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REVIEW ARTICLE

ADHD 24/7: Circadian clock genes, chronotherapy and sleep/wake cycle insufficiencies in ADHD

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ABSTRACT

Objectives: The current paper addresses the evidence for circadian clock characteristics associated with attention-deficit hyperactivity disorder (ADHD), and possible therapeutic approaches based on chronomodulation through bright light (BL) therapy.

Methods: We review the data reported in ADHD on genetic risk factors for phase-delayed circadian rhythms and on the role of photic input in circadian re-alignment.

Results: Single nucleotide polymorphisms in circadian genes were recently associated with core ADHD symptoms, increased evening-orientation and frequent sleep problems. Additionally, alterations in exposure and response to photic input may underlie circadian problems in ADHD. BL therapy was shown to be effective for re-alignment of circadian physiology toward morningness, reducing sleep disturbances and bringing overall improvement in ADHD symptoms. The susceptibility of the circadian system to phase shift by timed BL exposure may have broad cost-effective potential implications for the treatment of ADHD.

Conclusions: We conclude that further research of circadian function in ADHD should focus on detection of genetic markers (e.g., using human skin fibroblasts) and development of BL-based therapeutic interventions.

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Introduction

There is a substantial literature linking dysfunction of the circadian timing system to the aetiology and/or symptomatology of common neuropsychiatric disorders (Foster et al. 2013). Such evidence includes the use of ex vitro models for the monitoring of circadian rhythms in gene expression (Brown et al. 2005; Hida et al. 2017), behavioral monitoring through the use of actigraphy (Ancoli-Israel et al. 2003) and the assessment of other physiological, endocrine and psychological rhythmic processes (Refinetti et al. 2007). The relevance of the circadian system to neuropsychiatric disorders is further supported by genetic association studies (Kalman et al. 2016). One such disorder is attention-deficit hyperactivity disorder (ADHD).

ADHD is a neuropsychiatric condition characterized by inattention and/or hyperactivity-impulsivity that interferes with everyday functioning (Douglas 1999; Kaiser et al. 2014). Based on the prevailing symptomatology, ADHD has three presentations: (i) predominantly inattentive, (ii) predominantly hyperactive–impulsive and (iii) combined (Gaub and Carlson 1997). ADHD, although a childhood-onset neurodevelopmental condition, is nevertheless a frequent and disabling condition in adults (Magnin and Maurs 2017) due to the relatively high persistence rates of 40–50% (Lara et al. 2009). The prevalence of ADHD is around 5.3–7% for children and adolescence, and 3.4–4.4% for adults (Polanczyk et al. 2007, Fayyad et al. 2007, Polanczyk and Rohde 2007). Although the aetiology of ADHD remains poorly understood, ADHD in all age groups has a strong genetic component (Franke et al. 2011).

While attention problems are recognized as a core deficit (Douglas 1999), deficits in executive functions (e.g., planning, inhibition and set-shifting) (Pennington and Ozonoff 1996), motor functioning (Mostofsky et al. 2006; Adi-Japha et al. 2011; Kaiser et al. 2014; Goulardins et al. 2017), skill learning ('how to' memory) (Mostofsky et al. 2006; Nicolson and Fawcett 2007; Adi-Japha et al. 2011; Korman et al. 2017),

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emotional instability (Petrovic and Castellanos 2016) and sleep problems (Philipsen et al. 2006) are recognized as additional key characteristics.

The symptomatology of ADHD may be positively influenced by shifting misaligned circadian rhythms to more appropriate phase, through pharmacological or behavioural interventions (Mayer et al. 2018). A successful therapy to influence the circadian rhythm via changes in the expression of relevant genes, for example, in seasonal depression, is bright light (BL) therapy, and thus it might be useful for the treatment of ADHD (Kaladchibachi and Fernandez 2018; Pail et al. 2011). A recent position paper of physicians and researchers from the EU has addressed the need to explore and develop light based interventions to ameliorate ADHD (Coogan et al. 2016).

Neurophysiological underpinnings of behavioural manifestations of the ADHD were linked to brain structures such as the dorsal lateral prefrontal cortex, ventral lateral prefrontal cortex, insula, anterior cingulate and dysfunction of dopaminergic systems (Sowell et al. 2003; Tripp and Wickens 2008). Stimulants, such as methylphenidate and atomoxetine are currently the most common pharmacological treatments for ADHD (Chan et al. 2016). Appropriate doses of stimulants increasing dopamine's availability effectively improve attention, decrease hyperactivity, increase behaviour management and improve executive functions in individuals with ADHD (Arnsten 2006; Advokat 2010; Spencer et al. 2013; Rubia et al. 2014). Serious adverse events are very rare, but a high proportion, up to 50%, of stimulant users suffers a range of non-serious adverse events, which may explain the relatively high withdrawal rates (6–17%) (Storebo et al. 2018). Moreover, some patients are unresponsive to stimulant medications. Most common non-serious short- and long-term adverse effects include insomnia and other sleep problems, headache, abdominal pain and poor appetite (Graham and Coghill 2008; Storebo et al. 2018). Non-stimulants, such as atomoxetine may affect cardiovascular parameters, but do not affect sleep (Graham and Coghill 2008). These recently reported numbers call to investigate the cost of such 'non-serious" but chronic sleep problems and meal mis-timings due to medications? And how these problems are related to the inherent, treatment-independent problems with sleep and late chronotype in a significant proportion of ADHD patients across the lifespan (Coogan and McGowan 2017)?

In the current review we aim underscore the importance of continuing the search for biological markers of ADHD and the incorporation of non-pharmacological modalities in treatment protocols utilising chronobiological perspective on ADHD aetiology. We hypothesize that patients with ADHD are candidates for a novel clinical approach that includes a confirmatory laboratory evaluation, incorporating clock gene-based diagnosis and circadian behavioural and biomarker testing. We propose that the use of light therapy (LT) has a potential to induce short- and long-term improvements in cognitive, behavioural and emotional measures in patients with ADHD. Our review suggests a potential directive in encouraging research to (1) determine the benefits of coupling fibroblasts' genes expression phase markers with cognitive (e.g., reaction time) and physiological markers (e.g., melatonin, cortisol) as a multi-dimensional diagnostic method of circadian dysregulation in ADHD; (2) evaluating whether appropriately timed LT is a potent sleep, cognitive and emotional enhancer in ADHD, either directly or mediated via circadian phase shifting. In particular, of interest are the differential effects of three principally different light protocols (natural light, blue light and dawn-like gradually changing light) on the short- and long-term cognitive and emotional functional outcomes; and (3) evaluating, through randomized, placebo-controlled studies, the relative effectiveness of LT compared to standard pharmacological therapy to treat ADHD symptoms. We conclude that LT interventions that independently, or in conjunction with pharmacological treatment, may improve core symptomatology of ADHD or compensate for common adverse effect of stimulant medications, primarily, sleep insufficiency, is of highest clinical importance. Moreover, LT has the potential for augmentation or even prevention of psychiatric comorbidities in adult ADHD, such as sleep and mood disorders.

The review starts with an overview of sleep and circadian rhythm dysfunction in ADHD. Next, we describe the maintenance of the circadian timekeeping system 'by' clock genes, and its modulation by photic input. Recent findings unveiling the connection between the circadian function and clock genes in different psychiatric disorders and in ADHD, including the fibroblasts model, are summarised in the core part of the paper. In the concluding section, LT for circadian alignment in ADHD and future directions of integrated research, diagnosis and treatment are discussed.

ADHD, sleep and circadian rhythm dysfunction

ADHD in adolescents and adults is associated with the evening chronotype (Baird et al. 2012; Bumb et al.

2016; Coogan and McGowan 2017; Vogel et al. 2017), with ADHD individuals displaying preference for late sleep timing and, accordingly, late timing of awakening. While more than 40% of adults with ADHD display an evening preference, only about 11% of age-matched healthy peers show this preference (Rybak et al. 2007). Greater eveningness is associated with shorter night sleep periods. Consequently, a sleep debt may play a causal role in the core symptoms of inattention and increased impulsivity (Rybak et al. 2007). The hyperactivity of ADHD patients is expressed in greater motility at night-time and may lead to sleep deprivation (Philipsen 2006). Also, seasonal affective disorder (SAD), a type of depression disorder directly linked to circadian disruption, shows high comorbidity with ADHD (Wynchank et al. 2016). The core symptoms of ADHD, such as inattention, impulsivity and impatience, are typical outcomes of sleep deprivation even in typical adults (Corkum et al. 1998). As many as 70% of children and up to 83% of adults with ADHD have been reported as having sleep problems (Philipsen et al. 2006) with sleep onset insomnia (SOI) being the most common problem (Van der Heijden et al. 2005). Adults with ADHD also report reduced sleep quality, meaning difficulties in falling asleep and in waking up (Kooij and Bijlenga 2013). More than 60% of adults with ADHD report increased sleepiness during day-time (Kooij and Bijlenga 2013; Van der Heijden et al. 2005; Van Veen et al. 2010). Interestingly, neurobiological delayed timing of melatonin secretion is found in children and adults with ADHD (Van der Heijden et al. 2005; Van Veen et al. 2010). Sleep problems and ADHD seem to interact in a complex bidirectional manner with sleep disturbances exacerbating ADHD symptoms and ADHD symptoms exacerbating sleep disturbances (Owens et al. 2013). In normally developed adults, sleep after practicing a new motor skill, supports memory consolidation processes, contributing to the generation of stable, enhanced and long-lasting procedural memory representations (Debas et al. 2010; Korman et al. 2003), but when applying the protocols developed for normally developed controls to adults with ADHD, overnight motor memory consolidation is hampered (Adi-Japha et al. 2011; Fox et al. 2016; Korman et al. 2017).

