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A Randomised Controlled Trial of Bright Light Therapy and Morning Activity for Adolescents and Young Adults with Delayed Sleep-Wake Phase Disorder.

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Abstract

A randomised controlled trial evaluated bright light therapy and morning activity for the treatment of Delayed Sleep-Wake Phase Disorder (DSWPD) in young people. 60 adolescents and young adults (range= 13-24 years, mean= 15.9±2.2 y, 63% f) diagnosed with DSWPD were randomised to receive three weeks of post-awakening Green Bright Light Therapy (~507nm) and Sedentary Activity (sitting, watching TV), Green Bright Light Therapy and Morning Activity (standing, playing motion-sensing videogame), Red Light Therapy (~643nm) and Sedentary Activity or Red Light Therapy and Morning Activity. Sleep (ie sleep onset time, wake up time, sleep onset latency, total sleep time) and daytime functioning (ie morning alertness, daytime sleepiness, fatigue, functional impairment) were measured pre-treatment, post-treatment and at one and three month follow-up. Contrary to predictions, there were no significant differences in outcomes between treatment groups; interaction effects between treatment group and time for all outcome variables were not statistically significant. However, adolescents and young adults in the morning activity conditions did not meaningfully increase their objective activity (ie movement frequency). Overall, adolescents reported significantly improved sleep timing (d=0.30-0.46), sleep onset latency (d=0.32) and daytime functioning (d=0.45-0.87) post-treatment. Improvements in sleep timing (d=0.53-0.61), sleep onset latency (d=0.57), total sleep time (d=0.51), and daytime functioning (d=0.52-1.02) were maintained, or improved upon, at the three month follow-up. However, relapse of symptomology was common and 38% of adolescents and young adults requested further treatment in addition to the three weeks of light therapy. Although there is convincing evidence for the short-term efficacy of chronobiological treatments for DSWPD, long-term treatment outcomes can be improved. To address this gap in our current knowledge, avenues for future research are discussed.

Keywords: Delayed Sleep Phase Disorder, Treatment, Light Therapy, Exercise, Adolescents.

Clinical Trial: Australian & New Zealand Clinical Trials Registry,

https://www.anzctr.org.au, ACTRN12614000308695.

Introduction

Delayed Sleep-Wake Phase Disorder (DSWPD) arises when the endogenous circadian rhythm and sleep timing of individuals is significantly later than what is generally accepted by modern society (American Academy of Sleep Medicine [AASM], 2014). DSWPD presents as the inability to initiate sleep at a desired clock time and difficulty waking to fulfil morning requirements. DSWPD is estimated to affect between 1-16% of adolescents (AASM, 2014; Lovato et al. 2013).

Changes in sleep occur throughout puberty, placing adolescents at particular risk of DSWPD. There is a widespread and consistent tendency for later bedtimes (Crowleyet et al. 2007; Gradisar et al. 2011), driven by reduced homeostatic sleep pressure across waking and delayed circadian timing (ie relative to younger school-aged children, Gradisar. Crowley, 2013). Compounding obligations (eg study, part-time work, extra-curricular pastimes) increase the number of tasks adolescents and young adults need to complete before sleep (Carskadon, 2011; Gradisar, Crowley, 2013) and lessening of parent-set bedtimes may permit later bedtimes (Gangwisch et al., 2010; Short et al., 2011). When waking for school, this leads to sleep restriction and impaired daytime functioning (Lovato et al., 2013; Shochat, et al 2014; Sivertsen et al. 2015; Wilhelmsen-Langeland et al., 2013). Due to the prevalence and impact of DSWPD on adolescents and young adults, it is important to ensure efficacious treatments are available.

