

Wearables in Practice: A literature review
examining the current research on wearable
sleep measuring technology in mental
healthcare.

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Abstract (English)

Introduction: Wearable sleep measuring technology has established its place in the modern western society as useful tools to measure sleep related health behaviour in- and outside a professional medical environment. This non-invasive technology could bring about changes in the mental health sector and a consideration to be made is whether or not this novel technology is being investigated upon in order to recognize its potential for the mental health sector. Four research questions have been formulated in order to find an answer to this idea, concerning the kinds of devices used, the mental disorders being under investigation, the duration of studies and the main results of current research in the field. **Methods:** Literature was obtained via two different databases: PsycInfo and Scopus. A total amount of 17 studies has been thoroughly selected and analyzed for this review. Citations were also extracted in order to illustrate and analyze the main findings of studies considering wearable sleep technology. **Results:** Almost half of the studies made use of commercially available devices (FitBit, Actiwatch etc.) even though a general trend of researchers developing their own wearable measuring devices was observable. The main focus of studies lied on general sleep research themes or neurological impairments rather than mental disorders and most studies were conducted for shorter than a month. **Discussion:** The focus of research revolving around wearable sleep technology lies on patients with neurological impairments or mentally and physically healthy people in order to measure the general effects of sleep on health. No study has been found that investigates on psychological disorders such as depression or anxiety disorders, which leads to the conclusion that psychological disorders have still to be put into focus of wearable sleep measuring technology. More than half of the studies reviewed do not make use of the potential that wearable sleep measuring technology has to offer as they have been conducted for less than a month or as little as one night. Most studies made use of self-build devices to conduct wearable sleep measuring research which illustrates the fact that wearable devices can be used in a customizable manner. Customized wearables devices have to be viewed with caution, however, as too many self-build devices could from problems to find a consensus of devices used in the field.

Keywords: Wearables, Wearable technology, Sleep, Mental Health, non-invasive

Abstract (Nederlands)

Introductie: Draagbare technologie om slaap te meten heeft zijn plaats gevonden in de moderne westerse maatschappij en werd bekeken als een belangrijke gereedschap om slaap gerelateerde gedrag te meten. Deze niet-invasieve draagbare technologie brengt verschillende visionaire veranderingen teweeg in de geestelijke gezondheidszorg. Een belangrijke vraag is in hoeverre deze nieuwe draagbare technologie wordt onderzocht om het volledige potentieel voor de geestelijke gezondheidszorg te herkennen. Vier onderzoeksvragen zijn geformuleerd om een antwoord te vinden op deze vraag, betreffende de gebruikte hulpmiddelen, de onderzochte psychische stoornissen, de duur en de belangrijkste bevindingen van het huidige onderzoek. **Methodes:** Literatuur werd verkregen via twee verschillende databases: PsycInfo en Scopus. Een totaal van 17 onderzoeken is grondig geselecteerd en geanalyseerd voor deze beoordeling. Verder werden ook citaten geëxtraheerd om de belangrijkste bevindingen van studies met betrekking tot draagbare slaaptechnologie te illustreren en te analyseren. **Resultaten:** De helft van de onderzoeken maakte gebruik van in de handel verkrijgbare apparaten (FitBit, Actiwatch enz.), hoewel een algemene trend om hun eigen draagbare meettoestellen te ontwikkelen waarneembaar was. De belangrijkste focus van studies lag op algemene slaaponderzoeksthema's of neurologische stoornissen in plaats van geestelijke stoornissen en de meeste onderzoeken werden gedurende korter dan een maand uitgevoerd. **Discussie:** De belangrijkste uitkomst is dat de focus van het onderzoek rond draagbare slaaptechnologie op patiënten met neurologische stoornissen of mentaal en fysiek gezonde mensen ligt. Er is geen onderzoek gevonden dat gefocuseerd is op psychische stoornissen zoals depressie of angststoornissen, wat tot de conclusie leidt dat meer focus moet worden gelegd op psychologische stoornissen in het domein van draagbare slaapmeettechnologie. Meer dan de helft van de onderzoeken is beoordeeld om geen gebruik te maken van de mogelijkheden die draagbare slaapmeettechnologie te bieden heeft aangezien ze minder dan een maand of zo weinig als één nacht zijn uitgevoerd. De meeste studies maakten gebruik van zelfgebouwde apparaten. Aangepaste wearables-apparaten moeten echter met de nodige voorzichtigheid worden bekeken, omdat te veel zelfgebouwde apparaten problemen kunnen veroorzaken om consensus te bereiken over apparaten die in het veld worden gebruikt.

Keywords: Draagbare technologie, slaap, mentale gezondheidszorg, niet-invasief

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1. Introduction

This thesis concerns a review about the topic of innovative sleep measuring technology in the mental healthcare sector. The focus of this review is to identify relevant peer reviewed articles about wearable sleep measuring technology currently being used in health practice as well as wearable technology that is still being in development process or the try-out phase. The aim is to review these with regard to the new possibilities this technology could mean for the mental health sector and what the focus of current research is on this topic. Wearable sleep measuring technology has established its place in the contemporary western society as a useful tool to measure sleep related health behaviours in- and outside a professional medical environment. The new possibilities and doors that this technology could open form a basis for discussion when considering that the ‘golden standard’ for measuring sleep quality to this day is that of Polysomnography (PSG), which is a rather invasive, laboratory-bound technology that brings with it several limitations and concerns in the mental health sector. Non-invasive wearable technology can resolve several of these limitations as it is a non-invasive technology that is rather in-expensive, is easy to administer and can be used to collect data over a much longer timeframe than PSG, to name but a few. This can bring about substantial changes in the mental health sector considering the amount of data being available and the nature of the data-collection process itself, as people can be measured in their natural environment rather than a laboratory.

1.1 Wearable Technology

Wearable technology such as smart watches and activity trackers play an increasingly important role in twenty-first century society as it has great influence on how people construct a physically and mentally healthy lifestyle (Naslund et al., 2016). The number of relatively inexpensive, high-end technology in the past years aggregates to millions of sold devices that support users to monitor multiple health-related factors, such as diet, physical activity and sleep (Jeon & Finkelstein, 2015). This fairly new technology also comes in various forms and developers find ever new ways to evaluate concepts of new wearable or non-invasive technologies such as a pillowcase containing a microchip that may be able to measure the quality of one’s sleep or biometric shirts helping athletes to enhance their performance and keep track of their health and bodily improvements (Al Sayed, Vinches, & Hallé, 2017). The

substantial popularity of wearable technology can at least be partially explained by factors such as the ease of use of these devices as the person using it is usually guided thoroughly through the working mechanisms of the system at hand via tutorials and manuals and the ever increasing focus of people in the western world on health related behaviours (De Zambotti et al., 2016). Another point is that the diversity of use for these wearable health-trackers is as broad as it could be considering that they can be used by a lay person going for a run, as well as for elderly people suffering from Parkinson's disease or adults with intellectual disabilities and autistic spectrum disorders (Hare, Jones, & Evershed, 2006). Other factors adding to the popularity of wearable technology is that they are physically small and imply little to no adverse circumstances to use them, that they are comparatively in-expensive and the general non-invasiveness of the devices at hand as they do not demand a person to have a substantial amount of expertise and can be used in an everyday context without severe impact on mobility or quality of life (Sargent et al., 2018).