ADHD is also associated with disrupted regulation of arousal during wake (Brennan and Arnsten 2008; Hegerl and Hensch 2014). Arousal is the physiological and psychological state of being awoken or of sense organs stimulated to a point of perception (Schachter and Singer 1962). Individuals with ADHD tend to be under-aroused in 'normal' performance and learning conditions (James et al. 2016; Wainstein et al. 2017; Zentall and Zentall 1983). An optimal arousal level is considered a prerequisite for successful cognition functioning (Yerkes and Dodson 1908; Zentall and Zentall 1983). Cognitive theories of ADHD, such as the state regulation model (van der Meere 2005) and dual-process models (Halperin and Schulz 2006; Johnson et al. 2007) propose that the high within-subject fluctuations of cognitive performance in ADHD may reflect problems in regulating arousal. Unstable and low arousal results in the inability or difficulty to sustain attention on any task of waning novelty (Sikstrom and Soderlund 2007; Strauss et al. 2018). Resting electroencephalogram (EEG) parameters of arousal level (Strauss et al. 2018) and arousal stability (Sander et al. 2010; Strauss et al. 2018) were recently suggested as biomarkers for adult and paediatric ADHD. The restless behaviour of individuals with ADHD during wake is interpreted as self-stimulation in order to raise their arousal level (Baijot et al. 2016; Strauss et al. 2018) and, consequently, performance. Altogether, altered circadian functioning is associated with ADHD (Coogan and McGowan 2017), suggesting that inner, biological time-keeping malfunction may be an important factor in this clinical condition.

The circadian timekeeping system is generated by 'clock' genes

The circadian timekeeping system underpins the generation of near 24-h rhythms of variations in physiology and behavior. These cycles are not a response to the changes in the light or temperature around us: they are genetically encoded in a cell-autonomous manner, and at a systems level the circadian timekeeping is the result of a hierarchical, highly distributed whole organism system (Albrecht 2012). The circadian clock cycle continues running, in the absence of periodic environmental stimuli, to best synchronise physiology and behavior, and with reference to the external environment, to the earth's rotation (Duffy et al. 2001). However, the circadian clock can only reliably fulfil its function in a constantly changing environment if it is synchronised ('entrained') to appropriate temporal cues in the environment. For mammals, the most important entraining stimulus ('zeitgeber') is light (Hughes et al. 2015). Other non-photic day-time events, such as meal timing and social cues may also serve as zeitgebers, although under normal circumstances light is setting circadian phase (Roenneberg and Merrow 2016).

The master circadian clock is located in the suprachiasmatic nucleus (SCN) of the hypothalamus (Moore 1997; Reppert and Weaver 2002). The SCN comprises a cell-autonomous oscillatory network of synchronised individual clock neurons, which projects its rhythm onto cell-autonomous clocks throughout the brain and peripheral tissues (Welsh et al. 2010). A subset of SCN neurons are stimulated by photic input transmitted via the retinohypothalamic tract. The retinal receptors (intrinsically photosensitive retinal ganglion cells (ipRGCs)) are specialised cells independent of the visual system. The signal is monosynaptical propagated using glutamate as a transmitter. This results in activation of the retinal receptors through modulating the electrophysiological properties. (Welsh et al. 2010). Moreover, SCN neurones display circadian rhythms in their electrophysiological properties, and these electrophysiological rhythms are underpinned by circadian clock genes (Belle et al. 2009). At the molecular level, circadian rhythms are generated via feedback loops involving a panel of clock genes and their protein products (Albrecht 2012).

At the molecular level, circadian rhythms are generated via feedback loops involving a panel of clock genes and their protein products (Albrecht 2012). The most important circadian genes include *circadian-locomotor output-cycle kaput* genes (*Clock*), *brain and muscle-Arnt-like 1* gene (*Bmal1*), *periodic homolog* genes (Per1/2/3) and *cryptochrome* genes (*Cry1/2*) (Sato et al. 2006). The transcription factors *CLOCK* and *BMAL1* heterodimerise and consequently bind to the promotor region of *PER* and *CRY* resulting in activation of these genes. After translation and transcription, *PER* and *CRY* proteins are gradually stabilised during the day and inhibit the activity of *CLOCK* and *BMAL1*. The result of this negative feedback loop is the inhibition in the expression of *PER* and *CRY* (Lee et al. 2001; Shearman et al. 2000). After 24 h one cycle is finished and the process starts again. *CLOCK* and *BMAL1* are not only involved in the activation of *PER* and *CRY*. Both activate clock-controlled genes in different peripheral tissues (Janich et al. 2011; Marcheva et al. 2010; Paschos et al. 2012). This circadian clock gene cycle has a widespread influence on the transcriptome, with 40% of all mammalian genes showing circadian rhythms in their expression in at least one tissue (Zhang et al. 2014).

The SCN is rather a 'master synchroniser' than a pacemaker. Most tissues show circadian patterns of gene expression when cultured, although such rhythms dampen over a number of days (Buhr and Takahashi 2013). The SCN communicates with peripheral clocks over several pathways, including hormonal cues (glucocorticoids, melatonin) and indirect cues (body temperature, food intake (Panda 2016)). Each cue can phase-shift a peripheral oscillator but may not alter the phase of the central clock, potentially leading to an internal desynchrony of the circadian system, which in turn may lead to adverse outcomes (Roenneberg and Merrow 2016).

Chronotype, clock genes and ADHD

One interesting pivot-point for the examination of genetic factors that may link ADHD and circadian clocks is chronotype. Chronotype is usually measured as the manifestation of preferred or actual timing of sleep/wake behaviour, and is shaped by ontological, environmental and genetic factors (Adan et al. 2012). Later chronotype (eveningness) is characterised by a later phase of entrainment of the endogenous circadian system to environmental time cues resulting in later self-selected timing of sleep onset and offset, and morning types display an earlier phase of entrainment and converse effects on sleep timing (Roenneberg et al. 2003). Chronotype may also be shaped by inter-individual differences in sleep homeostasis, and as such should not be viewed as a purely circadian phenomenon (Mongrain et al. 2006). Later chronotype is associated with a number of psychopathological features in both clinical and non-clinical populations (Antypa et al. 2016; Hsu et al. 2012). Chronotype has also been shown to influence a broad range of cognitive functions, including the ADHD-relevant domains of attention (eveningness associated with more inattention; Hennig et al. 2017) and impulsivity and risk-taking (eveningness associated with more impulsive behaviours; Ponzi et al. 2014; McGowan et al. 2016). The relative advantage of assessing chronotype over other circadian parameters is that it can be reliably measured using validated questionnaires, and as such is more scaleable than other approaches such as actigraphy or physiological and molecular measures (Adan et al. 2012).

As mentioned previously, ADHD is associated with late chronotype, possibly indicating a later entrained phase of the clock, altered sleep homeostasis or an interaction between the two (Coogan and McGowan 2017). Similar to other behavioural traits, chronotype is found be to be heritable, with reported rates of heritability from family and twin studies in the range of 21% (Evans et al. 2011) to 40–50% (von Schantz et al. 2015; Barclay et al. 2014). The putative genetic basis of chronotype has recently been explored in a number of genome-wide association studies (GWAS). Lane

et al. (2016) report 12 loci significant at the genome-wide level that are associated with chronotype in the UK Biobank sample, including loci with previously described roles in the clock (*PER2*, an *ASPS* gene, *APH1A, RGS16* and *FBXL13*). These 12 loci accounted for 4.3% of the variance in the extremities of chronotype, which in the UK BioBank is assessed by a single Likert 5 choice self-assessment of diurnal preference (from the question 'Do you consider yourself to be … ' and answers ranging from 'Definitely a morning person' to 'Definitely an evening person'). A further study on the UK BioBank cohort reported 16 significant loci associated with morningness, including ones near *PER2* and *RGS16*, which are involved in phototransduction (Jones et al. 2016). Hu et al. (2016) report 15 loci associated with morningness (assessed with two question parsed into a binary morning or evening responses in the 23 and Me cohort), including seven loci near genes with known circadian roles such as those encoding vasoactive intestinal polypeptide (*VIP*), *PER3*, *FBXL3* and hypocretin receptor 2. Across these three studies, nine loci were common in at least two studies, indicating that genetic factors are important in shaping chronotype and that GWAS approaches are insightful for this question (Kalmbach et al. 2017). Interestingly, a recent study has shown overlap between genetic predisposition for eveningness and bipolar disorder (Melroy-Greif et al. 2017). Importantly, another recent study using umbilical fibroblast have shown that factors associated with protein turnover are associated with chronotype, indicating that circadian clock-non-specific factors may be important in influencing clock dynamics and shaping chronotype (Gaspar et al. 2017).

Two of the GWAS analyses of the genetic architecture of chronotype also examined genetic overlap between chronotype and ADHD: Lane et al. (2016) reported no significant genetic associations for chronotype with genetic risk for ADHD, and Jones et al. (2016) reported a similar null finding. Interestingly both studies do report significant associations for the genetic risk scores for chronotype with those for schizophrenia. There are a number of potential reasons for such observations. Firstly, the variance in chronotype accounted for by the identified loci is modest (∼4%, Lane et al. 2016), and chronotype is seemingly at most 50% heritable (von Schantz et al. 2015); as such, the later chronotype reported in ADHD may be behaviourally and environmentally determined to a greater extent than genetically so. Such an interpretation would situate phase-delays/later chronotype associated with ADHD more as 'egg' (i.e., results of other ADHD features) rather than as 'chicken' (i.e., causal genetic relationship from circadian to ADHD features). As such, a delayed circadian phase, as might be indicated by later chromotype, may provide a target for behavioural therapies designed to counteract these phase shifts and ultimately to alleviate ADHD symptoms (see Section 3). Clock gene polymorphisms may not confer increased stand-alone genetic risk for ADHD diagnosis, but may confer increased risk for ADHD symptom severity in interaction with environmental factors; a recent report utilising random forest regression reported a significant effect of *PER3* in interaction with stress in predicting ADHD severity (van der Meer et al. 2017). Another important caveat is that GWAS studies do not detect rare variants with a minor allele frequency of $<5\%$ (Kalmbach et al. 2017). As such, rare variants that have been reported to exert large effects on chronotype would not be captured in such analyses (Jones et al. 2016; Patke et al. 2017). Targeted, hypothesis-driven genetic analysis may reveal roles for such rare variants in ADHD. The final caveat in relation to GWAS studies of chronotype to date is that circadian phenotyping has been based on only one or two questions generating categorical scores based on diurnal preference, there is clear potential for loss of statistical power and granularity in assessing subtleties of circadian phenotype that would not be captured in such approaches (Kalmbach et al. 2017).