Current treatments include behaviourally-based methods to manipulate circadian timing (eg bright light therapy (BLT), exogenous melatonin) (Gradisar et al. 2014). However, clinical trials evaluating the efficacy of treatments for DSWPD are rare. There is weak evidence supporting the use of strategically timed melatonin (Eckerberg et al. 2012; Saxvig et al., 2014; van Geijlswijk et al. 2010; van Maanen, Dewald-Kaufmann et al. 2013) or combined post-awakening light (via light box) and prescribed sleep-wake scheduling (Auger

et al., 2015; Danielsson et al. 2015; Gradisar et al., 2011; Saxvig et al., 2014). However, the degree of phase advancement can be influenced by light timing (Crowley, Eastman, 2017; Khalsa et al. 2003), duration (eg ≥30 mins; Geerdink et al. 2016; Gradisar, Dohnt, et al., 2011; Saxvig et al., 2014), illuminance (eg ≥117 lux; Cajochen et al., 2005) and wavelength (eg shorter>longer; Warman et al. 2003; Wright et al. 2004). Portable light devices (ie light glasses, light visors) have been recently developed and may be more practical for adolescents and young adults preparing for school, university or work (Bonnar et al., 2015). However, there is insufficient evidence to support their use in treatment (Auger et al., 2015). Additionally, although short wavelength light is thought to be superior in the treatment of circadian rhythm sleep disorders, there is a lack of clinical research to support this hypothesis (Auger et al., 2015).

There is also a paucity of research relating to many new areas of enquiry, for example, scheduled physical activity (Auger et al., 2015). Individuals with DSWPD are active late at night and relatively inactive in the morning (ie 8-11am) (Joo et al., 2017), which may perpetuate delayed sleep-wake timing. Nocturnal exercise delays circadian timing (Baehr et al., 2003; Baehr et al., 1999; Barger et al., 2004; Buxton et al., 1997; Eastman et al., 1995; Van Reeth et al., 1994; Youngstedt et al., 2002), whereas exercise administered at other times of the day may result in phase advances (Richardson et al., 2017), particularly when advanced in small daily increments (ie 20 mins) (Miyazaki et al., 2001). Therefore, it is possible that post-awakening morning activity, when combined with gradually earlier wake-up times, may help to phase advance the circadian and sleep timing of young people with DSWPD. This protocol overlaps that of BLT for DSWPD (Gradisar et al., 2014). Given that BLT can now be delivered by portable, wearable glasses, it is possible that the addition of scheduled exercise could improve treatment outcomes.

Increased morning activity may also have therapeutic implications for the daytime functioning of adolescents and young adults with DSWPD, as there is some evidence for the relationship between postural change, thermoregulation (ie changes in body temperatures) and alertness (Krauchi et al., 1997). Adolescents with good sleep hygiene experience benefits in sleep (ie SOL, deep slow-wave sleep), mood, daytime concentration and sleepiness, after running for 30 mins at moderate intensity for five days per week before school, over three weeks (Kalak et al., 2012). These findings suggest that if bright light therapy is combined with physical activity adolescents and young adults with DSWPD may experience additional benefits to sleep and daytime functioning.

Clinical guidelines place importance on replicating laboratory-based research within less tightly controlled field settings (Auger et al., 2015). Therefore, the present randomised-controlled study aimed to evaluate the efficacy of BLT delivered by portable short-wavelength light glasses, and whether supplementing BLT with morning activity enhances treatment outcomes for adolescents and young adults with DSWPD. Outcomes of interest include sleep timing (ie sleep onset time, wake up time), sleep latency, total sleep time and daytime functioning (ie morning alertness, daytime sleepiness, fatigue, functional impairment). To extend upon a recent trial comparing bright broad-spectrum white light (active treatment) with dim red light (control condition), we compared the efficacy of green (short) wavelength light, to red (long) wavelength light. Within each of these conditions, participants were randomly allocated to complete physical activity (standing, playing motion-sensing videogame) or sedentary activity (sitting, watching TV) during morning LT. It was predicted that green LT groups, and morning activity groups, would have better outcomes at post-treatment.