1.2 Sleep research

Sleep is a topic of interest for research for hundreds of years, the average human spends an astonishing amount of time sleeping and it is known that sleep deprivation can lead to severe mental impairments and delusions (Bernert et al., 2017). To define sleep does, however, seem to be dependent on what aspects of sleep one is interested in. A general working definition of sleep considering this literature review would be that sleep is natural state of rest for body and mind in which a state of unconsciousness is reached that decreases bodily movement and responsiveness to external stimuli. Characteristic for this state of unconscious rest are changing cycles of brainwave activity, skin conduction and changes in body temperature (Maetzler et al., 2016). In order to measure sleep in a contemporary context these changes (brainwaves, bodily movement, skin conduction, body temperature etc.) are being used as parameters in order to measure facets of sleep with different kinds of medical devices.

One's quality of sleep plays a crucial role in a broad range of mental and physical impairments and has a substantial impact on the course of therapy and progression of disease (Fulgini, Arruda, Krull, & Gonzales, 2018). Studies have shown that poor sleep quality can cause and have a severe impact on the course of psychological impairments such as depression, anxiety-disorders and personality disorders such as 'Borderline personality disorder' (Schmutte, Davidson, & O'Connell, 2018), Parkinson's disease (Chahine, Amara, &

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Videnovic, 2017) and traumatic experiences (Ogeil & Baker, 2015). Many researchers have therefore concentrated their effort on identifying the positive effects of an improved sleep quality on mental and chronic medical illness as well as the negative effects of sleep deprivation or low quality of sleep. An improved sleep quality has shown to lower symptoms of depression and anxiety-disorders in patients with mild to severe impairments (Bernert et al., 2017). Other studies have shown that improving one's quality of sleep can play a role in the prevention of mental impairment such as traumatic experiences and mood disorders (Ogeil & Baker, 2015). An enhanced quality of sleep could therefore act as a buffer against mental disorders and impairments and it seems thus reasonable to develop ways to raise one's quality of sleep.

To this day most research revolving around the topic of sleep quality uses a measurement option called Polysomnography (PSG) to identify the different properties of sleep. PSG is the 'golden standard' in sleep tracking technology because it provides detailed, reliable and valid information about important biomarkers of quality of sleep such as the structure and depth (EEG feedback in form of brain waves, physical activity while sleeping, total sleep time, sleep wake phases etc.). PSG is, however, an extremely invasive technique (as seen in figure 1) which takes place in laboratory settings only and requires substantial technical and scientific expertise by the researcher administering it (Sargent et al., 2018). PSG is considered to be an invasive measuring technique, as seen in the picture provided below, as the person under investigation is strapped to an apparatus using several wires and diodes which makes even small movements inconvenient (Sargent et al., 2018). For people suffering from mental illnesses such as anxiety- or panic disorders the procedure of PSG itself can already cause the quality of sleep to be substantially lower than in a normal daily life setting (Saletu et al., 1996) and the expertise needed in order to administer sleep quality measurements with the help of PSG as well as interpreting the results forms a great disadvantage of the use of the 'golden standard' of PSG.

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Figure 1. On the left the Actiwatch worn around the wrist and on the right a patient being attached to Polysomnography.

To address these problems several companies have concentrated their effort to develop more non-invasive technologies that require less technical and scientific expertise. Wearables such as the Actiwatch are technology worn, for example, around the wrist and are used in order to measure several physiological properties of the person wearing it and can in turn give feedback on the overall characteristics of sleep in a natural setting. As these devices are financially affordable (in comparison to PSG) and almost non-invasive in the daily routines of a person in their natural environment they seem to form a realistic innovation for sleep tracking in daily life. This may be especially applicable for people suffering from different forms of mental disorders in which the quality of sleep plays a crucial role in the course and development of the disorder itself. As mentioned before, the procedure of PSG can be so invasive that the quality of sleep measured in the laboratory setting can become rather unclear and difficult to interpret especially for patients suffering from anxiety disorders (Saletu et al., 1996). This forms a rather crucial limitation to the use of PSG in a clinical setting as it was also shown that patients suffering from different mental disorders (such as depression or panic attacks) sometimes experience substantial issues with their general sleep quality even in their natural environment at home (Saletu et al., 1996). Wearables would therefore form a realistic non-intrusive and innovative alternative to sleep tracking in the mental health sector.

1.3 Sleep technology & mental healthcare

Regarding this literature review defining mental healthcare forms a challenging task as even the word healthcare alone can be described and defined in several ways. For this review, however, it seems applicable to use a broad definition of mental healthcare, namely, that mental healthcare is the preservation and improvement of mental health in all its different forms (prevention, diagnosis and treatment of mental illness and disorders). Mental healthcare is provided by health professionals such as psychotherapists or psychiatrists in various institutions such as clinics, hospitals or in an ambulant setting (Lawrence & Kisely, 2010). Mental healthcare institutions and professionals, as well as general health institutions and practitioners are bound to adapt and conform to modern technological discoveries in order to provide the best possible healthcare in terms of efficiency, success-rates and ethical considerations (Lawrence & Kisely, 2010). It could therefore be crucial for the mental health sector to consider the possibilities that wearable sleep measuring technology has to offer. Even though the producers of most wearable devices claim that their products were specifically designed for people in their day-to-day life and not for medical or scientific purposes, researchers all over the world started warming up to the idea of using wearable technology in their studies and a more clinical setting (De Zambotti et al., 2016). Apart from devices being used by laypersons in their everyday life a number of wearable technologies have therefore found their way into the general healthcare system and a more clinical setting and are currently being used by experts of different professions to measure and assist the therapy and diagnosis of physical and mental illness (Luxton, June, Sano, & Bickmore, 2016).