There are a number of older studies utilising analysis of single-gene polymorphisms in clock genes in ADHD samples. While such studies have many well-documented weaknesses, including lack of statistical power, failure to account for epistasis and failure to replicate (Farrell et al. 2015), it is interesting to note that specific polymorphisms in circadian genes may result in very strong phenotypes. For example, an uncommon (allele frequency of ∼0.1–0.6%) single-nucleotide polymorphism (SNP) in *CRY1* leads to a gain-of-function mutation that results in a larger phase delay of the rest/activity cycle, which manifests as delayed sleep phase disorder (Patke et al. 2017). A C/T SNP in the 3′-untranslated region of *CLOCK rs1801260* was suggested to be associated with chronotype in a candidate gene study (Katzenberg et al. 1998) (although see Iwase et al. 2002; Johansson et al. 2003; Pedrazzoli et al. 2007), and was subsequently examined in adult ADHD. Kissling et al. (2008) reported that the T allele was a risk factor for ADHD psychopathology in adults (Kissling et al. 2008). Xu et al. (2010) examined the same SNP in adult ADHD and reported that the allele was over-transmitted in ADHD. The C

allele in this SNP in *CLOCK* was also associated with ADHD symptoms in the general population. This association was not mediated through chronotype (Jeong et al. 2014). Of particular interest for these studies is a report that the rs1801260 SNP in CLOCK is associated with altered *CLOCK* transcript stability and altered *CLOCK* protein expression; therefore this is likely to be a functional mutation that alters the dynamics of the clock gene cycle and circadian physiology (Shi et al. 2008).

Another clock gene polymorphism that has received considerable interest is the 4/5 variable number tandem repeat (VNTR) polymorphism in *PER*3 (Dijk and Archer 2010). This VNTR has been associated with chronotype, sleep homeostasis and various psychiatric disorders (Archer et al. 2010). The VNTR in *PER3* has been associated with difference in executive function (planning performance assayed by the Tower-of-London task; González-Giraldo et al. 2015). Further, an SNP in *PER3* has recently been linked with ADHD in adults (van der Meer et al. 2017). As such, *PER3* may represent an interesting locus for future study in the genetic overlap between circadian function and ADHD. Other promising associations with clock genes that may be pertinent to ADHD include an association with a SNP in *PER2* with reward in healthy adolescents (Forbes et al. 2012) and an SNP in *PER1* predicting problematic alcohol use (Baranger et al. 2016). Future work will hopefully further address the genetic overlap between the circadian system and ADHD, in order to better understand the nature of the links between circadian timing and ADHD, and to offer new targets for experimental monitoring and even therapeutic targeting.

The behavioural role of clock genes can be studied using reverse genetic approaches in animal models, in which candidate genes are knocked out or altered (Merrow et al. 2005). A number of clock gene knockout animals show hyperactivity as part of their behavioural phenotype, as well as various cognitive alterations. Mice carrying the dominant negative *CLOCK* mutation show mania-like behaviour, including hyperactivity, decreased sleep, lowered depression-like behaviour, reduced anxiety and an increased reward value in association with elevated dopaminergic activities in the central tegmental area (McClung et al. 2005; Roybal et al. 2007). However, this line of inquiry is complicated by the lack of well-validated animal models of ADHD, and the fact that hyperactivity as observed in many models may be a highly non-specific phenotype and not particularly relevant to ADHD-related processes (Carvalho et al. 2016).

A challenge in all studies of circadian function in humans is which, and how many, phase biomarkers can and should be examined (Roenneberg and Merrow 2016). Given that SCN, and other central tissue, cannot be accessed in such studies as one would in animal studies, investigators seek to assay peripheral oscillators that can be reasonably sampled. One method is to measure circadian differences within and between populations in tissue biopsies yielding primary skin fibroblasts. Individual circadian characteristics are manifested in both central and peripheral oscillators (Brown et al. 2005), and as such skin fibroblasts may serve as useful substrates for the analysis of molecular circadian function. In fibroblasts transfected with a bmal1::luciferase reporter, period length is influenced by culture conditions (e.g., temperature, concentration of serum in growth medium), but cells displaying short- and long-period lengths retain their relative values under all conditions, and period length is also associated with chronotype (Brown et al. 2005). Alterations in per2::luc rhythms have also been reported in fibroblasts derived from patients with bipolar disorder, and these factors predict responses to lithium (McCarthy et al. 2013). Recently, a study by Hida et al. (2017) showed that an in vitro fibroblast rhythm assay accurately describes circadian behaviour of patients with two types of circadian rhythm sleep disorders: delayed sleep–wake phase disorder (DSWPD) and non-24-h sleep–wake rhythm disorder (N24SWD). Patients in this study received a 4-week chronotherapy (BL therapy + melatonin/melatonin receptor agonist administration). Longer in vitro period predicted poorer response to chronotherapy in patients with N24SWD (Hida et al. 2017). This, and additional studies (Vanselow et al. 2006), suggests that *in vitro* fibroblasts rhythm assays may provide a valid tool to assess individual genetic characteristics in the biological clock of different populations. Moreover, multiple pre-/post-treatment fibroblast samples may contribute to the evaluation of the efficacy of the phase-shifting treatments, including LT and melatonin administration. To our best knowledge, there are no studies reporting use of fibroblast assays in ADHD diagnosis; given previous indications of clock gene expression changes in ADHD (Baird et al. 2012), such approaches may yield important insights into the alterations of circadian processes at the molecular level in ADHD.

Cyclic production of pineal melatonin, released by the pineal gland in the absence of blue light via the sympathetic system, informs the clock about photoperiod (e.g., day length) (Stehle et al. 2003). As the

sympathetic drive to the pineal is gated through the SCN, the time of onset of melatonin biosynthesis under dim light conditions is a very useful phase marker (Keijzer et al. 2014). Melatonin may play an important role in rhythmic clock gene expression (*CLOCK*, *BMAL1*, *PER1-3*, and *CRY1-2*) (Dardente et al. 2003; von Gall et al. 2005), and in various neurological functions and in stress response (Hardeland et al. 2012). Exogenous melatonin and melatoninergic agonists are shown to entrain the sleep–wake cycle, advance endogenous melatonin secretion and enhance total time asleep in children with ADHD and chronic SOI (Van der Heijden et al. 2007; Chamorro et al. 2017). Further, adults with ADHD with chronic SOI show delayed onset of melatonin secretion (Van Veen et al. 2010; Bijlenga et al. 2013), indicating a delayed phase in an SCN-derived signal. Other rhythmic endocrine signals also show alterations in ADHD; cortisol, which shows a strong 24 rhythm driven by the SCN, shows a phase-delay relative to wake-time in adult ADHD (Baird et al. 2012), and changes in the diurnal cortisol profiles have been linked with alterations in arousal levels in children with ADHD (Imeraj et al. 2012). Therefore, assessment of rhythmic endocrine function in ADHD, and its relationship to ADHD symptom severity and ADHD medication, represents an important substrate for future investigation.

Light treatment for circadian alignment

Light is the primary synchroniser of the circadian timing system (Hughes et al. 2015). Visible light has a wavelength spectrum of 380 (violet) to 760 (red) nm. The intensity of sunlight, depending on geographical location and season of the year, range between 7,000 and 100,000 lux (Roenneberg et al. 2013). The effects of timing (Czeisler et al. 1986), duration (Chang et al. 2012), intensity (Boivin et al. 1996) and wavelength (Revell et al. 2005) of light stimuli on the human sleep–wake cycle are well established in a variety of measures, including phase resetting and the suppression of the sleep-promoting hormone, melatonin (Chellappa et al. 2011). The light-induced entraining is mediated via ipRGCs that project to the SCN in the hypothalamus. The ipRGCs contain melanopsin, an opsin-like protein, most sensitive to blue light (the shortest wavelength of the visual spectrum) (Hankins et al. 2008). However, ipRGC light response is a composite one, influenced by both the extrinsic (rod/cone) and the intrinsic (melanopsin) activation and ipRGC may play a role in visual image formation (Allen et al. 2017). Light, via response of ipRGCs to its spectral properties and intensity, induces a variety of non-visual responses, e.g., raising alertness, pupil constriction and suppression of pineal hormone melatonin release (Debra and Josephine 2006).

Thus, short-wavelength blue light (460 nm) possesses greater phase-shifting potential than the rest of the visible light spectrum (Lockley et al. 2003; Warman et al. 2003; Wright et al. 2004). Currently, there are no standardised guidelines for the application of LT. Based on laboratory and field studies, LT should be sufficiently bright (2000–10,000 lux) to elicit a clinically significant response and should last long enough (>30 min) (van Maanen et al. 2016). Blue light as an environmental factor has been shown to be toxic to rod photoreceptors when the retina is exposed to either high light intensities or to continuous light over a long period of time (Lack et al. 2007; Youssef et al. 2011). Therefore, long-term users of BL therapy lamps should be screened by ophthalmologists, and those with pre-existing retinal conditions or other risk factors should abstain from BL therapy (Youssef et al. 2011).

Natural daylight is considered the strongest zeitgeber for the circadian clock (Wright et al. 2013). Effects of daylight are different from the artificial light and, in particular, BL used in traditional light treatments, in several aspects. (1) In nature, dark–light transitions are always gradual, giving biological systems time to adjust; graduate light exposure has been shown to be an important factor in the photic entrainment of the biological clock (Grandner et al. 2013; Endo et al. 2015). Light-detecting neurons in the circadian system have response characteristics suitable for detection of slow changes in light intensity and spectrum during twilight (Usui 2000; Grandner et al. 2013; Endo et al. 2015). Exposure to BL, even through closed eyelids, was shown to be effective for melatonin suppression (Terman and Terman 2006; Figueiro et al. 2014). Studies that examined rhythm-entraining properties of artificial twilight and fluctuating light intensity cycles, underscored the importance of gradual transition between light and darkness for circadian rhythm entrainment in animal models and humans (Usui 2000; Avery et al. 2001; Boulos et al. 2002; Van De Werken et al. 2010). (2) Colour (spectral) qualities of natural daylight are rich and dynamically changing, while properties of BL used in therapy protocols and in ambient artificial lighting are usually invariable and thus biologically insufficient (Terman and Terman 1999; Beute and de Kort 2014; Hye Oh et al. 2014). (3) The cumulative amount of light during the day

impacts human circadian behavior; geographically defined amount of solar irradiation is linked to distributions of chronotypes in populations, with living at higher-latitudes areas predisposing to eveningness (Leocadio-Miguel et al. 2017). In line with the latter, lower prevalence of ADHD was recently associated with geographic areas of higher solar intensities (Arns et al. 2013). In general, modern people spend increasingly more time indoors, where ambient light is orders of magnitude lower in intensity compared to outdoor light on a clear day (Roenneberg et al. 2013). Despite the importance of daylight for human wellness and functionality, the neuropsychological consequences of exposure to natural light in comparison to interventions using artificial light are currently poorly understood, and the potential of exposure to daylight has not been systematically evaluated both in healthy and clinical populations. Thus, the mainstream of light treatment engages protocols of exposure to artificially generated BL (Terman and Terman 1999).

