The Internal Alarm Clock

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Abstract

An alarm clock has disadvantages as creating a lot of stress compared to waking up without one. Waking up at the desired time without an alarm clock thus sounds like the ideal situation. Studies show that people can do this 62% of the time with an accuracy of their target time ± 30 minutes. Other studies show that 55% self-awakens at home on a regular basis. People that self-awaken show physiological changes preceding the awakening. They also show a better mood and feel less tired. Taking this into consideration, self-awakening could be beneficial to a great deal of society as it is available to all. It should be considered as a standard awakening method.

Introduction

Sleep and related topics have caught a lot of interest, a simple search for 'sleep' in 'Google Scholar' gives around 2.3 million hits. This is because sleep and sleep disturbances show relations with a lot of issues that play a notable role in society. One example of major importance in today's society is obesity (Mitchell NS, 2011). Roenneberg et al. shows that sleep relates to obesity (Roenneberg T, 2012). Other studies show relationships between cardiovascular diseases and sleep (Kantermann T, 2013) and nicotine intake and sleep (Wittmann M, 2006). These studies and many other are related to the timing of sleep. The timing of sleep is defined as a two-process model, a combination of the oscillating process C and the homeostatic process S (Daan S, 1984) as shown in figure 1. The process S represents sleepiness which increases during wakefulness and decreases during sleep. It works much like a thermostat. Process S starts to rise when it hits the lower threshold and starts to decrease when it hits the higher thresholds. These thresholds are formed by the oscillating process C. This oscillating process is created by many physiological oscillations which are in turn generated and/or synchronized by the master oscillator: The circadian pacemaker. The master oscillator is synchronized to an external stimulus (Zeitgeber), the day-night-cycle (light-dark 24h) is one of the most important of these (Aschoff, 1965). Under constant conditions (e.g. constant darkness or constant light in contrast to light-dark) this master oscillator continues to function (free-running) but its period deviates from the entrained 24 hours rhythm and can either be longer or shorter (≤24h≥) (Aschoff, 1965). The length of the free-running period differs from one person to another. The differences in these free-running periods create the different

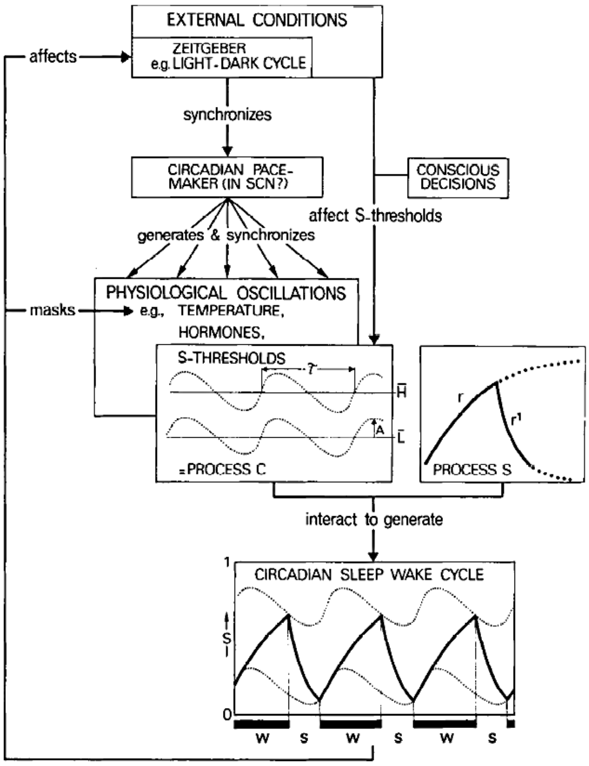

Fig. 1 The Two-process sleep model (Daan, et al., 1984)

activity onsets for everyone, which can be seen as the phase angle between dawn and activity onset (Roenneberg T, 2000). These differences are the basis of the distribution of 'chronotypes'. The distribution of chronotypes within a population is not unlike a normal distribution, only with a bias to the later chronotypes (Roenneberg, et al., 2007a). Figure 2 shows this distribution judged by MSFsc mainly assessed in Germany, Switzerland, the Netherlands and Austria (Roenneberg, et al., 2007a) and is based on the **M**unich **C**hrono**t**ype **Q**uestionnaire (MCTQ) (Roenneberg T, 2003).