Method

Participants

455 families made contact with the Child & Adolescent Sleep Clinic following referral from GPs, or in response to community advertisements (Figure 1). 164 adolescents and young adults met age criteria for inclusion and 83 were assessed. Of these, 63 met ICSD-3 (AASM, 2014) criteria for DSWPD, and 60 were randomised into the study (mean= 15.9±2.2 y, 63% f). The trial was registered with the Australian and New Zealand Clinical Trials Registry (ACTRN12614000308695) and approved by the Southern Adelaide Clinical Human Research Ethics Committee (Application Number 165.14).

Inclusion criteria for the study were as follows: participants aged between 13-24 years[1], and primary diagnosis of DSWPD. This age range of participants was chosen, as adolescents and young adults are biologically driven to have later chronotypes (Roenneberg et al., 2004), and it is common for young adults in Australia to reside with their parents, thus they were not considered distinct phenomenological groups. Participants were not excluded for psychological comorbidity, given its prevalence in individuals with DSWPD (Reid et al., 2012; Sivertsen et al., 2015), which enhances the generalisability of findings (Wilhelmsen-Langeland et al., 2013). However, severe suicidal ideation led to exclusion.

Adolescents and young adults were randomly allocated to receive Green BLT and sedentary activity (SA) (*N*=15, mean age= 15.9±1.8 y, 60% f), Green BLT and morning activity (MA) (*N*=15, mean= 16.2±2.8 y, 67% f), Red LT and SA (*N*=15, mean= 15.5±1.6 y, 67% f) or Red LT and MA (*N*=15, mean= 15.7±2.8 y, 60% f). Groups did not differ in terms of age, F (3,56) = 0.22, p=.88, or gender distribution, χ^2(1, N = 60) = 0.29, p= 0.96.

[1] 90% of the sample was aged between 13-19yrs.