Wearables revolutionize the healthcare system in a number of ways including a shift in the collaboration between and roles of expert and patient, the amount of data being available and the manner diseases can be monitored (De Zambotti et al., 2016), to name but a few. The amount of data being available could mean an important shift in the work of for example psychotherapists. These may have access to data about sleep patterns, quality of sleep and total length of sleep of their patients on a regular basis. The data being available also means changes for researchers as the data being available can stem from real-life collection rather than a laboratory setting (De Zambotti et al., 2016). Another crucial implication for researchers could be that due to modern wearable technology it will be possible to collect data in more longitudinal studies. In comparison to PSG, which takes place in a fixed and controlled laboratory setting and is immensely effortful to administer, it will be possible to conduct studies which collect data over a longer period of time and provide the researchers with data about

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sleep that was not available before (Melton, Buman, Vogel, Harris, & Bigham, 2016). This apparent opportunity will also be in the focus of this literature review. The before mentioned changes have been reported by experts being active in the domains of general medical-care, rehabilitation, sport-psychology and neurology. Until now there is, however, a lack of attention directed at the changes that wearable technology can bring about in the mental health sector and a rather important question that needs answering has been suggested to be whether wearable technology can play a role in the mental health sector as well (Mohr, Zhang, & Schueller, 2017). This question has been addressed by a number of studies concerning the use of wearable technology pertaining to weight loss (Naslund et al., 2016), Parkinson's disease (Bhidayasiri et al., 2016) or schizophrenia (Peters-Strickland et al., 2016).

A rather apparent construct that plays a crucial role in these and a variety of other mental disabilities and impairments that has to this day been the centre of attention to only a small amount of researchers is, however, that of wearable technology measuring sleep. This may seem surprising considering the fact that this technology is available and has been evaluated in a number of studies (De Zambotti et al., 2016). As mentioned above, quality of sleep can play a crucial role in the development and progression of a broad range of severe mental illnesses and the technology of wearable non-invasive sleep technology could offer a whole new way of being able to measure sleep, the amount and use of data, how to conduct research on sleep and offer valuable information for therapists. A crucial consideration at this point would be whether the above mentioned new possibilities that emerged due to wearable sleep measuring technology are being in the focus of research or not and furthermore what the current focus of mental health researchers is in general on this new sleep measuring technology. These possibilities sound rather appealing and the question arising would be whether researchers focused their effort towards the investigation of these themes and what research on wearable sleep measuring devices looks like in general to this day.

1.4 Summary and Research question

Considering the above-mentioned ascertainment, that wearable sleep technology offers a range of possibilities that could change the way the mental health sector measures sleep in patients with mental illness, the amount of data being available to researchers and therapists and the way they can make use of this available data. This literature review was conducted to find out what the main findings of other studies revolving around the topic of wearable sleep measuring technology in the mental health sector are and whether these new possibilities are being researched on. Four sub-questions were formulated in order to further narrow down this research question into measurable units

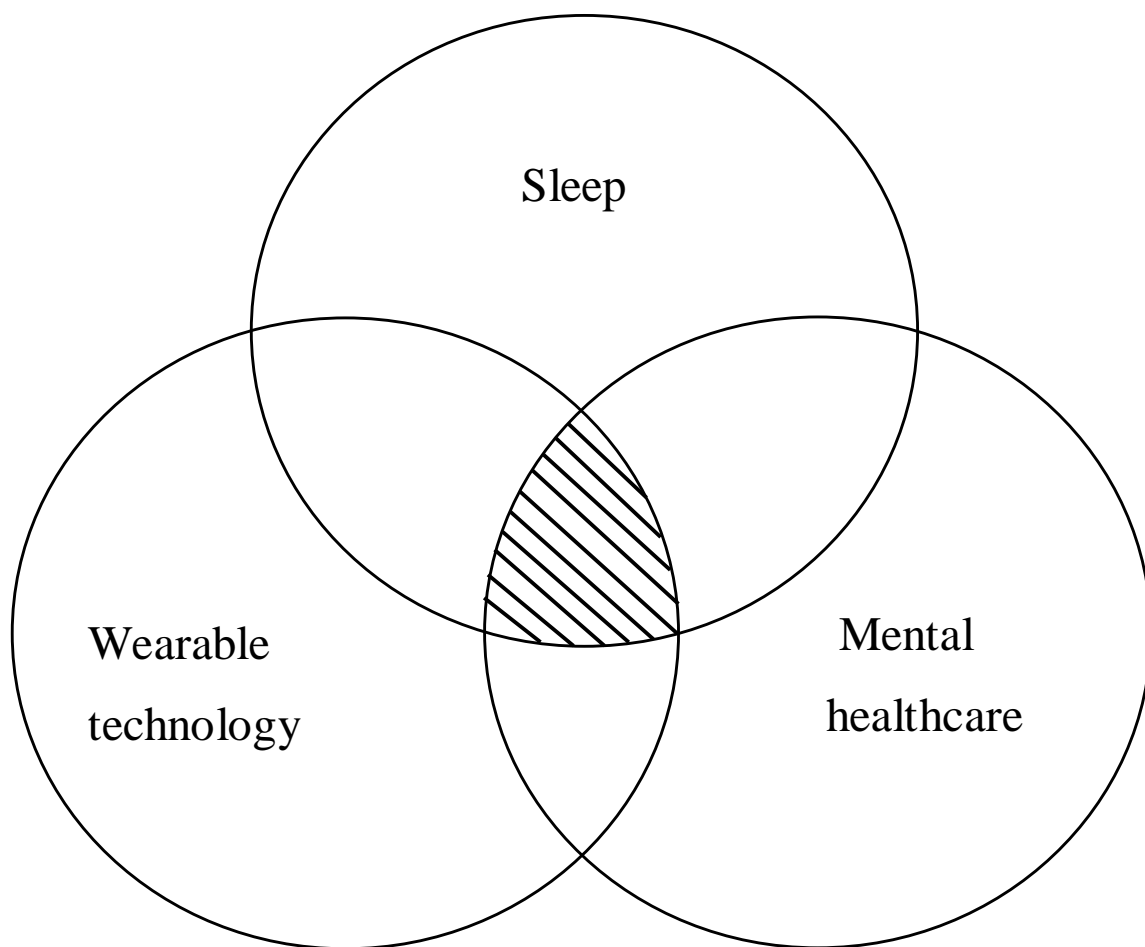


Figure 2. Representation of the relationships revolving around the aim of this literature review. The striped area depicts the research question of this thesis: ‘To what extent are the new possibilities that emerge from the use of wearable sleep measuring technology in the mental healthcare sector in the focus of current research?’

- 1) What wearable sleep measuring devices are currently in the focus of research in the mental health sector?
- 2) Which mental disorders are currently under investigation using wearable sleep measuring technology?
- 3) What is the duration of the studies revolving around the topic of wearable sleep measuring technology?
- 4) What are the main findings concerning wearable sleep measuring technology being used with patients with mental disorders?