MSFsc is an abbreviation for **m**id-**s**leep on **f**ree day (**s**leep **c**orrected) and in practice this is the

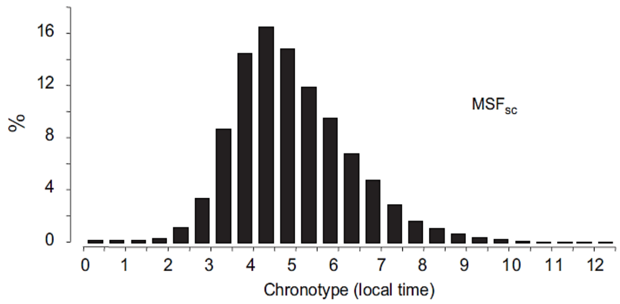

Fig. 2 The distribution of chronotypes in mid-sleep time on free days, corrected for oversleep (Roenneberg, et al., 2007a)

median of the time of sleep onset and the time of wake-up corrected for oversleep on free days (e.g. MSFsc of 5 could for instance mean a sleep onset 01:00 and a wake-up time of 09:00). Free days are used since during these days people sleep the hours they prefer to because they do not have obligations for which they would have to wake-up (e.g. their job, college etc.). The MSFsc is corrected for oversleep caused by compensation of the sleep deprivation accumulated on workdays (Roenneberg, et al., 2007a). On workdays people have their obligations. These obligations force them to awaken at an earlier time point then they would preferably do, this creates a sleep debt. Primarily the later chronotypes encounter this as they preferably would awaken at a time that is (much) later than the start of most common jobs (Wittmann M, 2006). Due to the fact that there is a bias in the population in favor of the later chronotypes (figure 2), many people experience this sleep debt. The sleep debt is calculated as the difference between the mid-sleep point on workdays (MSW) and the aforementioned mid-sleep point on free days (MSFsc) and goes by the name 'social jetlag' (Wittmann M, 2006). Social jetlag is correlated with multiple factors that cost society a lot. Smoking (Wittmann M, 2006) and obesity (Roenneberg T, 2012) are correlated with social jetlag. In 2010 smoking accounted for €2,8 billion of the total healthcare costs in the Netherlands, obesity accounted for €1,6 billion (in 't Panhuis - Plasmans M, 2012). As social jetlag occurs more in the later chronotypes it is also connected with attention problems, poorer school results and injuries as these factors are connected with eveningness (Gianotti F, 2002). Eveningness correlates with (a later) chronotype as shown by Roenneberg et al. (Roenneberg T, 2003). All the people that suffers from social jetlag have at least one thing in common, they all are forced to awaken at their workdays. This is usually by the means of an alarm clock, but forced-awakening implies all forms of non-voluntarily awakenings (e.g. in some studies phone calls are used). Forced-awakening brings certain disadvantages compared to awakening by yourself, these disadvantages could even play a role in the negative effects of social jetlag. A study by Berndt-Zipfel et al. shows that an alarm clock creates a stressful arousal that is high enough to raise glucose concentrations in patients with type 1 Diabetes (Berndt-Zipfel, et al., 2011). Awakening without the means of an alarm clock (self-awakening) would not have this effect and also poses other beneficial effects. Matsuura et al. write that people who self-awaken felt better when they woke up and dozed of less during the day (Matsuura N, 2002). Self-awakeners are also less tired and scored better at several cognitive tests (Ikeda H, 2012a). Self-awakening also decreases sleep inertia, as suggested by Ikeda et al. (Ikeda H, 2010). Sleep inertia is a period immediately following wake-up in which a person is disoriented and has impaired cognitive and sensory-motor performance (Ferrara M, 2000).

