day when they would sleep all alone in their home and set no alarm clock or in any other way take measures to avoid spontaneous wake-up in the morning. They were instructed to make the room as dark as possible before going to bed. Also, they were told to note, and write down, the time before lights out, then conceal all visible clocks and push a button on the actigraph, indicating the current time. When they woke up in the morning and had finished their sleep, the instructions were to fill out the questionnaire as soon as possible while staying in bed. After answering the first question in the questionnaire, they were instructed to once again push a button on the actigraph, indicating the current time.

Half of the subjects were asked, right after noting the current time before sleeping, to estimate when they thought they would wake up while the other half received no such question. The two groups were assigned by having every other questionnaire containing this question.

Questionnaire

In the questionnaire, the subjects were asked the following ten questions (which here are translated from Swedish):

1. What do you think the time is right now? (After answering this question, the subjects were instructed to push a button on the actigraph to register the actual time);
2. How long time do you think elapsed from lights out to sleep onset?;
3. How many times did you wake up and went to sleep again during the sleep period?;
4. What was the reason (if anything special) for your latest wake up?;
5. What factors in your environment do you think might have functioned as cues as to telling you what time it was when you woke up?;
6. Did you take any kind of medicine or stimulant drugs (including coffee and tea) 12 hours before going to bed? If so, approximately at what times and in what volumes?;
7. How regular sleep routines do you have regarding when you go to bed? (1. very irregular; 2. rather irregular; 3. rather regular; 4. very regular);
8. How regular sleep routines do you have regarding for how long you sleep? (same alternatives as question 7);
9. How regular sleep routines do you have regarding when you wake up? (same alternatives as question 7 and 8);
10. Generally, how big sleep disturbances do you have? (1. none; 2. small disturbances; 3. rather big disturbances; 4. very big disturbances);

Actigraph

The actigraph used was the Actiwatch-L from Camntech. The actigraph was set to register an average of the activity for every elapsed minute. The data was analyzed with Actiwatch Activity & Sleep Analysis 5.24 by Cambridge Neurotechnology Ltd. for Windows XP. Sleep analysis was performed automatically from within the program.

Time frame

The study was conducted in the Stockholm area between 18th of April to 15th of May. Under this period, the sun in the Stockholm area sat between 20:11 and 21:13, and rose between 05:25 and 04:15.

Data reduction

A sleep efficiency measure was calculated by dividing time assumed sleeping, as given from the actigraph and later analyses in the actigraph software, with time in bed. Further, a regularity measure was created through computing the average of the three questions from the questionnaire regarding regularity in sleep habits.

Time estimation ratio (TER) was computed by dividing subjective estimation of elapsed time after wake-up with objectively elapsed time, as given from the actigraph. Wake-up prediction ratio (WPR) was computed by dividing predicted elapsing time until wake-up with objectively elapsed time. In both TER and WPR, a value greater than 1 meant that the subject overestimated the time whereas a value lower than 1 meant that she underestimated it.

Results

Five participants were excluded from the study since they misunderstood and/or did not follow the instructions which in turn made their data unusable. Of these, two forgot to push the button on the actigraph at wake-up while the other three had a discrepancy between the noted bed time and the bed time according to the actigraph that exceeded 20 minutes. Also, three of the participants misunderstood the wake-up prediction question and estimated the time until they would fall asleep instead. These subjects were excluded from the wake-up prediction group and instead included in the group receiving no such question. After these rearrangements, 21 subjects where left in the study. Of these, 9 were in the wake-up prediction group while the other 12 were in the group receiving no such question.

Descriptive data

The average regularity measure of the participants was 2.65 (SD=0.53). The participants answered the question regarding how big sleep disturbances the had with an average of 1.48 (SD=0.512). On average, they spent 513 minutes (SD=91) in bed but estimated on average that they had spent 528 minutes (SD=88) in it. This resulted in an average TER of 1.04 (SD=0.15). On average, the participants went to bed at 23:11 (SD=64 minutes) and got up at 8:29 (SD=77 minutes). The participants had an average sleep efficiency measure of 84.6% (SD=5.7). None of the subjects got up before sunrise.