2. Methods

2.1 Search Strategy and selection-criteria

The articles taken into consideration for this literature review have been carefully selected on basis of a several inclusion/exclusion criteria in May 2018. These criteria will be illustrated below in form of a flow chart in line with all the other crucial criteria that have been established for this review. The articles were collected from two different databases: PsycInfo and Scopus. PsycInfo was a primary choice as it constitutes a database that was specifically designed for psychological research and articles and therefore automatically contains articles of the mental health domain. As the mental health context formed one of the main aspects of this thesis, PsycInfo was therefore selected. Scopus forms a second database that was selected in order to countercheck the articles being found against a source that does provide the research with articles from other fields rather than solely that of psychology. This was an important consideration as it was crucial to this research to also get acquainted with wearable sleep technology from other context such as the medical or neurological sector. The search-strings used for the databases were the following:

(Wearables **OR** wearable tech*) **AND** (Sleep)

(Wearables **OR** wearable tech*) **AND** (Sleep) **AND** (Mental Health)

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The first search string was applied for both databases and the number of articles differed: 39 for PsycInfo and 309 for Scopus. The second search-string was irrelevant for PsycInfo (as this database already provides solely articles from the domain of mental health) and was created for the Scopus database in order to further narrow down the 309 to 13 results from all different disciplines to the mental health sector after scanning for articles from other fields. An important side note may be that it was deliberately decided to include dissertations and theses as these often contain extraordinary novel findings in topics which formed an important basis for this rather innovation driven review.

For further progression of this review several inclusion/exclusion criteria were established. The first criterion was that only articles in English or German language were considered. The second criterion was then that only articles from 2005 until 2018 were taken into the review. The choice to exclude articles from before 2005 was made out of caution to exclude any possible outdated wearable sleep technology that has already been shown to not persist in a clinical mental health setting or any other irrelevant articles. As wearable technology is fairly new it was expected that a considerable amount of articles to this topic would have been released later than 2005. These criteria did, however, barely change the amount of articles retrieved from the databases as the number for PsycInfo did not change and for Scopus it merely dropped to 12 articles.

The articles retrieved were sorted by the databases according to their relevance to the search-strings and it was therefore observed that the articles shown on pages three to four (ten articles were shown per page) became substantially lower in their relevance to the search-string. It was therefore decided to only include those articles which titles and abstracts had a direct association to the key terms in question, namely, *wearable technology*, *sleep* or *mental health* (mental illness, mental impairment, disorder etc.). The first article displayed on the third page after applying the search-string in PsycInfo, for example, was named '*A novel and intelligent home monitoring system for care support of elders with cognitive impairment*' which forms a good example to illustrate this criterion. The title of this article did contain the topic of cognitive impairment and some sort of novel technology in form of a home monitoring system. The crucial aspects missing are, however, those of wearable technology as well as the domain of sleep measurement. Another example forms the third article on the same page, titled '*Systematic review of the validity and reliability of consumer-wearable activity trackers.*' This title leads to the conclusion that it contains information about wearable technology but gives no indication of whether the wearable activity trackers included in the research also measured

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sleep nor whether the research included to some extent the topic of mental health. This article, and articles alike, were thus screened via their abstract if they contain crucial information about the topic of this review or not.

After the application of these criteria the following amount of articles was retrieved from the databases: 15 from PsycInfo and 3 from Scopus. After removing the duplicates the number of articles found in the database of Scopus was reduced by one. All the remaining full articles were taken into account in this literature and the whole set was read and analysed in regards to the research question. The full set therefore was 17 articles that fulfilled the inclusion criteria and were taken into consideration for the analysis of this literature review.

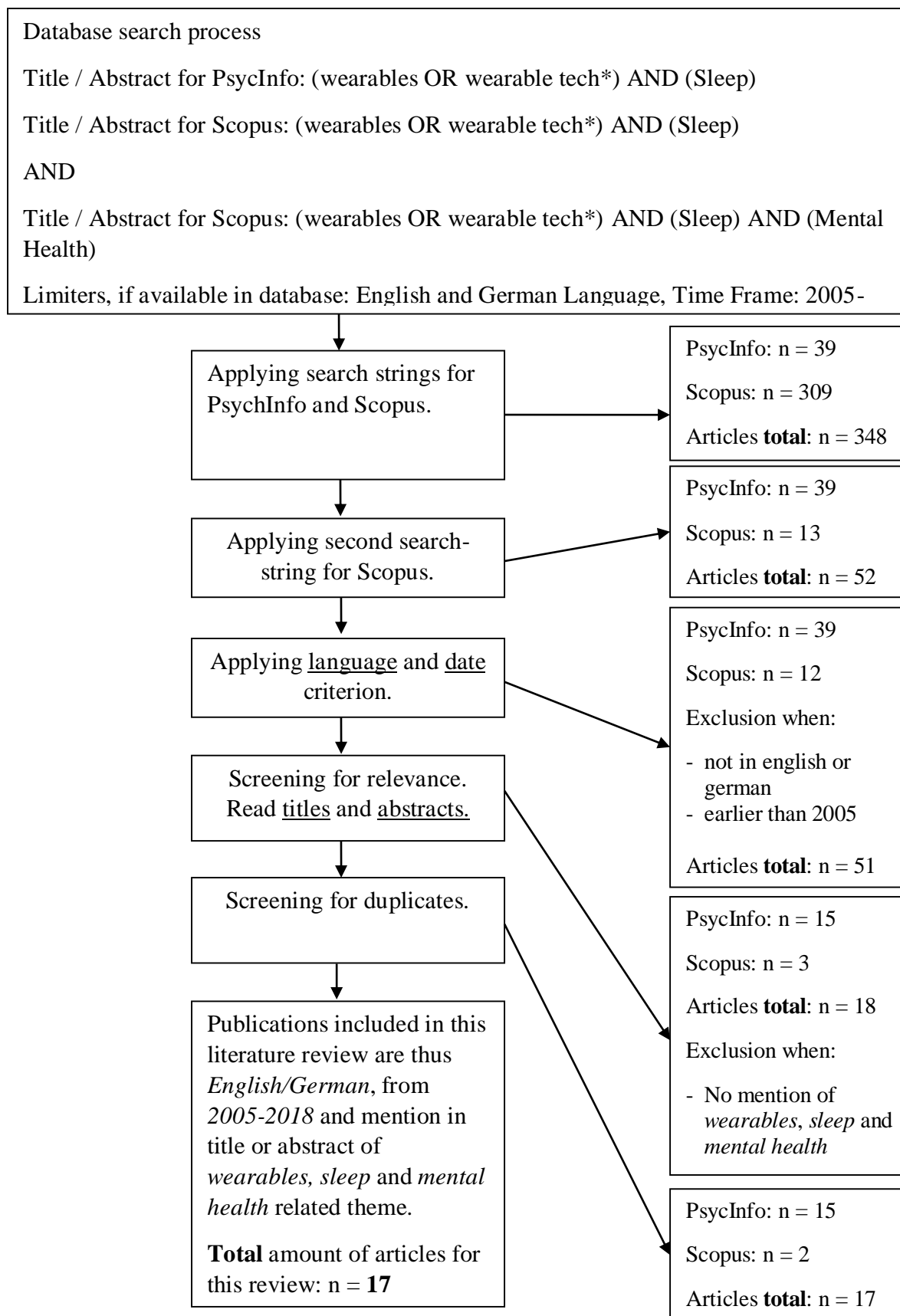


Figure 3. Flow Chart of the inclusion/exclusion process of the articles selected for this literature review.