This study aims at reviewing people’s ability to awaken at a time they predetermine before sleep onset with a certain accuracy and connecting this to research that shows the positive effects of self-awakening compared to forced-awakening. People would, in a way, set their ‘internal alarm clock’ and wake up when it goes off. This internal alarm clock would, if accurate, diminish the need of an external alarm clock. It would bring all the advantages of such an alarm (waking up at the requested time) without the side effects.

Methods

Data collection has been done by using the search term ‘Self-awakening’ in Pubmed (14 hits). From these results studies on short naps were excluded. Furthermore articles provided by my supervisor where used. The references of these articles were used to find more sources.

Results

Both questionnaire studies (Child, 1892) (Moorcroft WH, 1997) (Matsuura N, 2002) (Ikeda H, 2012b) and laboratory studies ((Hall WW, 1927) (Lavie P, 1979) (Bell, 1980) (Hawkins J, 1990) (Moorcroft WH, 1997) (Ikeda H, 2010) (Aritake, et al., 2012) have been done regarding waking up at a pre-determined time. In these studies a total of 1.319 participants have been investigated. These participants were between 19 and 84 years of age.

Questionnaire studies

The first of these studies was a study by Charles M. Child in 1892. His study included 200 participants (151 ♂ 49 ♀). Most of these participants are between 20 and 30 years of age, but the ages range from under 25 to above 30 (No exact age range is given). He asked his participants the following questions (Child, 1892):

1. Can you wake precisely at a given hour deter-mined upon before going to sleep, without waking up many times before the appointed time?

2. If you can,
   a. Is this habitual, or do you often fail?
   b. Are you conscious before waking of any feeling (describe it)?
   c. Do you come directly from oblivion into consciousness?

The results of this questionnaires are described in Table 1.

	1	2a		b	c	
	Yes.	Seldom fail.	Often fail.	Yes.	Directly.	Gradually.
General	59	69	25	30	64	16
Men	62	69	28	33	56	16
Women	51	68	12	20	80	16
Under 25	68	66	33	33	62	15
Between 25-30	47	73	20	33	60	13
Above 30	61	68	12	16	64	20

Table 1 The results of the questionnaire. The numbers on top correspond to the questions (see text) (Child, 1892)

Hall did a study with himself as a subject (1 ♂) in 1927. He tried to wake up at a certain minute. To do so he visualized what the face of his watch would be at the time he predetermined to wake-up at (Hall WW, 1927). The results of a hundred night trials are shown in table 2.

Wake-up relative to predetermined time	Percentage successful
Exact	18%
Not more than 15 min. wrong	53%
Not more than 30 min. wrong	75%
Not more than 45 min. wrong	81%

Table 2 The results of the night trials done by Hall. Based on Hall WW, 1927

Moorcroft et al. (1997) did both a questionnaire and a lab study in 1997. For the questionnaire part calls had been made to random numbers picked from the U.S.A. telephone book. This resulted in 269 adults

(129 ♂ 140 ♀) with ages ranging from 21 to 84 years. These participants were questioned about their general sleep habits and sleep patterns. According to these questions the participants were divided into 4 groups. They were either people who: 1) never use an alarm or external source, 2) use an alarm yet stated that they can awaken before the alarm goes off, 3) use an alarm but said they sometimes awaken before the alarm goes off, and 4) use an alarm and said they do not awaken before the alarm goes off (Moorcroft WH, 1997) (see table 3).

Table 3 shows the results of this study. 52% of the 269 adult participants claims that they can awaken by themselves (group 1 and 2) (Moorcroft WH, 1997).