Those participants who were asked to estimate their wake-up time estimated on average that they would stay in bed for 551 minutes (SD=100). This resulted in an average WPR of 1.17 (SD=0.11). Further, on average, this group actually stayed in bed for 476 minutes (SD=106) and thought that they had stayed in it for 525 minutes (SD=115). The same measures for the group receiving no wake-up prediction question was 540 minutes (SD=69) and 530 minutes (SD=67) respectively. On average, the wake-up prediction group went to bed at 00:01 (SD=63 minutes) and got up at 07:57 (SD=86 minutes) while the other group on average went to sleep at 23:53 (SD=67 minutes) and woke up at 08:53 (SD=62 minutes).

Statistical analyses

The alpha level of all the statistical analyses was set to 5%. First, the group prompted to predict wake-up time was compared to the group getting no such question regarding how long time passed between lights out and answering the questionnaire. Results showed no significant difference between the two (t_{19}=1.57, p=0.140). Also, there were no significant difference between when the two groups went to bed, when they got up or how long they estimated to have stayed in bed. No significant correlation between objectively elapsed time since lights out and WPR was found in the group that predicted wake-up time (r_7=-0.602, p=0.086). However, there was a significant correlation between WPR and TER (r_7=0.745, p=0.021) (figure 1). Since the two groups did not differ, analyses with both groups concatenated into one was performed. There was a significant negative correlation between objectively elapsed time since lights out and TER (r_{19}=-.444, p=0.044) (figure 2). No significant correlation could be found between sleep efficiency and TER.

Two linear multiple regression analyses were performed. First, an analysis of the wake-up prediction group was made using age, the regularity measure, sleep efficiency, time assumed sleeping, WPR and objectively elapsed time as independent variables. This revealed that WPR was the only predictor of TER (b=1,29, p=0,021) (figure 1.), explaining 49.2% of the variance in TER. Secondly, an analysis of all the participants was made with the same set of independent variables as in the first analysis except for the WPR variable. This revealed that time in bed since lights out was the only predictor of TER (b=0.00075, p=0,044) (figure 2.), explaining 15.5% of the variance.

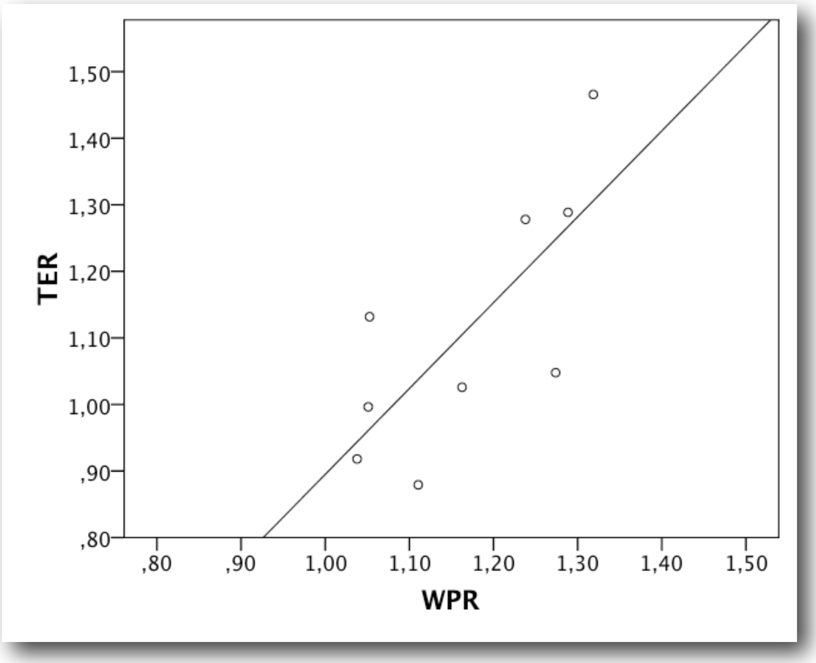

Figure 1. Correlation between WPR and TER
with a fitted regression line.