The susceptibility of the circadian clock to be shifted by time-specific light exposure is thoroughly studied and is broadly utilised in treatment protocols of sleep-phase and depressive disorders, e.g., SAD (Gooley 2008; Kaladchibachi and Fernandez 2018; Oldham and Ciraulo 2014). Long-term light interventions effectively advance sleep onset time (van Maanen et al. 2016; Watanabe et al. 1999) as well as result in less sleepiness after awakening in neurotypical adults with delayed sleep phase disorder (Lack et al. 2007; Van De Werken et al. 2010), for a review see (Figueiro 2016). Wu et al. (2009) treated patients with bipolar disorder with three interventions: sleep deprivation, BL and sleep phase advance. All three non-invasive interventions result in depression decrease (Wu et al. 2009). A study with patients suffering from non-seasonal major depressive disorder observed a positive effect of BL therapy, too. Treatment with BL, either as monotherapy or combined with medication (fluoxetine), showed a consistent effect (Lam et al. 2016). Simulated dawn was proposed as an adjunct and even alternative to BL therapy or medication in the treatment of SAD (Avery et al. 2001; Terman and Terman 2006). In addition to easing compliance, naturalistic dawn simulation eliminates possible ocular adverse effects due to exposure to high-intensity blue light of conventional BLT protocols (Terman and Terman 1999).

One inherent problem of BL studies is the choice of an appropriate placebo condition (Eastman et al. 1998). Several types of placebo or a combination of them are used in placebo-controlled LT studies: dim red light (as opposed to bright blue light), differently timed light (evening vs morning), an inert placebo (a light box emitting no visible light) or an inert (deactivated) negative ion generator (for examples see Chojnacka et al. 2016; Eastman et al. 1998; Sit et al. 2018). Indeed, due to the lack of an obvious type of placebo treatment, LT studies have been extensively criticised for their flawed experimental design. And yet, at least for the treatment of seasonal and non-seasonal depression, an accumulated bulk of randomised and double-blind clinical trials approves the utility of LT and invites further studies in other psychiatric, neurodevelopmental and neurocognitive disorders (for review see Kaladchibachi and Fernandez 2018).

Most patients with ADHD demonstrate delays in sleep–wake rhythms and irregularities in melatonin and cortisol production times compared to healthy controls. Considering the fact that ADHD has high comorbidity with depression (Amons et al. 2006; Turgay and Ansari 2006), it is strongly associated with delayed sleep phase syndrome (Amons et al. 2006; Baird et al. 2012; Coogan and McGowan 2017; Turgay and Ansari 2006), and given an association between ADHD prevalence and solar intensity at geographic loci (Arns et al. 2013), the body of literature on the effects of LT in ADHD is currently very limited.

A 3-week trial of LT to a group of 29 adults with ADHD (Rybak et al. 2006) used a full-spectrum fluorescent light box, which emitted 10,000 lux, for half an hour each morning, showed that morning BL therapy did help alleviate subjective reports of deficits in maintaining effort and arousal, while improving problems with inattention. Furthermore, neuropsychological testing further confirmed that LT produced significant improvements on attentional functioning which was shown in basic auditory attention span as well as for two key components of the Conner's Continuous Performance Test (CPT-II), indicating improvements in impulsivity and behavioural inhibition. Circadian shift towards morningness was shown in many of the participants (Rybak et al. 2006).

A 2-week LT in the morning (30 min morning 10,000 lux exposure 3 h after mid-sleep time) in pharmacologically treated participants with ADHD (with different, individually prescribed drugs) significantly advanced the phase of dim light melatonin onset (DLMO) and mid-sleep time (Fargason et al. 2017). These phase advances correlated with decreased total scores in ADHD rating scales as well as hyperactivity-impulsivity indices (Fargason et al. 2017). Even a single week of LT (1 h at 09:00 h,

2500 lux) in adolescents with ADHD, who were medicated (40 mg methylphenidate daily) and engaged in psychotherapy, was successful (Niederhofer 2013). Behavioural improvements were found in both for the Conner's inattention score and in the hyperactivity score. Moreover, evening melatonin levels increased post-treatment (Niederhofer 2013).

Compared to the long-term effects of light on human circadian rhythms, little attention has been paid to its acute alerting action. High-intensity light exposure acutely reduces subjective sleepiness, improves well-being and neurobehavioral performance, reduces attentional lapses and activates the waking EEG (Badia et al. 1991; Beute and de Kort 2014). These alerting effects appear to be dose dependent, such that higher illuminances have greater immediate effects (Cajochen et al. 2000). Significant advance of DLMO was shown following a single morning exposure to BL during morning hours (>3000 lux) (Kozaki et al. 2011).

Surprisingly, light as an acute alerting agent has not been clinically studied in ADHD. We hypothesise that exposure to BL in ADHD may produce effects similar to other types of sensory stimulation during wakefulness. Various types of extra-task sensory stimulations were reported to be beneficial for cognitive performance of children with ADHD, e.g., background linguistic noise during a reading/arithmetic task (Zentall and Shaw 1980), pictures during a continuous performance auditory task (Zentall and Meyer 1987), background music during arithmetic tasks (Abikoff et al. 1996) and auditory white noise during a visually cued Go/NoGo task (Baijot et al. 2016). If sensory stimulation in one or more forms may enhance cognitive functioning of people with ADHD, similar acute effects may be found for light treatment, especially given that light positively affects attention and performance in neurotypical adults (Beute and de Kort 2014).

It has been previously suggested that core cognitive processes, such as memory consolidation, are extant but under-engaged in adults with ADHD, and that this potential can be unveiled in specific bio-behavioural conditions, contingent on the individual's chronotype (Korman et al. 2017), e.g., by scheduling of training session to evening. A different, chronotherapy approach by appropriately timed LT may eliminate the need to adapt conditions of training and performance to chronotype by long-term phase advancement of the clock. LT is associated with dopaminergic (Kim et al. 2017), adrenergic (Bowrey et al. 2017) and serotonergic (Li 2018) brain circuit activation, pathways directly associated with learning, executive functioning and mood. The SCN's endogenous ~24-h time-generator comprises a dynamic series of functional brain states, which gate neuronal plasticity following daily experiences. The circadian clock, the reward system, and memory processes have many in common: light acts on all three systems through MAPK signalling pathway (Iyer et al. 2014) and all three are affected by the HPA axes via cortisol, thereby leading to short-term changes (Albrecht 2011; Eckel-Mahan et al. 2008). Moreover, most clock genes are expressed in brain areas that are associated with learning, memory and reward (Albrecht 2011), such as the amygdala (Lamont et al. 2005), the hippocampus (Jilg et al. 2010; Wakamatsu et al. 2001) and the ventral tegmental area (Hampp et al. 2008).

Conclusions

ADHD is a common neuropsychiatric disorder affecting both wake and sleep phases of the diurnal cycle. Altered function of clock genes in ADHD is so far poorly understood, but mounting evidence suggests that atypical brain maturation and neurogenesis processes, sleep problems and the emergence of cognitive, executive functioning and self-regulation symptoms present in ADHD are at least partially subserved by circadian disruption (Charrier et al. 2017; Kobayashi et al. 2015). Thus, on the one hand, studies showed that genetic risk factors exist, e.g., associations between ADHD and other neuro-developmental and psychiatric disorders and polymorphism (rs1801260) at the 3′-untranslated region of the *CLOCK* gene predispose to eveningness and sleep problems. On the other hand, the susceptibility of the circadian system to phase shift by timed BL exposure has broad cost-effective potential implications for the treatment of core symptoms of ADHD, as well as for augmentation for prevention of psychiatric comorbidities in ADHD. Moreover, for the non-responders to pharmacological treatment, introduction of LT protocols may be of outmost importance. Further studies are needed to evaluate therapeutic outcomes of different types of LT (blue-light emitting boxes versus simulated dawn versus natural daylight) and to explore causality between BL therapy and changes in circadian gene expression. A suitable model for studying circadian gene expression and molecular circadian function could be human skin fibroblasts. A recent study using BL therapy showed a poorer response to chronotherapy predicted by longer in vitro period in patients with N24SWD (Hida et al. 2017), suggesting that the period length is associated

with chromotype, and that fibroblast rhythm correlates with circadian behaviour. The combined approach of assessment and phase shifting the circadian rhythm introduces new avenues for integrated diagnosis, treatment and the evaluation of treatment of ADHD.

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References

Abikoff H, Courtney ME, Szeibel PJ, Koplewicz HS. 1996. The effects of auditory stimulation on the arithmetic performance of children with ADHD and nondisabled children. J Learn Disabil. 29(3):238–246.

Adan A, Archer SN, Hidalgo MP, Di Milia L, Natale V, Randler C. 2012. Circadian typology: a comprehensive review. Chronobiol Int. 29(9):1153–1175.

Adi-Japha E, Fox O, Karni A. 2011. Atypical acquisition and atypical expression of memory consolidation gains in a motor skill in young female adults with ADHD. Res Dev Disabil. 32(3):1011–1020.

Advokat C. 2010. What are the cognitive effects of stimulant medications? Emphasis on adults with attention-deficit/hyperactivity disorder (ADHD). Neurosci Biobehav Rev. 34(8):1256–1266.

Albrecht U. 2011. The circadian clock, reward, and memory. Front Mol Neurosci. 4:41. doi:10.3389/fnmol.2011.00041.

Albrecht U. 2012. Timing to perfection: the biology of central and peripheral circadian clocks. Neuron. 74(2):246–260.

Allen AE, Storchi R, Martial FP, Bedford RA, Lucas RJ. 2017. Melanopsin contributions to the representation of images in the early visual system. Curr Biol. 27(11):1623–1632.

Amons PJ, Kooij JJ, Haffmans PM, Hoffman TO, Hoencamp E. 2006. Seasonality of mood disorders in adults with lifetime attention-deficit/hyperactivity disorder (ADHD). J Affect Disord. 91(2–3):251–255.

Ancoli-Israel S, Cole R, Alessi C, Chambers M, Moorcroft W, Pollak CP. 2003. The role of actigraphy in the study of sleep and circadian rhythms. Sleep. 26(3):342–392.