Group	Sleep habit	Percentage of total
1	never use an alarm or external source	23%
2	use an alarm yet stated that they can awaken before the alarm goes off	29%
3	use an alarm but said they sometimes awaken before the alarm goes off	24%
4	use an alarm and said they do not awaken before the alarm goes off	24%

Table 3 The groups and their percentage of participants. Based on Moorcroft WH, 1997

In 2002 Matsuura et al. did a questionnaire study which contained 643 participants (354 ♂ 289 ♀) with a mean age of 19 (SD=1,7) years . These participants were divided into self-awakening and non-self-awakening groups in the same way as in Moorcroft WH, 1997. They were asked how they usually wake up in the morning. The optional answers were: 1) never use an alarm, 2) use an alarm yet awaken before the alarm, 3) use an alarm but sometimes awaken before the alarm goes off and 4) use an alarm and do not awaken before the alarm goes off. Participants who answered with either 1 or 2 were placed in the self-awakening group (SA-group), the others in the non-self-awakening group (non-SA-group). 66 (10,3%) participants were in the SA-group (mean age=19,2 (SD=1,2) years) (Matsuura N, 2002).

Ikeda et al. did a study in 2012. In this study 362 students (mean age 15,1 ± 0,3 SD). They were asked the question “How do you usually awaken in the morning?”. The questions where categorized as in Moorcroft 1997 (table 5). Furthermore they were asked to complete 24 questions about their sleep/wake habits. These questionnaires were completed for 5 consecutive years. The percentage of participants that reported to have a habit of self-awakening was 26%, 19%, 17%, 17% and 16% respectively for years 1 to 5. This leads to an average of 19% having a habit of self-awakening (Ikeda H, 2012b).

Questionnaire studies: Correlations

Child (1892) shows that 30% of his participants were conscious of a feeling (they felt they should wake up) before waking up.

Moorcroft et al. 1997 show a significant age factor (P<0,05), as illustrated in figure 3. The Self-awakening groups have a higher mean age, compared to the others. This study also shows that the consistency of sleep duration plays a significant role (P<0,05), as can be seen in figure 4 (Moorcroft, et al., 1997).

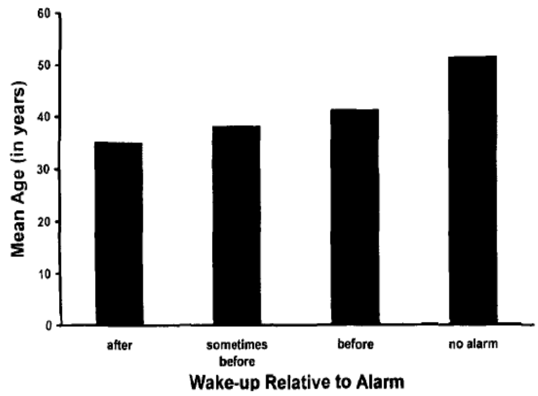

Fig. 3 Mean age (years) of subjects in each of the four wake-up groups (Moorcroft, et al., 1997).

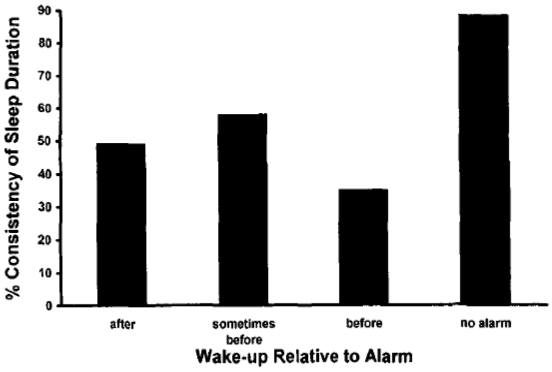

Fig. 4 Percentage of subjects in each wake-up group who report a consistency in the amount of sleep per night (Moorcroft, et al., 1997).

Matsuura et al. (2002) Show that subjective ratings of mood were significantly better in the self-awakening group. They also had a higher morningness score (Matsuura N, 2002).