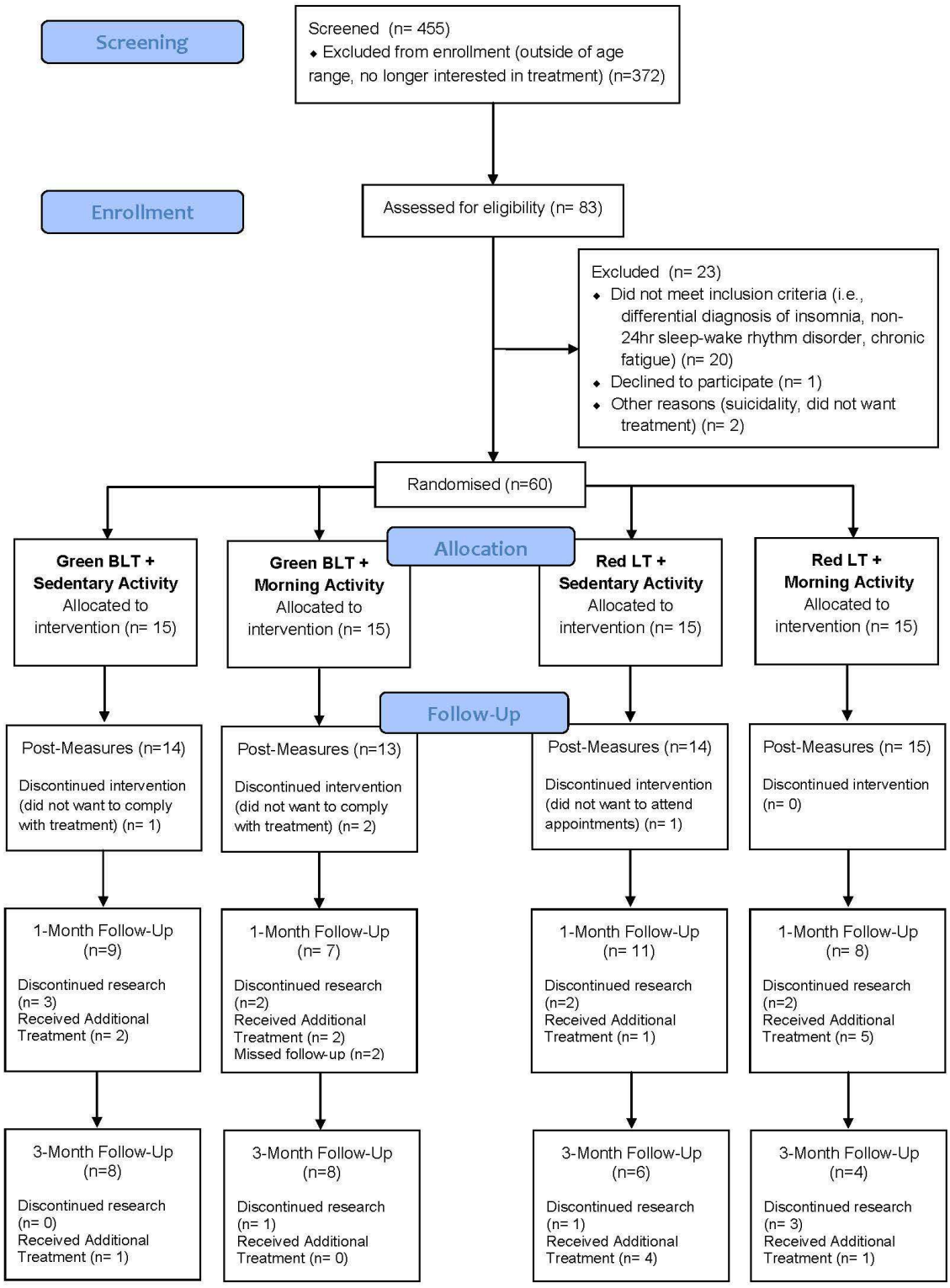

Figure 1 Participant flow.

Materials and Apparatus

Clinical Sleep History Interview (CSHI)

A revised semi-structured interview (Gradisar, Dohnt, et al., 2011) was used to diagnose DSWPD, as per the ICSD-3 (AASM, 2014). The CSHI elicited information pertaining to Criterion A (chronic difficulty initiating sleep and awakening); Criterion B (present for ≥three months) and Criterion E (differential diagnosis). In terms of quantifying the severity of delay in sleep timing, participants self-reported their *ad libitum* wake up time (ie wake up time on days they do not have morning commitments) and their required wake up time (eg to attend school, university, work), in the clinical sleep history interview. Adolescents and young adults reported an *ad libitum* wake up time (mean=11:28am±1.76hr) significantly later than the wake up time required to fulfil morning commitments (mean=7:30am±1.15hr). Sleep diaries were also used to confirm a delay in the timing of the habitual sleep period.

Sleep Diary

Sleep diaries are considered essential for DSWPD diagnosis, (AASM, 2014). The daily online sleep diary measured sleep timing, sleep onset latency (SOL), wake after sleep onset (WASO) and total sleep time (TST). Sleep parameters were averaged for school nights (Sun-Thurs) and weekend nights (Fri-Sat) separately. Daily sleep diaries completed throughout treatment also required participants to self-report the duration (mins) of morning light therapy and activity completed.

Wrist Actigraphy

Participants wore a MicroMini Motionlogger wrist actigraphy monitor (Ambulatory Monitoring Inc., Ardsley, NY) for one week following the assessment, and for the three weeks of treatment (ie not at follow-up). Data was collected using zero-crossing mode in one

min epochs. Actigraphy is useful for identifying sleep problems caused by mistimed circadian rhythms and is sensitive to improvements in sleep as a result of treatment (Ancoli-Israel et al., 2003). Adolescent's sleep onset time and offset time were scored using an algorithm validated for adolescents (AMI-Sadeh, Action 4, Ambulatory Monitoring Inc, Ardsley, NY) (Meltzer et al. 2012; Sadeh et al.,1994), to confirm delayed sleep timing at baseline (Criterion D), and to monitor changes across treatment. Motor activity for the hour after awakening (ie activity frequency count per one min epoch) was also scored to confirm compliance with allocated morning activity. For data to be included in analysis, participants needed to have at least three days of actigraphy recording per school week (Acebo et al., 1999). An increase in post-awakening motor activity from baseline to treatment was the criteria for compliance with the physical activity intervention, whereas stabilisation, or a reduction, of physical activity was anticipated for participants within the sedentary activity conditions.