2.2 Procedure and analysis

The 17 articles that have been deductively derived and included in this review were fully read and analysed following the four research questions mentioned above. The first research question was about what wearable sleep measuring devices are currently used in research in the mental health sector. In order to find an answer to this question the articles were screened for which sleep measuring devices were in the focus of each single study. The frequencies were then collected and added into table 1. If a study was conducted in order to compare two or more different sleep measuring devices all of them have been taken into consideration as each single one of them has thus been in the focus of this research. When a study, however, used a mix of wearable sleep measuring devices and applications on cell phones, then only the wearable sleep measuring device was taken into consideration as applications on cell phones are not included in this literature review. 'Not specified' was used whenever the article did mention that sleep was measured with some kind of wearable device but did not further describe what device was specifically used (commercial name of the device).

The second question, namely, which mental disorders are currently under investigation using wearable sleep measuring technology has been analysed by collecting the frequencies of the mental disorders under investigation in the 17 articles that have been collected for this literature review. For answering this question the same rules applied as mentioned for the first research question. Thus if an article took more than one mental disorder into consideration than all disorders were collected and reported in table 1. In the case that the sample consisted of only healthy participants without any mental disabilities or impairments, the category of 'general mental health practice' was applied. This category was considered as all articles considered in this review were measuring sleep in some way or another. Even in a study with only mentally healthy participants it is therefore evident that sleep has been measured in order to test a hypothesis considering general mental health.

The third research question which was aimed at identifying the overall duration of studies revolving around the topic of wearable sleep technology in mental healthcare was answered by collecting the total duration of each single study of the 17 articles at hand. The categories that were developed in order to capture and categorize the duration of the studies were 'longer than one month', 'between three days and one week' and 'under 3 days'. Other studies were categorized as 'not specified' as the studies did not explicitly state how long the

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study was conducted. These categorizations were created by the researcher of this review in order to logically capture the different durations of the study. The categories derived mostly from the overall duration of the studies at hand.

The fourth and last research question was aimed at identifying and collecting the main findings of the articles considering wearable sleep measuring devices being used in mental health studies. For this purpose the studies included in this literature review will be screened to identify whether or not they revolve around a mental health issue. To further explain this process it has to be mentioned that the articles included in this review all revolve around the main topic of sleep to investigate the effect sleep has on the performance of mental and physical abilities of people. This fourth research question, however, is only concerned with studies that have investigated on explicitly stated disabilities such as insomnia, disorders of the autistic spectrum or borderline rather than mental health as a general construct as mentioned before. It was furthermore decided to add the articles concerning Parkinson's disease into this focus even though Parkinson's disease is generally defined as a neurological disorder, as some symptoms about this disease are of mental nature and can be treated with psychotherapy. The results of this fourth research question will be presented in form of quotations from the articles and descriptions of the identified main themes being covered in these relevant articles. The themes taken into consideration in this review are advantages and disadvantages of wearable sleep technology and the disorders that have been in the focus of the research at hand. The quotations that have been selected represent the main conclusion of the corresponding authors concerning wearable sleep measuring technology in a mental healthcare context.

3. Results

3.2 Descriptives

In the following section the results of the four different research questions will be illustrated in form of the identified descriptive values. Furthermore, this section will provide a table that contains an overview of all 17 articles and a classification for the first three different research objectives as well as the name of the key author and the year the study was conducted. A last illustration will be formed by citations that underline the results of the fourth research question.

3.2.1 Sleep measuring devices

The 17 articles that have been included have shown to have a great variability when considering the first research question under investigation. The first focus was laid on what device was used in the studies and the results were rather broad. Two of the 17 studies did not specify which devices have been used in the study (11.80%). In some instances non-commercial wearable sleep measuring devices and even self-build technologies have been used in the study. This was the case in seven out of the 17 studies (41.20%). It was then recorded where on the participants body the wearable was worn and how it was supposed to measure sleep (Biometric Shirt, Wearable oculometric technology etc.). In eight out of the total of 17 articles (47.10%) commercially available wearable technologies such as the Actiwatch or the FitBit were used.

3.2.2 Mental disorder

The second question crucial to this literature review was that of mental disorders. Considering this research question there was also a great variability in research focuses. The mental/neurological disorder that has been in the focus in most of the articles, three out of the total of 17 articles (17.64%), was that of Parkinson's disease. Considering the above-mentioned category of 'general mental health practice' it can be stated that ten out of 17 articles (58.82%) fall into this category. Disorders that have been mentioned only once in the total of 17 articles are Insomnia, Bipolar disorder and ADHD, Obstructive Sleep Apnea and furthermore Intellectual disability and autistic spectrum disorder (respectively 5.88%).

3.2.3 Duration of the study

The third question of this review was to determine the duration of the 17 included studies. Most studies belong to the category of ‘under 3 days’, seven in total (41.17%). In the category of ‘between three days and one week’ were four (23.53%) and in ‘longer than one month’ also four studies in total (23.53%). Two studies did not specify the duration of the study and were therefore categorized as ‘not specified’ (11.80%).

Table 1

Characteristics of the Included Articles in Regards to the Four Questions of This Literature Review.

Nr. of study	Device	Mental Disorder	Duration	Author/Year
1	FitBit	General mental health practice	8 months	Kalmbach, 2018
2	FitBit, Apple Watch, Jawbone, Pebble, ActiGraph	General mental health practice	Not specified	Sathyanarayana, 2017
3	Not specified	General mental health practice	Not specified	Dunn, 2018
4	Jawbone UP	General mental health practice	6 months	Melton, 2016
5	FitBit HR Charge	General mental health practice	3 days	Sargent, 2018

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6	Actiwatch4 Actigraph	Adults with Intellectual disability and autistic spectrum disorder	7 nights	Hare, 2006
7	Affectiva Q sensor	General mental health practice	65 nights	Luxton, 2017
8	FitBit Flex, Actiwatch 2	Insomnia patients	1 night	Kang, 2017
9	Not specified	General mental health practice	7 days	Fagherazzi, 2017
10	Biometric shirt	General mental health practice	2 nights	Pion- Massicotte, 2018
11	Actiwatch 64, GT3X+	General mental health practice	2 nights	Cellini, 2016
12	Belt-worn Actigraph (minimotionlogger watch, Ambulatory Monitoring)	Children 5 – 18 With bipolar disorder and attention- deficit/hyperactivity disorder	3-5 nights	Faedda, 2016
13	Axial inertial sensor	Parkinson's disease (nocturnal hypokinesia)	3 months	Bhidayasiri, 2016