Experimental studies

In 1979 Lavie et al. conducted a study for which he included 7 subjects (6 ♂ 1 ♀) with ages ranging from 21 to 30. These subjects were selected on their self-acclaimed ability to awaken at a pre-determined time. These participants slept in the laboratory for four nights (00:00-06:00). These nights were categorised as: one adaptation night without recordings, one baseline night and two experimental nights. On these experimental nights the participants received a note with their target wake-up time, 20 minutes before lights-off. These target times could be either 3:30 or 5:30 (balanced crossover order). The Participants were paid according to their accuracy, which was divided in the following categories: ±10 minutes, ±20 minutes, ±30 minutes and ± 40 minutes from target time. The participants had to signal the experimenter via an intercom system when awakened. Watches and any other timing devices had to be taken of at bedtime (Lavie P, 1979). In the 14 experimental nights (7 participants each 2 nights) there were 12 self-awakenings with varying accuracies as shown in table 4 (Lavie P, 1979).

Minutes from target time	Number of successful nights	Cumulative
±10	5 (36%)	5 (36%)
±20	3 (21%)	8 (57%)
±30	1 (7%)	9 (64%)
≥40	5 (36%)	14(100%)

Table 4 The number of night of successful self-awakening for each target time. Based on Lavie P, 1979

Clifford R. Bell did a study in 1980 for which he included 38 adult subject (20 ♂ 18 ♀). The study took place on three consecutive nights from which night 1 was an adaptation session and night 2 or 3 could be either an experimental or a control night (depending on the subjects preference). The participants chose their own target time to wake-up at, but this had to meet certain criteria: It had to be an unusual time for them to awaken and at least 45 minutes earlier than their normal time of awakening the following morning. 19 subjects chose night 2 as their experimental night (9 ♂ 10 ♀) and 19 other chose night 3 (11 ♂ 8 ♀). On the control night the participants recorded their actions (I, II, III, IV, V) as described in table 5. In the morning the participants had to rate their sleep as being more, the same or less restful than usual, more, the same or less disturbed than usual, with more, the same or less dreaming than usual. On the experimental night the participants recorded their actions (I,II,III,IV,V,VI,VII,VIII) as described in table 5 The two groups did not significantly differ and thus they were pooled. 53% recorded an awakening within their target time ± 15 minutes. (Bell, 1980).

I	The time of getting into bed
II	The time of each awakening during the night
III	If they were dreaming when they awoke at each time
IV	The time they finally awoke for the day
V	Their estimate of the total number of hours sleep they had that night
VI	Their chosen target time
VII	An estimate of the confidence they had in their ability to awaken at the target-time (by indicating on a 100-mm line labelled from 'total confident certainty' to 'not a hope in the world')
VIII	The method they had used to try to set themselves to awaken at the target time.

Table 5 The recorded actions of the participants. Based on Bell CR, 1980

In 1990 James Hawkins and Paul Shaw conducted a study with a group of 146 undergraduates (38 ♂ 108 ♀) with a mean age of 22,9 years (SD=6,2) (Hawkins J, 1990). These participants chose eight nights (not necessary consecutive) during which they would do the experiment. For each of these nights they had to set an alarm for the time they intended to wake up. In addition to that all subjects had a target time. This could be an 'early' target time (60 minutes after light-off) or a 'late' target time (60 minutes before alarm). The early and late nights should be alternated (e.g. early, late, early, late etc.) and there should be four of each. Participants recorded their own data with a sleep log. When the participant awakened at target-time ± 30 minutes, the self-awakening is considered successful. The mean proportion of nights during which the participants awakened successful was 50% for the early awakenings and 60% for the late awakenings. The difference in success for early and late awakenings was statistically significant (P< 0,003) (Hawkins J, 1990). Moorcroft et al (1997) selected 15 participants (6 ♂ 9 ♀) based on their self-acclaimed ability to self-awaken with ages ranging from 19 to 62. They were given a sleep diary and an Ambulatory Monitoring, Inc. actigraph (a device that records the frequency of a subject's movements per minute) to record the sleep and wake periods including their time of the final awakening. This actigraph had to be worn from 20:00 until 10 minutes after they woke up. They needed to fill in part of the sleep diary before going to bed and after wake-up, this also included their target wake-up time. All this had to be done for three consecutive nights. This resulted in data from 44 nights. The mean time of awakening was target time + 3 minutes and 20 seconds (mean= 3,34 minutes (SD=13,37 minutes)). This time did not differ significantly from the average target time (P<0,05). Table 6 shows the number of nights the participants awakened within a certain time relative to target time (Moorcroft WH, 1997).