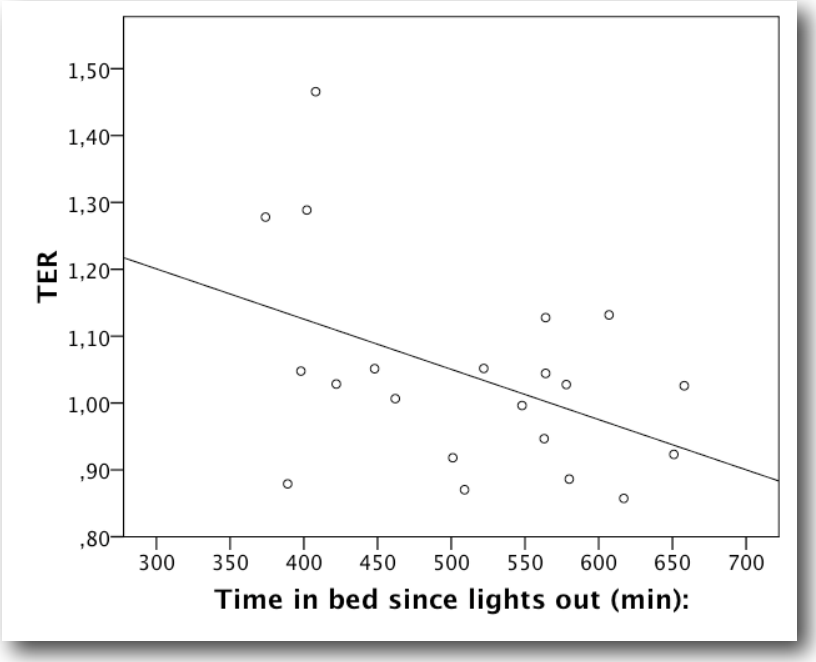

Figure 2. Correlation between objectively elapsed time since lights out and TER with a fitted regression line.

Discussion

Time estimation in this study is assumed to consist of three different parts. First, the subject have an intellectually formed belief based on experience about how long one usually sleeps during certain conditions. Secondly, the subject gets external cues through stimuli from the environment (e.g. light and sounds). Thirdly, the subject have internal time perception cues as to how long she has slept which, per definition, consists of all the cues that does not fit into the two earlier cue categories. These three different parts (figure 3) might not always be separably available for introspection for the subject herself, but they should all contribute to the final time estimation, though in different amounts for different subjects.

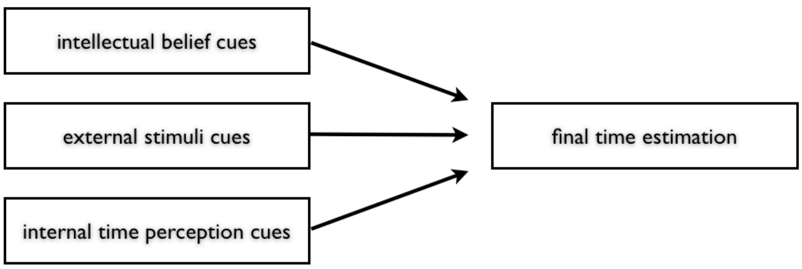

Figure 3. Theoretical model of separate parts contributing to final time estimation.

The aim in this study was to replicate Aritake-Okada et. al.‘s finding (2009) by measuring how internal time perception cues varies with amount of sleep which in turn was expected to reflect relative amount of slow-wave sleep. As expected, there was a significant correlation between time in bed since lights out and TER. Also, time in bed since lights out was the only predictor for TER in a linear regression analysis, including all the subjects. However, the important question is if this effect was a product of variance in internal time perception cues or if it was caused by some of the other two categories of cues that could effect the time estimation of the participants.