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14	Limb- or trunk worn sensor	Parkinson's disease (nocturnal hypokinesia)	1 night	Sringean, 2016
15	Bong smart sports bracelet	Parkinson's disease	2 nights	Cai, 2017
16	Wearable oculometric technology	General mental health practice	1 night	Cardillo, 2013
17	Wearable ultrasound device	Obstructive sleep Apnea	3 hours in 1 night	Chen, 2017

3.2.4 Analysis of articles

The fourth question is represented in the form of citations from the articles that have been included to answer this research question. A total number of seven studies (41.80%) has been selected to fulfil the criteria, namely, the articles concerning adults with intellectual disability and autistic spectrum disorder, insomnia, children with bipolar disorder and attention-deficit/hyperactivity disorder and Parkinson's disease. The seven articles are analysed and then reported in terms of agreement of topics between them. To each theme that is illustrated in this section a citation from an article will be provided that best reflects the general statement made by several articles.

The main themes that are identifiable in all seven articles can be categorized as 'advantages' that wearable sleep technology has to offer. These themes were inductively retrieved from the articles at hand and are objectivity, non-invasiveness and low costs. These three themes are recognizable in almost all of the publications as they are directly mentioned and recognized as such. Themes that could also fall under the category of 'advantages' of wearable sleep measuring technology could be that of measuring accuracy and reliability. The article by Faedda et al. (2016) summarizes the advantages of wearable sleep measuring technology clearly.

“Several features make actigraphy a potentially useful laboratory test for psychiatric research and practice. It is non-invasive, inexpensive, well tolerated, free of side effects, and provides accurate and objective measures of sleep continuity and circadian regulation. Further, the technology is now being incorporated into a vast array of consumer products so that millions of individuals own or will soon own the necessary hardware. If these findings are confirmed, actigraphy might add an objective component and increase the accuracy and reliability of assessment of children for early onset BD (Bipolar disorder)”
(Faedda et al., 2016, p. 714).

The publication of Cai et al. (2017) illustrates another possibility and advantage of wearable sleep measuring technology that is crucial to this literature review as it directly regards the third research question, namely that wearable sleep measuring technology allows longer durations of studies and therapy being conducted.

“We used wearable devices for real-time monitoring of [...] sleep quality of PD patients, thus replacing subjective evaluation with objective, facile, and cheap assessment. Bracelets can be used to evaluate the therapeutic effect of drugs and, thus, instruct rational dosage changes. Wearable devices are an economical, non-invasive, and portable tool for quantitative assessment and monitoring of daily physical activity and sleep in PD patients and can promote long-term exercise rehabilitation and become a method to monitor sleep disorders” (Cai et al., 2017, p. 1662).

Another topic being mentioned several times is that of limitations of wearable sleep measuring technology. Several articles demand caution when investigating with the help of wearable sleep measuring technology. Themes being mentioned in this regard are that the validity of wearable instruments has yet to be established to a higher degree and that the measurement of some sleep related parameters such as TST (total sleep time) or SE (sleep efficacy) are currently known to be a weakness of wearable measuring devices. The need for validation studies that has been mentioned by several authors can be illustrated by the article of Kang et al. (2017).

“In summary, the findings of both this and recent previous studies suggest the validity of the commercial sleep trackers in measuring the TST (total sleep time) in good sleepers. [...] However, when applying commercial devices to insomnia patients and patients with other sleep disorders, clinicians need to consider their limitations of overestimating the TST and SE (sleep efficiency), and therefore apply these devices for clinical and/or research purposes with discretion. It will also be necessary to further develop and validate the algorithms that the sleep trackers use to determine the sleep and wakefulness states [...]” (Kang et al., 2017, p. 43).

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A last theme when considering the mental healthcare domain of this literature review would be that of mental illness or disorder as such. The articles that have been included for this analysis have all been studies revolving around mental illnesses to some degree such as borderline personality disorder or Parkinson's disease. When considering these mental/neurological disorders it is important to mention that all publication take into account that wearable sleep technology can form a realistic and advantageous novel manner to measure, investigate and understand these certain mental/neurological disorders and impairments. This idea is best described in a quote by Hare et al. (2006).

“The present study has established that the use of actigraph technology is both practical and appropriate to the investigation of circadian rhythm functioning in adults with ID (intellectual disability) and ASDs (autistic spectrum disorder). Such discreet measurement technologies allow a range of clinical and research questions to be more objectively investigated in a manner more acceptable to people with ID and their carers” (Hare et al., 2006, p. 707).

In conclusion it can be noted that the main advantages of wearable sleep measuring technology that have been mentioned by a variety of articles are objectivity, non-invasiveness, low costs and that it allows longitudinal studies to be conducted within the realms of sleep research. It is furthermore noted by several articles that research in regards of wearable sleep measuring technology has to be viewed with caution as long as there are not enough validation studies. A last theme extracted would be that this novel technology forms a realistic manner to measure and investigate mental/neurological disorders.

4. Discussion

4.1 Overview of the current literature review

This review was conducted in order to thoroughly investigate the current literature being concerned with wearable sleep measuring technology in the mental health sector. This general idea was then specified by regarding the new possibilities that this technology could possibly bring about in a mental health context and as the results show the new possibility to conduct more longitudinal sleep studies seems to not be applied yet. It was furthermore of interest of this review to find out what the focus of the current mental health research domain is. The findings of this review allow the conclusion that researchers seem to be well aware of the advantages that wearable sleep measuring technology can bring about and that (within the scope of this review) no mental disorders have been under investigation of research but rather neurological and partially mental disorders. The main findings of this research will be discussed in the following section.