Antypa N, Vogelzangs N, Meesters Y, Schoevers R, Penninx BW. 2016. Chronotype associations with depression and anxiety disorders in a large cohort study. Depress Anxiety. 33(1):75–83.

Archer SN, Carpen JD, Gibson M, Lim GH, Johnston JD, Skene DJ, von Schantz M. 2010. Polymorphism in the PER3 promoter associates with diurnal preference and delayed sleep phase disorder. Sleep. 33(5):695–701.

Arns M, van der Heijden KB, Arnold LE, Kenemans JL. 2013. Geographic variation in the prevalence of attention-deficit/hyperactivity disorder: the sunny perspective. Biol Psychiatry. 74(8):585–590.

Arnsten AF. 2006. Stimulants: therapeutic actions in ADHD. Neuropsychopharmacol. 31(11):2376–2383.

Avery DH, Eder DN, Bolte MA, Hellekson CJ, Dunner DL, Vitiello MV, Prinz PN. 2001. Dawn simulation and bright light in the treatment of SAD: a controlled study. Biol Psychiatry. 50(3):205–216.

Badia P, Myers B, Boecker M, Culpepper J, Harsh JR. 1991. Bright light effects on body temperature, alertness, EEG and behavior. Physiol Behav. 50(3):583–588.

Baijot S, Slama H, Soderlund G, Dan B, Deltenre P, Colin C, Deconinck N. 2016. Neuropsychological and neurophysiological benefits from white noise in children with and without ADHD. Behav Brain Funct. 12(1):016–0095.

Baird AL, Coogan AN, Siddiqui A, Donev RM, Thome J. 2012. Adult attention-deficit hyperactivity disorder is associated with alterations in circadian rhythms at the behavioural, endocrine and molecular levels. Mol Psychiatry. 17(10):988–995.

Baranger DA, Ifrah C, Prather AA, Carey CE, Corral-Frias NS, Drabant Conley E, Hariri AR, Bogdan R. 2016. PER1 rs3027172 genotype interacts with early life stress to predict problematic alcohol use, but not reward-related ventral striatum activity. Front Psychol. 7:464. doi:10.3389/fpsyg.2016.00464.

Barclay NL, Watson NF, Buchwald D, Goldberg J. 2014. Moderation of genetic and environmental influences on diurnal preference by age in adult twins. Chronobiol Int. 31(2):222–231.

Belle MD, Diekman CO, Forger DB, Piggins HD. 2009. Daily electrical silencing in the mammalian circadian clock. Science. 326(5950):281–284.

Beute F, de Kort YA. 2014. Salutogenic effects of the environment: review of health protective effects of nature and daylight. Appl Psychol Health Well Being. 6(1):67–95.

Bijlenga D, Van Someren, EJ, Gruber R, Bron TI, Kruithof IF, Spanbroek EC, Kooij JJ. 2013. Body temperature, activity and melatonin profiles in adults with attention-deficit/hyperactivity disorder and delayed sleep: a case-control study. J Sleep Res. 22(6):607–616.

Boivin DB, Duffy JF, Kronauer RE, Czeisler CA. 1996. Dose-response relationships for resetting of human circadian clock by light. Nature. 379(6565):540–542.

Boulos Z, Macchi MM, Terman M. 2002. Twilights widen the range of photic entrainment in hamsters. J Biol Rhythms. 17(4):353–363.

Bowrey HE, James MH, Aston-Jones G. 2017. New directions for the treatment of depression: targeting the photic regulation of arousal and mood (PRAM) pathway. Depress Anxiety. 34(7):588–595.

Brennan AR, Arnsten AF. 2008. Neuronal mechanisms underlying attention deficit hyperactivity disorder: the influence of arousal on prefrontal cortical function. Ann N Y Acad Sci. 1129:236–45.

Brown SA, Fleury-Olela F, Nagoshi E, Hauser C, Juge C, Meier CA, Chicheportiche R, Dayer J -M, Albrecht U, Schibler U. 2005. The period length of fibroblast circadian gene expression varies widely among human individuals. PLoS Biol. 3(10):27.

Buhr ED, Takahashi JS. 2013. Molecular components of the mammalian circadian clock. In: Kramer A, Merrow M, editors. Circadian clocks. Handbook of experimental pharmacology, vol 217. Berlin, Heidelberg: Springer; 3–27.

Bumb JM, Mier D, Noelte I, Schredl M, Kirsch P, Hennig O, Liebrich L, Fenske S, Alm B, Sauer C, et al. 2016. Associations of pineal volume, chronotype and symptom severity in adults with attention deficit hyperactivity disorder and healthy controls. Eur Neuropsychopharm. 26(7): 1119–1126.

Cajochen C, Zeitzer JM, Czeisler CA, Dijk DJ. 2000. Dose-response relationship for light intensity and ocular and electroencephalographic correlates of human alertness. Behav Brain Res. 115(1):75–83.

Carvalho C, Vieira Crespo M, Ferreira Bastos L, Knight A, Vicente L. 2016. Contribution of animal models to contemporary understanding of Attention Deficit Hyperactivity Disorder. Altex. 33(3):243–249.

Chamorro M, Lara JP, Insa I, Espadas M, Alda-Diez JA. 2017. Evaluation and treatment of sleep problems in children diagnosed with attention deficit hyperactivity disorder: an update of the evidence. Rev Neurol. 64(9):413–421.

Chan E, Fogler JM, Hammerness PG. 2016. Treatment of attention-deficit/hyperactivity disorder in adolescents: a systematic review. JAMA. 315(18):1997–2008.

Chang A-M, Santhi N, St Hilaire M, Gronfier C, Bradstreet DS, Duffy JF, Lockley SW, Kronauer RE, Czeisler CA. 2012. Human responses to bright light of different durations. J Physiol. 590(13):3103–3112.

Charrier A, Olliac B, Roubertoux P, Tordjman S. 2017. Clock genes and altered sleep–wake rhythms: their role in the development of psychiatric disorders. Int J Mol Sci. 18(5): 938.

Chellappa SL, Gordijn MC, Cajochen C. 2011. Can light make us bright? Effects of light on cognition and sleep. Prog Brain Res. 190:119–133.

Chojnacka M, Antosik-Wojcinska AZ, Dominiak M, Bzinkowska D, Borzym A, Sokol-Szawlowska M, Bodzak-Opolska G, Antoniak D, Swiecicki L. 2016. A sham-controlled randomized trial of adjunctive light therapy for non-seasonal depression. J Affect Disord. 203:1–8.

Coogan AN, Baird AL, Popa-Wagner A, Thome J. 2016. Circadian rhythms and attention deficit hyperactivity disorder: the what, the when and the why. Prog Neuropsychopharmacol Biol Psychiatry. 67(Supplement C): 74–81.

Coogan AN, McGowan NM. 2017. A systematic review of circadian function, chronotype and chronotherapy in attention deficit hyperactivity disorder. Atten Defic Hyperact Disord. 7(10):016–0214.

Corkum P, Tannock R, Moldofsky H. 1998. Sleep disturbances in children with attention-deficit/hyperactivity disorder. J Am Acad Child Adolesc Psychiatry. 37(6):637–646.

Czeisler CA, Allan JS, Strogatz SH, Ronda JM, Sanchez R, Rios CD, Freitag WO, Richardson GS, Kronauer RE. 1986. Bright light resets the human circadian pacemaker independent of the timing of the sleep-wake cycle. Science. 233(4764): 667–671.

Dardente H, Menet JS, Poirel VJ, Streicher D, Gauer F, Vivien-Roels B, Klosen P, Pévet P, Masson-Pevet M. 2003. Melatonin induces Cry1 expression in the pars tuberalis of the rat. Brain Res Mol Brain Res. 114(2):101–106.

Debas K, Carrier J, Orban P, Barakat M, Lungu O, Vandewalle G, Tahar AH, Bellec P, Karni A, Ungerleider LG, et al. 2010. Brain plasticity related to the consolidation of motor sequence learning and motor adaptation. Proc Natl Acad Sci U S A. 107(41):17839–17844.

Debra JS, Josephine A. 2006. Human circadian rhythms: physiological and therapeutic relevance of light and melatonin. Ann Clin Biochem. 43(5):344–353.

Dijk DJ, Archer SN. 2010. PERIOD3, circadian phenotypes, and sleep homeostasis. Sleep Med Rev. 14(3):151–160.

Douglas VI. 1999. Cognitive control processes in attention deficit/hyperactivity disorder. In Quay HC, Hogan AE, editors. Handbook of disruptive behavior disorders. Boston, (MA): Springer US; 105–138.

Duffy JF, Rimmer DW, Czeisler CA. 2001. Association of intrinsic circadian period with morningness–eveningness, usual wake time, and circadian phase. Behav Neurosci. 115(4):895–899.

Eastman CI, Young MA, Fogg LF, Liu L, Meaden PM. 1998. Bright light treatment of winter depression: a placebo-controlled trial. Arch Gen Psychiatry. 55(10):883–889.

Eckel-Mahan KL, Phan T, Han S, Wang H, Chan GC, Scheiner ZS, Storm DR. 2008. Circadian oscillation of hippocampal MAPK activity and cAmp: implications for memory persistence. Nat Neurosci. 11(9):1074–1082.

Endo T, Kripke DF, Ancoli-Israel S. 2015. Wake up time, light, and mood in a population sample age 40-64 years. Psychiatry Investig. 12(2):177–182.

Evans DS, Snitker S, Wu SH, Mody A, Njajou OT, Perlis ML, et al. 2011. Habitual sleep/wake patterns in the Old Order Amish: heritability and association with non-genetic factors. Sleep. 34(5):661–669.

Fargason RE, Fobian AD, Hablitz LM, Paul JR, White BA, Cropsey KL, Gamble KL. 2017. Correcting delayed circadian phase with bright light therapy predicts improvement in ADHD symptoms: a pilot study. J Psychiatr Res. 91:105–110.

Farrell MS, Werge T, Sklar P, Owen MJ, Ophoff RA, O'Donovan MC, Corvin A, Cichon S, Sullivan PF. 2015. Evaluating historical candidate genes for schizophrenia. Mol Psychiatr. 20(5):555–562.

Fayyad J, De Graaf R, Kessler R, Alonso J, Angermeyer M, Demyttenaere K, et al. 2007. Cross-national prevalence and correlates of adult attention-deficit hyperactivity disorder. Br J Psychiatry. 190:402–409.

Figueiro MG. 2016. Delayed sleep phase disorder: clinical perspective with a focus on light therapy. Nat Sci Sleep. 8: 91–106.