Sleepiness and Fatigue

Sleepiness and fatigue are distinct daytime consequences of inadequate adolescent sleep (Shen et al. 2006; Short et al., 2013). The Pediatric Daytime Sleepiness Scale (PDSS) is an eight item self-report scale of daytime sleepiness (eg "*How often do you fall asleep or feel drowsy in class*?"; zero="*Never*", four= "*Always*") (Drake et al., 2003). Total scores range from 0-32, with higher scores indicating higher sleepiness. Drake and colleagues (2003) reported good internal consistency (Cronbach $\alpha = 0.80$); however, reliability was lower in the current study (Cronbach $\alpha = 0.57$).

The Flinders Fatigue Scale (FFS) is a seven item self-report measure of global fatigue (eg "*Was fatigue a problem for you?*"; zero="*Not at all*", four="*Extremely*") (Cameron et al., 2017; Gradisar et al., 2007). Total scores range from 0-31, with higher scores indicating greater fatigue. The FFS had good reliability (Cronbach $\alpha = 0.86$).

Adolescents and young adults provided a daily rating of morning alertness, using a five point Likert scale with pictorial stimuli (eg *"which face best describes how you are feeling one hour after waking up in the morning"*) (Maldonado et al., 2004). Scores ranged from one-five, with higher scores indicating higher alertness.

Functional Impairment

Individuals with DSWPD report lifestyle impairment (Giannotti et al., 2002; Micic et al., 2015; Rajaratnam et al., 2015; Saxvig et al., 2012). The Sheehan Disability Scale (SDS) is a five item measure of functional impairment (eg "*To what extent has your sleep pattern disrupted your school work*"; 0="*Not at all*", 10="*Extremely*") (Sheehan et al., 1996). Participant also reported the number of missed and under-productive days/week (zero-seven). Total scores range from 0-47, with higher scores indicating more impairment. The SDS had adequate reliability (Cronbach $\alpha = 0.71$).

Portable Light Glasses

Re-Timers (ie glasses with two LED lights on the bottom frame, per eye; Re-time Pty Ltd., Adelaide, Australia) were the light source for LT. Participants received either commercially available green light (~507nm) glasses on the highest setting (~112 lux per diode at two cm distance[2]), or Re-timer frames, altered to emit red light (~643nm), on the lowest setting (~54 lux per diode at two cm distance) (spectrometer: Ocean Optics, Florida, USA; lux meter: A.P.C.S., NSW, Australia). Discounting the wavelength of light emitted, the glasses looked otherwise identical for both treatment conditions. As the human circadian rhythm is least sensitive to long-wavelengths of light (Wright et al., 2004), red light was used as a control condition (Saxvig et al., 2014). All participants were asked to draw curtains and

[2] Re-Timer LEDs sit approximately two cm from the eye.

blinds in the home during LT, reducing ambient light and isolating light emitted from the glasses.

Morning Activity

Adolescents and young adults in the morning activity conditions were asked to complete 30-60 mins of mild physical activity during LT. Physical activity involved playing a motion-sensing videogame (eg, XBox Kinect, Nintendo Wii, Playstation Move), whilst standing upright. This modality was chosen, as videogames are played indoors (ie, not weather-affected) and adolescents were anticipated to enjoy this activity. Active videogames increase heart rate, oxygen consumption and energy expenditure in adolescents, relative to sedentary videogames (Graves et al., 2008; Peng et al., 2011) and are more enjoyable relative to walking/ jogging (Graves et al., 2010). Adolescents and young adults in the sedentary conditions remained seated, watching TV for 30-60 mins. It was anticipated that participants received the same amount of light emitted from the television and thus, screen light was controlled across conditions.