4.1.1 Main findings

Concerning the first sub question of this review it can be concluded that a substantial amount of devices have been non-commercial or self-build devices (41.20%). This is a high number considering that there are devices commercially available that could have been used in the studies rather than investing resources into creating new devices or using one's that are not commonly known. One possible explanation would be that some of the studies falling into this category were concerning complex mental and neurological impairments. The wearable sleep measuring devices needed to measure the variables at hand, for example quality of sleep as well as movements of different parts of the body of patients suffering from Parkinson's disease, may simply demand more complex algorithms or hardware that commercially available devices could not offer. A problem with this approach is, however, that wearable devices have been used that have not been thoroughly tested for reliability nor for validity yet. Designing new wearable devices for scientific purpose has its perks and issues. On the one hand it is crucial to develop novel wearable sleep measuring technology and encourage innovation. On the other hand it can, however, be problematic to introduce too many 'no-name' devices into the scientific domain. The issue is apparent as at some point there will be a mass of prototypes of wearable sleep measuring devices that have not extensively been validated or analysed in terms

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of reliability. The approach to use commercially available devices which was the case in almost half of the studies (47.10%) struggles less severely with these issues. Different versions of the Actiwatch or the FitBit have been used and partially validated in a number of studies and have established their place as a reliable wearable sleep measuring device. The advantage of finding consensus to some extent as to what wearable sleep measuring device could best be used in the vast amount of studies would be that of standardization. Studies in the domain of wearable sleep measurement would become probably substantially more reliable. Two studies (11.80%) did not explicitly specify which wearable device they were using in their study. It has to be noted that one article did not specify at all what devices have been used in the research except for mentioning that the devices were manufactured by Withings (currently Nokia).

The second question was concerning the use of wearable sleep measuring devices in regards to people with mental or neurological illness. It was notable that more than half of the articles included in this review (58.82%) were not actually conducted with people suffering from mental disorders or impairments. These studies were revolving around sleep deprivation experiments with students or the effects of healthy sleep on African American women. As mentioned in the introduction sleep plays a crucial role in the development, progression and therapy of a broad range of mental disorders. Sleep deprivation, low quality of sleep or extensive levels of sleep play a crucial role in some of the mayor mental disorders, for example depression, and also form an epiphenomenon in several anxiety disorders (Bernert et al., 2017). According to this literature review, and in regards to the search-strategy applied, not a single article using wearable sleep measuring technology to investigate these rather prevalent and widespread mental disorders could be included. The mental and neurological disorders that have been under investigation are insomnia, bipolar disorder and ADHD, obstructive sleep apnea, intellectual disability and autistic spectrum disorder and Parkinson's disease. This may be due to the fact that all these disorders are based on neurological impairments that are more scientifically observable than purely psychological disorders such as anxiety disorders. It is indicated that neurological factors also play a crucial role in the development and progression of depression, these are, however, not yet been as well established as the psychological factors (Spiegel & Giese-Davis, 2003). This trend may therefore be explained by considering that neurological abnormalities and biomarkers may be less complex to be measured by wearable devices as directly measureable variables can be accounted for which are not as easily measurable in purely psychological impairments. Another more presumable explanation is naturally the scope that is defined by the search-string applied, the exclusion/inclusion criteria

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and the databases having been used in this literature review. As mentioned above titles and abstracts have been scanned in order to find the constructs of wearables, sleep and mental health. This means that if a researcher actually did conduct a study using wearable sleep measuring technology with patients suffering from depression but did not explicitly mention in the title or the abstract that wearables have been used to determine the quality of sleep in the patients suffering from depression it will not have been included in this research. This may therefore form a reason that studies that have been done using wearable sleep measuring technology with patients suffering from mental disorders cannot be reported by this review.

The third sub question was formed in order to gain an insight into the duration of studies. This was a crucial consideration as the substantial advantage of wearable sleep measuring technology in comparison to PSG is that it enables researchers to conduct longitudinal studies and not only one point in time measurements (Melton et al., 2016). It was again surprising to see that only a minor amount of studies (23.53%) made use of this advantage of wearable sleep measuring technology and reported a duration of the study longer than one month. A vast amount of studies (41.17%) were even under three days, some of the studies falling into this category only being conducted as long as one single night. There may be several reasons for a sleep study being as short as one night (schedule of the participants, granted funds, research teams being available etc.) it seems, however, rather unforeseen that a clear advantage of wearable sleep technology is that of being able to conduct longitudinal sleep studies in comparison to PSG. Longitudinal data from studies concerning sleep could provide crucial information as mentioned above in the introduction part of this review.

The fourth and last sub question was of qualitative nature and the main findings of the studies revolving around people with mental/neurological disorders were collected. The main conclusions were that wearable sleep measurement technology forms an in-expensive, objective and non-invasive alternative to PSG. Several studies did admittedly point out that further validation studies will have to be made but the overall trend gave an indication towards scientific research being able to use wearable sleep measuring technology as a useful tool in the future. Considering the fact that PSG is the 'golden standard' when it comes to sleep measuring to this day it is crucial that the main conclusions are that wearable sleep technology is indeed in comparison to PSG tremendously less expensive. A vast amount of studies revolving around sleep did rely heavily on subjective measurement methods such as sleep diaries or questionnaires. A main finding from the literature concerning this fact is that wearable sleep measuring devices form a more objective method to account for sleep as they

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do not rely on subjective feedback by the user but compute objective quantitative data about sleep. A further main finding by the articles included in this review illustrates one of the main advantages of wearable sleep measuring technology, namely that of non-invasiveness. It becomes clear that the researchers being included in this literature review seem to be well aware of the advantages that wearable sleep technology has to offer but a more substantial finding is that the citations illustrated above show that wearable sleep technology forms a realistic alternative to PSG when investigating on people with Parkinson's disease, borderline disorder, autism spectrum disorders and insomnia.

The advantages listed above seem to allow wearable measuring technology to be used with mental patients (suffering from neurological impairment to some extent) effectively and objectively. In the past it has been a complex and difficult task to conduct sleep measuring experiments with patients suffering from diseases like Parkinson's disease or impairments due to autism. Especially conducting studies with patients suffering from severe cases of autism in a laboratory setting had proven to be difficult as these patients have severe problems with being strapped to a machine such as PSG. For patients being born with disabilities in the autistic spectrum wearable sleep measuring technology therefore forms a crucial alternative to PSG as it is a rather non-invasive technique. In the future it would thus be of substantial value to also apply wearable sleep measuring technologies to people suffering from other mental disorders. Depression or anxiety disorders patients could probably benefit from wearable sleep measuring technology as much as it could be shown in studies concerning autism or bipolar disease.

4.1.2 General interpretation of findings and future research

This literature review was conducted in order to gain an overview of the new possibilities that wearable sleep technology has to offer and whether or not these new possibilities are being accounted for by scientists. The fact that only 17 articles have been selected for this literature review already exhibits the point that wearable sleep measuring technology has yet to establish its place in the mental health research but the articles that have been reviewed have made it possible to establish an overview over the current practice in the field. To this day the mental health sector does rely heavily on subjective and laboratory bound measurements of sleep whilst the alternative of wearable sleep measuring technology is available (Pion-Massicotte, Godbout, Savard, & Roy, 2018). According to this review there is a number of commercial wearable technology available that is being used (mainly the Actiwatch and FitBit). Some

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researchers did, due to their research focus, develop self-build devices. This approach has to be seen critically as these devices do not necessarily allow standardization and generalizability of the findings at hand. It is, however, useful when investigating on topics that need devices tailored around a certain research focus. This approach also illustrates the fact that wearable devices can be used in a rather innovative manner. It may be highly expensive and circumstantial to customize a device such as an apparatus used for Polysomnography. The customizability of wearable sleep measuring devices made it, however, possible for research to investigate a broader range of disorders or impairments. It is therefore important for future studies and scientists to develop new customizable wearable devices tailored around the mental disorder in question. This has, however, to be done with caution and logically only if the new development of a sleep measuring device is really necessary. In general research has to focus on finding some kind of consensus on what wearable sleep measuring devices to use.