Minutes around target time (#)	Number of nights	Percentage of total nights
7 minutes	22	50%
15 minutes	28	64%
30 minutes	35	80%

Table 6 The number of nights per group of minutes around target time. Based on Moorcroft WH, 1997

Aritake et al. (2012) used fifteen healthy male volunteers (15 ♂) with regular sleeping habits and a mean age of 22,1 (SD= 0,7) years. These volunteers participated in the consecutive two-night, single-blind, cross-over conditions. They were randomly allocated into either the 'request' or 'surprise' group. Request subjects were instructed at lights off (0:00) to wake up at 03:00. Surprise subjects were instructed to wake up at 08:00, but they were unexpectedly woken at 03:00. When a subject could self-awaken at 03:00 ± 30 minutes, it was counted as a success. Seven of these fifteen (47%) subjects succeeded in their self-awakening (Aritake, et al., 2012).

Ikeda et al. (2010) did a study with 10 students (3 ♂ 7 ♀) with a mean age of 21,8 (SD=0,6) years, none of which had the habit of self-awakening. They all used alarms to awaken and either woke up by or before the alarm. They were kept at the sleep laboratory for five consecutive nights. The first night was an adaptation night, the second a forced-awakening night, the remaining three nights were self-awakening nights. The awakening and retiring times were their average times from the week before the experiment. From these participants 90% (2 ♂ 7 ♀) succeeded in self-awakening (target time ± 30 minutes) (Ikeda H, 2010).

Experimental studies: Correlations

Lavie et al. (1979) show that 67% of their self-awakenings were from REM sleep. This proved to be significantly more (P<0,02) then the self-awakenings from non-REM sleep (Lavie, et al., 1979).

Bell (1980) showed that the accuracy of his participants to awaken at their target significantly correlated with the following variables: 1) the participants' confidence in their ability to self-awaken (P<0,01), 2) the brevity of the period of sleep immediately preceding the attempted target time awakening (P<0,01), 3) the shortness of the mean period of continuous sleep between awakenings preceding the attempted target time awakening (P<0,05), 4) a sleep disturbance index calculated from subject's ratings of the previous night's sleep on the experimental night (P<0,05). Variables 2, 3 and 4 also intercorrelated significantly (Bell, 1980).

Discussion

Before anything can be said regarding the results of the aforementioned studies, a definition of successful self-awakening has to be made. As some of the studies (Ikeda & Hayashi, 2010) (Aritake, et al., 2012) (Hawkins & Shaw, 1990), only give information on an awakening at target time ± 30 minutes and see this as an successful awakening, this study will also follow in that line. The only (experimental) study that does not give information on target time ± 30 minutes is the study of Bell (1980). He only give information on target time ± 15 minutes. His percentage of self-awakeners will not be taken into account when considering a successful self-awakening as his condition is not comparable (Bell, 1980). None of the studies state why target time ± 30 minutes is chosen as a successful self-awakening. Future studies should state why a particular number of minutes is chosen as a successful self-awakening.