Instead of using repeated awakening trials as in Aritake-Okada et. al.‘s studies, the subjects in this study were allowed to sleep until spontaneous wake-up. This made it possible for the participants to use their experience as to how long they were going to sleep. Also, they were sleeping at home which, while it made the design less artificial, also meant that external cues as light and sound were available. In other words, while the participants in Aritake Okada et al.‘s studies did not have access to external stimuli cues and had no earlier experience with the used time interval between wake-up trials, the participants in this study could use both these cues to some extent in addition to internal time perception cues.

Measures to minimize the external cues were taken through instructing the participants to sleep alone and to darken their rooms as much as possible. However, external cues could neither be fully excluded, nor fully controlled or measured in any satisfying way. The assumption about external cues in this study was that (I) subjects with access to external cues will under normal circumstances, in the long run, give more accurate estimates of the time than subjects without external cues and (II) external cues will narrow the variance of the answers but will not change the mean in any way. An eventual effect of objectively elapsed time on TER should therefore only be weakened, not extinguished, by external stimuli cues. However, this should only hold true if there is not some kind of easily noticeable global cue, available for all the subjects, giving an indication of the current time, the most obvious example of this being if the sun is up or not. This would not only narrow the variance of the answers but also probably distort the relationship between objectively elapsed time and TER by, for example, making overestimations rare before sunrise and underestimations rare after sunrise. Since all the subjects woke-up after sunrise, it can be assumed that this factor did not distort the relationship between objectively elapsed time and TER, only that it might have weakened it.

Intellectual belief cues were partly measured through asking one group of the participants for a prediction of their wake-up time. Statistical analyses showed that there was a significant correlation between WPR and TER. This correlation also showed up in the linear regression analysis where WPR was the only predictor for TER for this group. Further, there were no significant correlation between time in bed since lights out and WPR. However, since the wake-up prediction group was so small, one could be skeptical to the external validity of this latter analysis, even more so because of its small p-value. One could speculate that if WPR correlates with TER, and time in bed since lights out also correlates with TER, time in bed since lights out really should correlate with WPR too. If this is the case, time estimation after spontaneous wake-up from sleep can be assumed to largely be a product of intellectual belief cues. However, that would not mean that internal time perception cues are not affecting final time estimation, only that the effect was to small to find in this study. If a multiple regression analysis had shown that time in bed since lights out was a predictor of TER even when WPR was held constant, it would have given some clues as to how big an eventual effect of internal time perception cues might be.

There was no significant difference between how long the wake-up prediction group and the group receiving no such question slept. However, one could be skeptical to the validity of this analysis too, once again because of the small groups and the relatively small p-value. Earlier studies have shown that expectations regarding wake-up time can influence the sleep and associated physiological measures in certain ways (Born, Hansen, Marshall, Mölle & Fehm, 1999). This could suggest that the mere fact that the participants guessed the wake-up time could have influenced how long they subsequently slept. However, if this effect would be found in future studies with the same research design as in this one, the extent of the effect could be measured and adjusted for in the main analysis.

Further, as a secondary analysis, two interesting things could be seen when browsing through the data. First of all, nobody underestimated how long they would sleep when asked to predict the wake-up time. Further, all the given time estimations after sleeping that were over 0.20 points away from 1 on the TER-scale were overestimations and were made by short sleepers. This might suggest that the biggest risk of making grossly incorrect estimations of the time will be when waking up early, rather than late. However, both these tendencies really should be investigated further before anything concrete could be said about them.

The general problem with the kind of research design that was used in this study is that it is difficult to control that the participants follows instructions and do not deviate from each other to much in terms of home environment and other external factors. This problem could partly be fixed by including more participants in the study, making the variance due to these factors cancel each other out. Also, letting subjects sleep in an isolated lab setting, cleared of external stimuli cues, until spontaneous wake-up would fix the problem.

In summary, the result from this study is inconclusive regarding if amount of slow-wave sleep is causally linked to TER under normal sleeping conditions. More research, concentrating on identifying the relationship between intellectual belief cues and internal time perception cues and how they together form the time estimation after sleep, is needed.

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