Figueiro MG, Plitnick B, Rea MS. 2014. Pulsing blue light through closed eyelids: effects on acute melatonin suppression and phase shifting of dim light melatonin onset. Nat Sci Sleep. 6:149–156.

Forbes EE, Dahl RE, Almeida JR, Ferrell RE, Nimgaonkar VL, Mansour H, Sciarrillo SR, Holm SM, Rodriguez EE, Phillips ML. 2012. PER2 rs2304672 polymorphism moderates circadian-relevant reward circuitry activity in adolescents. Biol Psychiatry. 71(5):451–457.

Foster RG, Peirson SN, Wulff K, Winnebeck E, Vetter C, Roenneberg T. 2013. Sleep and circadian rhythm disruption in social jetlag and mental illness. Prog Mol Biol Transl Sci. 119:325–346.

Fox O, Karni A, Adi-Japha E. 2016. The consolidation of a motor skill in young adults with ADHD: Shorter practice can be better. Res Dev Disabil. 52:135–144.

Franke B, Faraone SV, Asherson P, Buitelaar J, Bau CHD, Ramos-Quiroga JA, Mick E, Grevet EH, Johansson S, Haavik J, et al. 2011. The genetics of attention deficit/hyperactivity disorder in adults, a review. [Feature Review]. Mol Psychiatr. 17:960.

Gaspar L, Howald C, Popadin K, Maier B, Mauvoisin D, Moriggi E, Gutierrez-Arcelus M, Falconnet E, Borel C, Kunz D, et al. 2017. The genomic landscape of human cellular circadian variation points to a novel role for the signalosome. Elife. 4(6):24994.

Gaub M, Carlson CL. 1997. Behavioral characteristics of DSM-IV ADHD subtypes in a school-based population. J Abnorm Child Psych. 25(2):103–111.

González-Giraldo Y, González-Reyes RE, Mueller ST, Piper BJ, Adan A, Forero DA. 2015. Differences in planning performance, a neurocognitive endophenotype, are associated with a functional variant in PER3 gene. Chronobiol Int. 32(5):591–595.

Gooley JJ. 2008. Treatment of circadian rhythm sleep disorders with light. Ann Acad Med Singapore. 37(8):669–676.

Goulardins JB, Marques JC, De Oliveira JA. 2017. Attention deficit hyperactivity disorder and motor impairment. Percept Motor Skill. 124(2):425–440.

Graham J, Coghill D. 2008. Adverse effects of pharmacotherapies for attention-deficit hyperactivity disorder. [journal article]. CNS Drugs. 22(3):213–237.

Grandner MA, Kripke DF, Elliott J, Cole R. 2013. Short wavelength light administered just prior to waking: a pilot study. Biol Rhythm Res. 44(1):13–32.

Halperin JM, Schulz KP. 2006. Revisiting the role of the prefrontal cortex in the pathophysiology of attention-deficit/hyperactivity disorder. Psychol Bull. 132(4):560–581.

Hampp G, Ripperger JA, Houben T, Schmutz I, Blex C, Perreau-Lenz S, Brunk I, Spanagel R, Ahnert-Hilger G, Meijer JH, et al. 2008. Regulation of monoamine oxidase a by circadian-clock components implies clock influence on mood. Curr Biol. 18(9):678–683.

Hankins MW, Peirson SN, Foster RG. 2008. Melanopsin: an exciting photopigment. Trends Neurosci. 31(1):27–36.

Hardeland R, Madrid JA, Tan DX, Reiter RJ. 2012. Melatonin, the circadian multioscillator system and health: the need for detailed analyses of peripheral melatonin signaling. J Pineal Res. 52(2):139–166.

Hegerl U, Hensch T. 2014. The vigilance regulation model of affective disorders and ADHD. Neurosci Biobehav Rev. 44: 45–57.

Hennig T, Krkovic K, Lincoln TM. 2017. What predicts inattention in adolescents? An experience-sampling study comparing chronotype, subjective, and objective sleep parameters. Sleep Med. 38:58–63.

Hida A, Ohsawa Y, Kitamura S, Nakazaki K, Ayabe N, Motomura Y, Matsui K, Kobayashi M, Usui A, Inoue Y, et al. 2017. Evaluation of circadian phenotypes utilizing fibroblasts from patients with circadian rhythm sleep disorders. Transl Psychiat. 7(4):75.

Hsu CY, Gau SS, Shang CY, Chiu YN, Lee MB. 2012. Associations between chronotypes, psychopathology, and personality among incoming college students. Chronobiol Int. 29(4):491–501.

Hu Y, Shmygelska A, Tran D, Eriksson N, Tung JY, Hinds DA. 2016. GWAS of 89,283 individuals identifies genetic variants associated with self-reporting of being a morning person. Nat Commun. 7:10448.

Hughes S, Jagannath A, Hankins MW, Foster RG, Peirson SN. 2015. Photic regulation of clock systems. Methods Enzymol. 552:125–143.

Hye Oh J, Ji Yang S, Rag Do Y. 2014. Healthy, natural, efficient and tunable lighting: four-package white LEDs for optimizing the circadian effect, color quality and vision performance. [Original Article]. Light-Sci Appl. 3:e141.

Imeraj L, Sonuga-Barke E, Antrop I, Roeyers H, Wiersema R, Bal S, Deboutte D. 2012. Altered circadian profiles in attention-deficit/hyperactivity disorder: an integrative review and theoretical framework for future studies. Neurosci Biobehav Rev. 36(8):1897–1919.

Iwase T, Kajimura N, Uchiyama M, Ebisawa T, Yoshimura K, Kamei Y, Shibui K, Kim K, Kudo Y, Katoh M, et al. 2002. Mutation screening of the human Clock gene in circadian rhythm sleep disorders. Psychiatry Res. 109(2):121–128.

Iyer R, Wang TA, Gillette MU. 2014. Circadian gating of neuronal functionality: a basis for iterative metaplasticity. Front Syst Neurosci. 8:164.

James S-N, Cheung CHM, Rijsdijk F, Asherson P, Kuntsi J. 2016. Modifiable arousal in attention-deficit/hyperactivity disorder and its etiological association with fluctuating reaction times. Biol Psychiat. 1(6):539–547.

Janich P, Pascual G, Merlos-Suarez A, Batlle E, Ripperger J, Albrecht U, Cheng HY, Obrietan K, Di Croce L, Benitah SA. 2011. The circadian molecular clock creates epidermal stem cell heterogeneity. Nature. 480(7376):209–214.

Jeong SH, Yu JC, Lee CH, Choi KS, Choi JE, Kim SH, Joo EJ. 2014. Human CLOCK gene-associated attention deficit hyperactivity disorder-related features in healthy adults: quantitative association study using Wender Utah Rating Scale. Eur Arch Psychiatry Clin Neurosci. 264(1):71–81.

Jilg A, Lesny S, Peruzki N, Schwegler H, Selbach O, Dehghani F, Stehle JH. 2010. Temporal dynamics of mouse hippocampal clock gene expression support memory processing. Hippocampus. 20(3):377–388.

Johansson C, Willeit M, Smedh C, Ekholm J, Paunio T, Kieseppa T, Lichtermann D, Praschak-Rieder N, Neumeister A, Nilsson LG, et al. 2003. Circadian clock-related polymorphisms in seasonal affective disorder and their relevance to diurnal preference. Neuropsychopharmacol. 28(4): 734–739.

Johnson KA, Kelly SP, Bellgrove MA, Barry E, Cox M, Gill M, Robertson IH. 2007. Response variability in attention deficit hyperactivity disorder: evidence for neuropsychological heterogeneity. Neuropsychologia. 45(4):630–638.

Jones SE, Tyrrell J, Wood AR, Beaumont RN, Ruth KS, Tuke MA, Yaghootkar H, Hu Y, Teder-Laving M, Hayward C, et al. 2016. Genome-wide association analyses in 128,266 individuals identifies new morningness and sleep duration loci. PLoS Genet. 12(8):e1006125.

Kaiser ML, Schoemaker MM, Albaret JM, Geuze RH. 2014. What is the evidence of impaired motor skills and motor control among children with attention deficit hyperactivity disorder (ADHD)? Systematic review of the literature. Res Dev Disabil. 36C:338–357.

Kaladchibachi S, Fernandez F. 2018. Precision light for the treatment of psychiatric disorders. Neural Plast. 2018: Article ID 5868570.

Kalman S, Garbett KA, Janka Z, Mirnics K. 2016. Human dermal fibroblasts in psychiatry research. Neuroscience. 320: 105–121.

Kalmbach DA, Schneider LD, Cheung J, Bertrand SJ, Kariharan T, Pack AI, Gehrman PR. 2017. Genetic basis of chronotype in humans: insights from three landmark GWAS. Sleep. 40(2):zsw048.

Katzenberg D, Young T, Finn L, Lin L, King DP, Takahashi JS, Mignot E. 1998. A CLOCK polymorphism associated with human diurnal preference. Sleep. 21(6):569–576.

Keijzer H, Smits MG, Duffy JF, Curfs LM. 2014. Why the dim light melatonin onset (DLMO) should be measured before treatment of patients with circadian rhythm sleep disorders. Sleep Med Rev. 18(4):333–339.

Kim J, Jang S, Choe HK, Chung S, Son GH, Kim K. 2017. Implications of circadian rhythm in dopamine and mood regulation. Mol Cells. 40(7):450–456.

Kissling C, Retz W, Wiemann S, Coogan AN, Clement RM, Hunnerkopf R, Conner AC, Freitag CM, Rösler M, Thome J. 2008. A polymorphism at the 3'-untranslated region of the CLOCK gene is associated with adult attention-deficit hyperactivity disorder. Am J Med Genet B Neuropsychiatr Genet. 147(3):333–338.

Kobayashi Y, Ye Z, Hensch TK. 2015. Clock genes control cortical critical period timing. Neuron. 86(1):264–275.

Kooij JJ, Bijlenga D. 2013. The circadian rhythm in adult attention-deficit/hyperactivity disorder: current state of affairs. Expert Rev Neurother. 13(10):1107–1116

Korman M, Levy I, Karni A. 2017. Procedural memory consolidation in attention-deficit/hyperactivity disorder is promoted by scheduling of practice to evening hours. Front Psychiatry. 8:140.

Korman M, Raz N, Flash T, Karni A. 2003. Multiple shifts in the representation of a motor sequence during the acquisition of skilled performance. Proc Natl Acad Sci USA. 100(21):12492–12497.