Sleep Therapy

All treatment groups received three, weekly 50-minute one-on-one therapy sessions, delivered by the same psychologist who conducted the initial assessment (ie a clinical, registered or provisional psychologist). The first session consisted of psychoeducation about circadian rhythms, instructions to reduce evening light two hr prior to bed and plans for morning LT. Adolescents and young adults were instructed to sleep-in until their natural wake time to begin treatment (Gradisar, et al., 2011; Saxvig et al., 2014). Participants wore the portable light glasses for 30-60 mins immediately after rising from bed each day and commenced LT 30-mins earlier each subsequent day, until they reached a wake-up time of 06:00 (Gradisar et al., 2014). Treatment was completed on school mornings and weekends. If participants reached this target time, they ceased use of the Re-Timer glasses and sleep

patterns were stabilised, with a wake-up time no later than 7:30am. Adolescents and young adults were instructed to complete their allocated morning activity for the same duration and at the same time as LT. To prevent relapse following cessation of LT, participants were instructed to continue to minimise evening light, avoid sleeping in and seek ambient light after awakening (Gradisar et al., 2014).

Procedure

Recruitment occurred from July 2014 to December 2016. 83 adolescents and young adults underwent an assessment with a clinical, registered or provisional psychologist, consisting of the CSHI, seven day sleep diary and questionnaires[3]. Participants wore an actigraphy wristwatch and completed another sleep diary and questionnaires between the assessment and first treatment session (Gradisar et al., 2014). DSWPD diagnosis was confirmed at a consensus meeting between therapists and the clinic supervisor (MG). Participants deemed eligible were randomly allocated into one of four treatment conditions, using a block randomisation schedule, and completed three weekly sleep therapy sessions with a psychologist. Sleep diaries and questionnaires were completed across treatment and at one and three month follow-up. An abridged version of the CSHI was administered at three month follow-up to re-assess DSWPD diagnosis.

Statistical Analyses

To minimise the potential impact of missing data (~25% from pre-treatment to three month follow-up), Linear Mixed Modelling (LMM) was used to analyse data (Landau, Everitt, 2004). Effect sizes (Cohen's *d*) were calculated to establish the magnitude of within- and between-subjects differences. Cohen's *d* was calculated as $d = M_1 - M_2 / (SD_{pooled})$.

[3] The sleep diary and questionnaires completed prior to the assessment were for diagnostic purposes only and were not included in data analysis. Pre-treatment data were collected over seven days/nights following the assessment and prior to treatment session 1, so that actigraphy data aligned with sleep diary and questionnaire data.

Results

Clinical Features of Adolescents and Young Adults with DSWPD

Most adolescents and young adults reported their sleep problem occurred gradually (88%), with mean chronicity of three years months. See Table 1 for clinical presentation, as per clinical sleep history interview. 66% of participants reported a diagnosed psychological condition, with anxiety (45%) and depression (43%) most common. Distribution of psychological comorbidity between groups was similar, $\chi^2(1, N = 59) = 0.32$, $p = 0.10$. Participants were taking medication to treat mood (n=15, Endep, Seroquel, Lexapro, etc.), sleep (n=7, melatonin, circadin rhythm) and asthma (n=7, Ventolin). Medication timing and dosage remained consistent, except melatonin/circadin rhythm, which were ceased prior to treatment. Adolescents and young adults receiving psychological intervention ceased therapy during the sleep trial. Treatment effects did not differ based on medication use or psychological co-morbidity and therefore were not controlled for in final analyses. Four adolescents who withdrew prior to treatment completion reported significantly lower baseline sleep diary total sleep time, $t(57) = -3.00$, p=.004, d= 1.75, and sleep efficiency, $t(57) = -2.45$, p=.017, d= 1.08, on school nights, and greater functional impairment, $t(9.07) = -3.68$, p=.005, d= 1.00.

Table 1

Clinical Presentation of Adolescents and Young Adults with DSWPD.