A substantially surprising finding is that major mental disorders in which sleep plays a crucial role when considering the development and progression of the disorders such as depression or anxiety disorders, have not been in the focus of research yet according to the search-strategy used in this review. Other mental and neurological disorders that have been in the focus of research are, however, insomnia, bipolar disorder and ADHD, obstructive sleep apnea, intellectual disability/autistic spectrum disorder and Parkinson's disease. The fact that all these disabilities have a neurological component to a more or lesser degree may account for these impairments being in the centre of attention rather than depression and anxiety disorders which are to some extent of more psychological nature. According to this literature review it is thus suggested to shift mental disorders into the focus of research revolving around sleep measuring devices in the future. Wearable sleep measuring devices can form a realistic and efficient alternative to PSG in the realms of mental healthcare.

A rather apparent new possibility that has been mentioned several times in this review is that wearable sleep measuring technology allows longitudinal studies in the realms of sleep research. Only a minor number of studies was conducted for longer than a month and a substantial amount was even shorter than three days. As wearable sleep measuring devices do show to be more beneficial in comparison to PSG considering the duration of data collection it is suggested by this review that more longitudinal studies could be conducted considering mental healthcare and sleep related mental health issues. As mentioned above, longitudinal data from patients with mental disorders could have tremendous effects on the work of psychotherapists and the prevention and progression of mental disorders. Using longitudinal

studies for measuring sleep in mentally ill people forms several advantages. As longitudinal studies, in general, allow objective observation over a longer period of time it could bring about change in the mental health sector as patients are often asked to report quality of sleep retrospectively for the past weeks or even months. It goes without saying that this method of measurement relies on subjective rather than objective feedback given by the patients (Ployhart & Vandenberg, 2010). Considering people suffering from manic and depressive phases this point can be illustrated as these patients will tend to report good sleep quality in a phase of mania and vice versa (Faedda et al., 2016). Using wearable sleep measuring technology would allow a longitudinal monitoring strategy in order to objectively measure sleep in these patients. It is furthermore of value that longitudinal studies allow researchers to observe how defined circumstances or end-states came to be (Ployhart & Vandenberg, 2010). This forms a crucial point as patients often do not have reliable memory of past events. In regards to the mental health sector this could allow fine-meshed monitoring of patient's symptoms for psychotherapists and simplify tracking progression of disorders.

A last important implication of this review is that researchers seem to be well aware of the advantages of wearable sleep measuring technology as illustrated by the citations in the result section. It is thus surprising that only 17 articles could be included in this review as only this minor amount of studies revolved around the topic of wearable sleep measuring technology in the mental healthcare sector. An even more important finding is, however, that this novel technology already forms an efficient and beneficial approach in several mental disorders that are based on more neurological impairments. For future research it would be a main task to further validate wearable sleep measuring technology and as mentioned before, shift psychological disorders into the focus of investigation.

4.2 Limitations and strengths of this study

This following section will outline the limitations of the current literature review. The first limitation that can be mentioned is the scope of the review itself. This review was conducted as a relatively short master thesis and the overall scope and amount of time invested in this review was therefore not as complex as in other systematic literature reviews which does naturally not mean that the effort and resources invested in this review were of any less quality. This fact merely means that the scope of this literature review has been limited. A limitation in general, that applies to every systematic literature review is the search-strategy itself. The

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applied search-string included and more importantly excluded a certain set of articles, meaning that it could have been possible to find studies examining people suffering from depression using wearable sleep measuring technology. As the inclusion and exclusion criteria for this literature review were, however, thoroughly created in order to develop a working scope of research, this forms a natural limitation of systematic literature reviews. This fact is also applicable for the fact that only two databases have been used in order to investigate the topic in question. Using more resources in order to gain more articles and insight into the domain would possibly have had the effect of increasing the amount of literature being able to review in this study. The two databases used for this review are, however, widely renowned and accepted databases that have provided this review with the articles needed to investigate the topic to the extent that the scope of this study allowed it. Also applicable when considering the before mentioned argument it should be noted that the search-string used for this review could have been altered in order to achieve more results. According to the knowledge of the researcher this search-string has, however, thoroughly been created in light of the scope of this thesis and compared to other possible search strings. The used string did accordingly contain the most articles fitting within the criteria of this review.

Considering what could be improved when conducting a literature review similar to the one at hand, it could be mentioned that a higher investment in the resources available could have a positive effect on the results of this review. As mentioned above, this literature review was conducted as a relatively short master thesis and sacrifices in terms of amplitude of this research had to be made. Using more databases, applying more and different search-strings as well as loosening the inclusion/exclusion criteria could have led this research to different results. As it was, however, not possible to read through all articles that would have been included when screening not only titles and abstracts but the whole articles in order to find out whether the three variables of *wearables*, *sleep* and *mental health* are present in the studies, this review had to reduce its scope to manageable bits. Considering these limitations this literature review was, however, able to extract important results considering current research on wearable sleep measuring technology in the mental health sector and to make crucial suggestions for research in the future.

4.3 Conclusion

The most crucial relevance of conducting this literature review lies in its exploratory nature. With this literature review it was possible to identify the main focus of current research in the realm of wearable sleep measuring technology in a mental health context and to summarize the most important trends and applications of this novel technology in the mental health sector. In general it seems surprising that there is only such a minor amount of sleep related studies using the advantages of wearable sleep measuring technology. The advantages are clear, wearable sleep measuring technology forms an in-expensive, objective and non-invasive alternative to PSG. The researchers included in this review stated these advantages independently and seem to be aware that wearable sleep measuring technology can bring about these benefits.

Another important finding besides the fact that scientific research could make more efficient use of some of the advantages of wearable sleep measuring technology (even though the advantages seem to be clear in the realms of research) is furthermore that there is no research within the scope of this research that is considering psychological disorders such as depression or anxiety disorders. The main focus of wearable sleep measuring research seems to lie in neurological impairments and general mental health practice (exploring the effects that sleep has on physical and mental health in general). It is therefore a substantial opportunity to raise an awareness to use wearable sleep measuring technology in more psychological health related research. This could in time lead to interesting and eminent findings in the future and have a massive impact on sleep measuring research and the mental health domain in multitudinous ways.

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