Kozaki T, Toda N, Noguchi H, Yasukouchi A. 2011. Effects of different light intensities in the morning on dim light melatonin onset. J Physiol Anthropol. 30(3):97–102.

Lack L, Bramwell T, Wright H, Kemp K. 2007. Morning blue light can advance the melatonin rhythm in mild delayed sleep phase syndrome. Sleep Biol Rhythms. 5(1):78–80.

Lam RW, Levitt AJ, Levitan RD, Michalak EE, Cheung AH, Morehouse R, Ramasubbu R, Yatham LN, Tam EM. 2016. Efficacy of bright light treatment, fluoxetine, and the combination in patients with nonseasonal major depressive disorder: a randomized clinical trial. JAMA Psychiatry. 73(1):56–63.

Lamont EW, Robinson B, Stewart J, Amir, S. 2005. The central and basolateral nuclei of the amygdala exhibit opposite diurnal rhythms of expression of the clock protein Period2. Proc Natl Acad Sci U S A. 102(11):4180–4184.

Lane JM, Vlasac I, Anderson SG, Kyle SD, Dixon WG, Bechtold DA, Gill S, Little MA, Luik A, Loudon A, et al. 2016. Genome-wide association analysis identifies novel loci for chronotype in 100,420 individuals from the UK Biobank. Nat Commun. 7:10889.

Lara C, Fayyad J, de Graaf R, Kessler RC, Aguilar-Gaxiola S, Angermeyer M, et al. 2009. Childhood predictors of adult attention-deficit/hyperactivity disorder: results from the World Health Organization World Mental Health Survey Initiative. Biol Psychiatry. 65(1):46–54.

Lee C, Etchegaray JP, Cagampang FR, Loudon AS, Reppert SM. 2001. Posttranslational mechanisms regulate the mammalian circadian clock. Cell. 107(7):855–867.

Leocadio-Miguel MA, Louzada FM, Duarte LL, Areas RP, Alam M, Freire MV, Fontenele-Araujo J, Menna-Barreto L, Pedrazzoli M. 2017. Latitudinal cline of chronotype. Sci Rep. 7(1):5437.

Li X. 2018. The antidepressant effect of light therapy from retinal projections. Neurosci Bull. 34(2):359–368.

Lockley SW, Brainard GC, Czeisler CA. 2003. High sensitivity of the human circadian melatonin rhythm to resetting by short wavelength light. J Clin Endocrinol Metab. 88(9): 4502–4505.

Magnin E, Maurs C. 2017. Attention-deficit/hyperactivity disorder during adulthood. Rev Neurol. 173(7–8):506–515.

Marcheva B, Ramsey KM, Buhr ED, Kobayashi Y, Su H, Ko CH, Ivanova G, Omura C, Mo S, Vitaterna MH, et al. 2010. Disruption of the clock components CLOCK and BMAL1 leads to hypoinsulinaemia and diabetes. Nature. 466(7306):627–631.

Mayer JS, Hees K, Medda J, Grimm O, Asherson P, Bellina M, Colla M, Ibáñez P, Koch E, Martinez-Nicolas A, et al. 2018. Bright light therapy versus physical exercise to prevent co-morbid depression and obesity in adolescents and young adults with attention-deficit/hyperactivity disorder: study protocol for a randomized controlled trial. Trials. 19(1):017–2426.

McCarthy MJ, Wei H, Marnoy Z, Darvish RM, McPhie DL, Cohen BM, Welsh DK. 2013. Genetic and clinical factors predict lithium's effects on PER2 gene expression rhythms in cells from bipolar disorder patients. Transl Psychiatry. 22(3):90.

McClung CA, Sidiropoulou K, Vitaterna M, Takahashi JS, White FJ, Cooper DC, Nestler EJ. 2005. Regulation of dopaminergic transmission and cocaine reward by the Clock gene. Proc Natl Acad Sci U S A. 102(26):9377–9381.

McGowan NM, Voinescu BI, Coogan AN. 2016. Sleep quality, chronotype and social jetlag differentially associate with symptoms of attention deficit hyperactivity disorder in adults. Chronobiol Int. 33(10):1433–1443.

Melroy-Greif WE, Gizer IR, Wilhelmsen KC, Ehlers CL. 2017. Genetic influences on evening preference overlap with those for bipolar disorder in a sample of Mexican Americans and American Indians. Twin Res Hum Genet. 20(6):499–510.

Merrow M, Spoelstra K, Roenneberg T. 2005. The circadian cycle: daily rhythms from behaviour to genes. EMBO Rep. 6(10):930–935.

Mongrain V, Carrier J, Dumont M. 2006. Circadian and homeostatic sleep regulation in morningness-eveningness. J Sleep Res. 15(2):162–166.

Moore RY. 1997. Circadian rhythms: basic neurobiology and clinical applications. Annu Rev Med. 48:253–266.

Mostofsky SH, Rimrodt SL, Schafer JGB, Boyce A, Goldberg MC, Pekar JJ, Denckla MB. 2006. Atypical motor and sensory cortex activation in attention-deficit/hyperactivity disorder: a functional magnetic resonance imaging study of simple sequential finger tapping. Biol Psychiat. 59(1): 48–56.

Nicolson RI, Fawcett AJ. 2007. Procedural learning difficulties: reuniting the developmental disorders? Trends Neurosci. 30(4):135–141.

Niederhofer, H. 2013. Stabilization of circadian rhythm, its augmentation by bright light treatment and its importance for ADHD and depression of adolescents. Neurosci Med. 04(03):5.

Oldham MA, Ciraulo DA. 2014. Bright light therapy for depression: a review of its effects on chronobiology and the autonomic nervous system. Chronobiol Int. 31(3): 305–319.

Owens J, Gruber R, Brown T, Corkum P, Cortese S, O'Brien L, Stein M, Weiss M. 2013. Future research directions in sleep and ADHD: report of a consensus working group. J Atten Disord. 17(7):550–564.

Pail G, Huf W, Pjrek E, Winkler D, Willeit M, Praschak-Rieder N, Kasper S. 2011. Bright-light therapy in the treatment of mood disorders. Neuropsychobiology. 64(3):152–162.

Panda, S. 2016. Circadian physiology of metabolism. Science. 354(6315):1008–1015.

Paschos GK, Ibrahim S, Song WL, Kunieda T, Grant G, Reyes TM, Bradfield CA, Vaughan CH, Eiden M, Masoodi M, et al. 2012. Obesity in mice with adipocyte-specific deletion of clock component Arntl. Nat Med. 18(12):1768–1777.

Patke A, Murphy PJ, Onat OE, Krieger AC, Ozcelik T, Campbell SS, Young MW. 2017. Mutation of the human circadian clock gene CRY1 in familial delayed sleep phase disorder. Cell. 169(2):203–215.

Pedrazzoli M, Louzada FM, Pereira DS, Benedito-Silva AA, Lopez AR, Martynhak BJ, Korczak AL, Koike Bdel V, Barbosa AA, D'Almeida V, et al. 2007. Clock polymorphisms and circadian rhythms phenotypes in a sample of the Brazilian population. Chronobiol Int. 24(1):1–8.

Pennington BF, Ozonoff S. 1996. Executive functions and developmental psychopathology. J Child Psychol Psyc. 37(1):51–87.

Petrovic P, Castellanos FX. 2016. Top-down dysregulation—from ADHD to emotional instability. Front Behav Neurosci. 10:70.

Philipsen A. 2006. Differential diagnosis and comorbidity of attention-deficit/hyperactivity disorder (ADHD) and borderline personality disorder (BPD) in adults. Eur Arch Psychiatry Clin Neurosci. 256(1):i42–46.

Philipsen A, Hornyak M, Riemann D. 2006. Sleep and sleep disorders in adults with attention deficit/hyperactivity disorder. Sleep Med Rev. 10(6):399–405.

Polanczyk G, de Lima MS, Horta BL, Biederman J, Rohde LA. 2007. The worldwide prevalence of ADHD: a systematic review and metaregression analysis. Am J Psychiatry. 164(6):942–948.

Polanczyk G, Rohde LA. 2007. Epidemiology of attention-deficit/hyperactivity disorder across the lifespan. Curr Opin Psychiatry. 20(4):386–392.

Ponzi D, Wilson MC, Maestripieri D. 2014. Eveningness is associated with higher risk-taking, independent of sex and personality. Psychol Rep. 115(3):932–947.

Refinetti R, Lissen GC, Halberg F. 2007. Procedures for numerical analysis of circadian rhythms. Biol Rhythm Res. 38(4):275–325.

Reppert SM, Weaver DR. 2002. Coordination of circadian timing in mammals. Nature. 418(6901):935–941.

Revell VL, Arendt J, Terman M, Skene DJ. 2005. Short-wavelength sensitivity of the human circadian system to phase-advancing light. J Biol Rhythms. 20(3):270–272.

Roenneberg T, Kantermann T, Juda M, Vetter C, Allebrandt KV. 2013. Light and the human circadian clock. Handb Exp Pharmacol. 217:311–331.

Roenneberg T, Merrow M. 2016. The circadian clock and human health. Curr Biol. 26(10):011.

Roenneberg T, Wirz-Justice A, Merrow M. 2003. Life between clocks: daily temporal patterns of human chronotypes. J Biol Rhythms. 18(1):80–90.

Roybal K, Theobold D, Graham A, DiNieri JA, Russo SJ, Krishnan V, Chakravarty S, Peevey J, Oehrlein N, Birnbaum S, et al. 2007. Mania-like behavior induced by disruption of CLOCK. Proc Natl Acad Sci U S A. 104(15):6406–6411.

Rubia K, Alegria AA, Cubillo AI, Smith AB, Brammer MJ, Radua J. 2014. Effects of stimulants on brain function in attention-deficit/hyperactivity disorder: a systematic review and meta-analysis. Biol Psychiat. 76(8):616–628.

Rybak YE, McNeely HE, Mackenzie BE, Jain UR, Levitan RD. 2006. An open trial of light therapy in adult attention-deficit/hyperactivity disorder. J Clin Psychiatry. 67(10): 1527–1535.

Rybak YE, McNeely HE, Mackenzie BE, Jain UR, Levitan RD. 2007. Seasonality and circadian preference in adult attention-deficit/hyperactivity disorder: clinical and neuropsychological correlates. Compr Psychiat. 48(6):562–571.