Questionnaire studies have been done from 1892 up until 2012 (Child, 1892) (Moorcroft, et al., 1997) (Matsuura, et al., 2002) (Ikeda & Hayashi, 2012b). They investigated 1474 people in total (928 ♂ 546 ♀) with ages ranging from 15 to 84 years. On average 27% (mean corrected for number of participants per study) of them claimed to be able to self-awaken. Moorcroft et al. (1997) show a significant age factor in the ability to self-awaken in which a higher age give a higher self-awakening percentage. Matsuura et al. (2002) refer to Moorcroft's age factor as a reason why their number of people that can self-awaken is lower (10%). This might also be the case for the study of Ikeda et al., they also show a low self-awakening percentage (19%) (Ikeda & Hayashi, 2012b) and they too have a lower age range (mean age 15,1 ± 0,3). Excluding these last two studies creates an average self-awakening percentage of 55%. Matsuura et al. (2002) show a higher morningness score for the self-awakeners. A higher morningness score correlates with an earlier chronotype (Roenneberg, et al., 2003) which correlates with less social jetlag (Wittmann, et al., 2006). As social jetlag is defined as the difference between MSW and MSFsc (Roenneberg, et al., 2007a), less social jetlag means less difference. Moorcroft et al. shows that the self-awakening group shows a higher consistency in sleep duration (Moorcroft, et al., 1997). This higher consistency in sleep duration could be connected with earlier chronotypes. Chronotypes are age dependent, a higher age correlates with an earlier chronotype (Roenneberg, et al., 2007b). This could be why Moorcroft et al. (1997) show an age factor in self-awakening.

Experimental studies have been done with a total of 193 participants (72 ♂ 121 ♀) (Lavie, et al., 1979)(Hawkins & Shaw, 1990) (Moorcroft, et al., 1997) (Ikeda & Hayashi, 2010) (Aritake, et al., 2012). Their ages ranged from 19 to 62 years of age. In all the trials combined an average of 62% (mean corrected for number of participants per study) was able to self-awaken within a 30 minute time-frame around their target time. Moorcroft et al. (1997) show that the actual time of awakening did not significantly differ from the target time. The age factor mentioned earlier cannot be found in these studies as the highest rate of self-awakening (90%, (Ikeda & Hayashi, 2010) and the lowest (47%, (Aritake, et al., 2012) are found in comparable age categories, 21,8 (SD=0,6) and 22,1 (SD=0,7) respectively.

When people were asked how they awakened without or prior to an alarm clock, the common response was that they had a sense of an internal clock (Moorcroft, et al., 1997). The accuracy of time estimation during sleep increases as sleep progresses (Aritake, et al., 2004). In later research Aritake et al. (2012) show that subjects that successfully self-awakened had increased hemodynamic activation in the right pre-frontal cortex pre-awakening. Born et al. (1999) show a distinct increase in adrenocorticotropin (ACTH) levels within an hour before awakening in participants that anticipated to be awakened at 06:00 (Born, et al., 1999). This increase in ACTH might help the participants to wake up (Allen, 2001). This could be connected to what the participant in Child 1892 feel before awakening. Lavie et al (1979) show that significantly more (P>0,02) self-awakenings were from REM sleep. As REM sleep decreases with age (Van Cauter, et al., 2000) these findings could be connected to the age factor mentioned earlier. But the role of REM sleep in self-awakening is still unclear (Moorcroft, et al., 1997).

Conclusion

These studies suggest self-awakening is something people can actually do with enough accuracy to rival the effects of a typical alarm clock. Age appears to be an important factor in the ease with which self-awakening can be done, although practical studies do not confirm this. People that self-awaken show better mood ratings and dozed of less during the day (Matsuura, et al., 2002), show less sleep inertia (Ikeda & Hayashi, 2010), score better on cognitive tests and feel less tired (Ikeda & Hayashi, 2012a). All these effects plus not having to deal with the stress-full arousal that is associated with an alarm clock (Berndt-Zipfel, et al., 2011) should already be enough reason to seriously consider self-awakening as the standard awakening method.

Implications

Self-awakening could already be part of many studies related to sleep without being taken into account. The sleep on free-days, used for the MCTQ, is only one example that could be influenced by it. If a person is going to bed he is now expected to sleep until he is fully charged and to oversleep to counter sleep deprivation. One assumption is that the subject would oversleep as much as he can. When taking self-awakening into consideration one could also aim to awaken not later than a specific time for any reason whatsoever. Further research should take self-awakening into account, as it can influence many of the time points measured in sleep studies. Self-awakening could also play a role in the negative effects of self-awakening, as some of these effects could be caused by alarm use.

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