Sander C, Arns M, Olbrich S, Hegerl U. 2010. EEG-vigilance and response to stimulants in paediatric patients with attention deficit/hyperactivity disorder. Clin Neurophysiol. 121(9):1511–1518.

Sato TK, Yamada RG, Ukai H, Baggs JE, Miraglia LJ, Kobayashi TJ, Welsh DK, Kay SA, Ueda HR, Hogenesch JB. 2006. Feedback repression is required for mammalian circadian clock function. Nat Genet. 38(3):312–319.

Schachter S, Singer J. 1962. Cognitive, social, and physiological determinants of emotional state. Psychol Rev. 69(5):379. doi:10.1037/h0046234.

Shearman LP, Sriram S, Weaver DR, Maywood ES, Chaves I, Zheng B, Kume K, Lee CC, van der Horst GT, Hastings MH, et al. 2000. Interacting molecular loops in the mammalian circadian clock. Science. 288(5468):1013–1019.

Shi J, Wittke-Thompson JK, Badner JA, Hattori E, Potash JB, Willour VL, McMahon FJ, Gershon ES, Liu, C. 2008. Clock genes may influence bipolar disorder susceptibility and dysfunctional circadian rhythm. Am J Med Genet B Neuropsychiatr Genet. 5(7):1047–1055.

Sikstrom S, Soderlund G. 2007. Stimulus-dependent dopamine release in attention-deficit/hyperactivity disorder. Psychol Rev. 114(4):1047–1075.

Sit DK, McGowan J, Wiltrout C, Diler RS, Dills JJ, Luther J, Yang A, Ciolino JD, Seltman H, Wisniewski SR, et al. 2018. Adjunctive bright light therapy for bipolar depression: a randomized double-blind placebo-controlled trial. Am J Psychiatry. 175(2):131–139.

Sowell ER, Thompson PM, Welcome SE, Henkenius AL, Toga AW, Peterson BS. 2003. Cortical abnormalities in children and adolescents with attention-deficit hyperactivity disorder. Lancet. 362(9397):1699–1707.

Spencer TJ, Brown A, Seidman LJ, Valera EM, Makris N, Lomedico A, Faraone SV, Biederman J. 2013. Effect of psychostimulants on brain structure and function in ADHD: a

qualitative literature review of magnetic resonance imaging-based neuroimaging studies. J Clin Psychiat. 74(9): 902–917.

Stehle JH, von Gall C, Korf HW. 2003. Melatonin: a clock-output, a clock-input. J Neuroendocrinol. 15(4):383–389.

Storebo OJ, Pedersen N, Ramstad E, Kielsholm ML, Nielsen SS, Krogh HB, Moreira-Maia CR, Magnusson FL, Holmskov M, Gerner T, et al. 2018. Methylphenidate for attention deficit hyperactivity disorder (ADHD) in children and adolescents - assessment of adverse events in non-randomised studies. Cochrane Database Syst Rev. (5):CD012069.

Strauss M, Ulke C, Paucke M, Huang J, Mauche N, Sander C, Stark T, Hegerl, U. 2018. Brain arousal regulation in adults with attention-deficit/hyperactivity disorder (ADHD). Psychiatry Res. 261:102–108.

Terman M, Terman JS. 1999. Bright light therapy: side effects and benefits across the symptom spectrum. J Clin Psychiatry. 60(11):799–808.

Terman M, Terman JS. 2006. Controlled trial of naturalistic dawn simulation and negative air ionization for seasonal affective disorder. Am J Psychiatry. 163(12):2126–2133.

Tripp G, Wickens JR. 2008. Research review: dopamine transfer deficit: a neurobiological theory of altered reinforcement mechanisms in ADHD. J Child Psychol Psyc. 49(7): 691–704.

Turgay A, Ansari R. 2006. Major depression with ADHD: in children and adolescents. Psychiatr. 3(4):20–32.

Usui S. 2000. Gradual changes in environmental light intensity and entrainment of circadian rhythms. Brain Dev. 22(1):S61–S64.

Van De Werken M, Gimenez MC, De Vries B, Beersma DG, Van Someren EJ, Gordijn MC. 2010. Effects of artificial dawn on sleep inertia, skin temperature, and the awakening cortisol response. J Sleep Res. 19(3):425–435.

Van der Heijden KB, Smits MG, Van Someren EJ, Gunning WB. 2005. Idiopathic chronic sleep onset insomnia in attention-deficit/hyperactivity disorder: a circadian rhythm sleep disorder. Chronobiol Int. 22(3):559–570.

Van der Heijden KB, Smits MG, Van Someren EJ, Ridderinkhof KR, Gunning WB. 2007. Effect of melatonin on sleep, behavior, and cognition in ADHD and chronic sleep-onset insomnia. J Am Acad Child Adolesc Psychiatry. 46(2):233–241.

van der Meer D, Hoekstra PJ, van Donkelaar M, Bralten J, Oosterlaan J, Heslenfeld D, Faraone SV, Franke B, Buitelaar JK, Hartman CA. 2017. Predicting attention-deficit/hyperactivity disorder severity from psychosocial stress and stress-response genes: a random forest regression approach. Transl Psychiat. 7(6):114.

van der Meere J. 2005. State regulation and attention deficit hyperactivity disorder. In: Gozal D, Molfese DL, editors. Attention deficit hyperactivity disorder. Contemporary clinical neuroscience. Totowa (NJ): Humana Press; 413–433.

von Schantz M, Taporoski TP, Horimoto AR, Duarte NE, Vallada H, Krieger JE, et al. 2015. Distribution and heritability of diurnal preference (chronotype) in a rural Brazilian family-based cohort, the Baependi study. Sci Rep. 5(9214).

van Maanen A, Meijer AM, van der Heijden KB, Oort FJ. 2016. The effects of light therapy on sleep problems: A systematic review and meta-analysis. Sleep Med Rev. 29: 52–62.

Van Veen MM, Kooij JJS, Boonstra AM, Gordijn MCM, Van Someren EJW. 2010. Delayed circadian rhythm in adults with attention-deficit/hyperactivity disorder and chronic sleep-onset insomnia. Biol Psychiat. 67(11):1091–1096.

Vanselow K, Vanselow JT, Westermark PO, Reischl S, Maier B, Korte T, Herrmann A, Herzel H, Schlosser A, Kramer A. 2006. Differential effects of PER2 phosphorylation: molecular basis for the human familial advanced sleep phase syndrome (FASPS). Genes Dev. 20(19):2660–2672.

Vogel SWN, Bijlenga D, Benjamins JS, Beekman ATF, Kooij JJS, Van Someren EJW. 2017. Attention deficit hyperactivity disorder symptom severity and sleep problems in adult participants of the Netherlands sleep registry. Sleep Med. 40:94–102.

von Gall C, Weaver DR, Moek J, Jilg A, Stehle JH, Korf HW. 2005. Melatonin plays a crucial role in the regulation of rhythmic clock gene expression in the mouse pars tuberalis. Ann N Y Acad Sci. 1040:508–511.

Wainstein G, Rojas-Libano D, Crossley NA, Carrasco X, Aboitiz F, Ossandon T. 2017. Pupil size tracks attentional performance in attention-deficit/hyperactivity disorder. Sci Rep. 7(1):017–08246.

Wakamatsu H, Yoshinobu Y, Aida R, Moriya T, Akiyama M, Shibata S. 2001. Restricted-feeding-induced anticipatory activity rhythm is associated with a phase-shift of the expression of mPer1 and mPer2 mRNA in the cerebral cortex and hippocampus but not in the suprachiasmatic nucleus of mice. Eur J Neurosci. 13(6): 1190–1196.

Warman VL, Dijk DJ, Warman GR, Arendt J, Skene DJ. 2003. Phase advancing human circadian rhythms with short wavelength light. Neurosci Lett. 342(1–2):37–40.

Watanabe T, Kajimura N, Kato M, Sekimoto M, Takahashi K. 1999. Effects of phototherapy in patients with delayed sleep phase syndrome. Psychiatry Clin Neurosci. 53(2): 231–233.

Welsh DK, Takahashi JS, Kay SA. 2010. Suprachiasmatic nucleus: cell autonomy and network properties. Annu Rev Physiol. 72(1):551–577.

Wright HR, Lack LC, Kennaway DJ. 2004. Differential effects of light wavelength in phase advancing the melatonin rhythm. J Pineal Res. 36(2):140–144.

Wright KP, McHill AW, Birks BR, Griffin BR, Rusterholz T, Chinoy ED. 2013. Entrainment of the human circadian clock to the natural light-dark cycle. Curr Biol. 23(16): 1554–1558.

Wu JC, Kelsoe JR, Schachat C, Bunney BG, DeModena A, Golshan S, Gillin JC, Potkin SG, Bunney WE. 2009. Rapid and sustained antidepressant response with sleep deprivation and chronotherapy in bipolar disorder. Biol Psychiat. 66(3):298–301.

Wynchank DS, Bijlenga D, Lamers F, Bron TI, Winthorst WH, Vogel SW, Penninx BW, Beekman AT, Kooij, JS. 2016. ADHD, circadian rhythms and seasonality. J Psychiatr Res. 81:87–94.

Xu X, Breen G, Chen C-K, Huang Y-S, Wu Y-Y, Asherson P. 2010. Association study between a polymorphism at the 3′-untranslated region of CLOCK gene and attention deficit hyperactivity disorder. [journal article]. Behav Brain Funct. 6(1):48.

Yerkes RM, Dodson JD. 1908. The relation of strength of stimulus to rapidity of habit-formation. J Comp Neurol Psycho. 18(5):459–482.

Youssef PN, Sheibani N, Albert DM. 2011. Retinal light toxicity. Eye. 25(1):1–14.

Zentall SS, Meyer MJ. 1987. Self-regulation of stimulation for ADD-H children during reading and vigilance task performance. J Abnorm Child Psychol. 15(4):519–536.

Zentall SS, Shaw JH. 1980. Effects of classroom noise on performance and activity of second-grade hyperactive and control children. J Educ Psychol. 72(6):830–840.

Zentall SS, Zentall TR. 1983. Optimal stimulation: a model of disordered activity and performance in normal and deviant children. Psychol Bull. 94(3): 446–471.

Zhang R, Lahens NF, Ballance HI, Hughes ME, Hogenesch JB. 2014. A circadian gene expression atlas in mammals: implications for biology and medicine. Proc Natl Acad Sci U S A. 111(45):16219–16224.