Primary Sleep Problem	**Daytime Impairments***
Difficulty falling asleep (68%)	Tired/ fatigued (98%)
Difficulty waking (15%)	Daytime sleepiness (93%)
Unrefreshing sleep (7%)	Poor attention/ concentration/ memory (93%)
Night time awakenings (5%)	Low energy/ motivation (85%)
Daytime consequences (5%)	Moody/ irritable (82%)
Secondary Sleep Problem	Worries about sleep (68%)
Difficulty waking (50%)	Poor school performance (65%)
Night time awakenings (23%)	Somatic complaints (55%)
Difficulty falling asleep (20%)	Problems socialising (48%)
Daytime consequences (7%)	Accident prone (40%)
Past Sleep Problem/s	Behavioural issues (ie, hyperactivity) (37%)
Incidence of past sleep problem (e.g., chronic insomnia disorder, bedtime resistance) (28%)	Repeatedly woken in morning (68%)
Parental presence required to sleep in primary schooling (25%)	Frequent lateness to school, university or work (68%)

* Participants could select more than one daytime impairment.

Treatment Compliance

Similarly to the self-reported estimation of *ad libitum* wake up time (ie during clinical sleep history interview, 11:28am±1.76hr), participants woke at 11.04am±1.7hr on the first morning of therapy, with no significant difference in therapy start point between groups, $F(3,56)= 1.60$, $p=0.20$). On average, participants completed therapy across 13.89days±4.47. Duration of therapy did not differ significantly between groups, $F(3,53)= 0.848$, $p=0.47$. There was also no significant difference in self-reported duration of daily LT between groups ($F(3,50)= 0.146$, $p=0.93$). However, duration of use reduced between treatment week one (M=32min, SE=2) and two (M=31min, SE=2) to week three (M=15min, SE=2, $F(2,49)= 20.14$, $p<0.001$). This is due to some participants reaching a six am wake-up time and ceasing use of the light glasses in the final treatment week.

18.4% of participants reported experiencing side effects related to use of the light glasses, with a similar distribution between therapy groups (ie green vs red light) $\chi^2(3, N =$

49) = 0.76, p= 0.86. Participants reported brief change in visual colour perception, following cessation of light therapy (n=7), mild headaches (n=4), watery/ sore eyes (n=2) and light aversion (n=1), however these symptoms were not severe enough for participants to opt out of light therapy.

There were no between group differences for self-reported daily activity duration (F(3,52)= 0.969, p=0.41). Activity duration also reduced from treatment week one (M=27min, SE=2) and two (M=27min, SE=2) to week three (M=16min, SE=2, F(2,49)= 8.247, p=0.001). Motor activity for the hour after awakening showed a small decrease in activity from baseline across the first two weeks of treatment, for the Green BLT + Sedentary group (d=-0.31). However, changes in activity frequency for the Red LT + Sedentary (d=-0.13), Green BLT + Activity (d=-0.06) and Red LT + Activity groups (d=0.12) were negligible, and there were no significant between-group differences, F(3,29)= 1.62,p=0.206. Results were similar when activity frequency was analysed separately for the first 30 min after awakening. These findings suggest the experimental manipulation did not lead to a meaningful increase in physical activity.

Treatment

Figures 2 to 4 show changes in sleep diary sleep, actigraphy sleep timing and daytime functioning, respectively. Descriptive statistics are presented in full in Appendix A. Contrary to predictions, there were no differences among the four groups; interaction effects (group*time) for all outcome variables were not statistically significant (p>0.05). However, main effects of time were found for all variables, except bedtime and WASO.

From pre- to post-treatment, across all groups, adolescents demonstrated significant improvements for SOL, SOT and WUT, and a 47min improvement in TST (Figure 2). Actigraphy defined SOT and WUT also showed significant improvement (Figure 3; ie 39 mins, 43 mins, respectively). In terms of daytime functioning, morning alertness, daytime

sleepiness, fatigue and functional impairment improved from pre- to post-treatment (Figure 4).

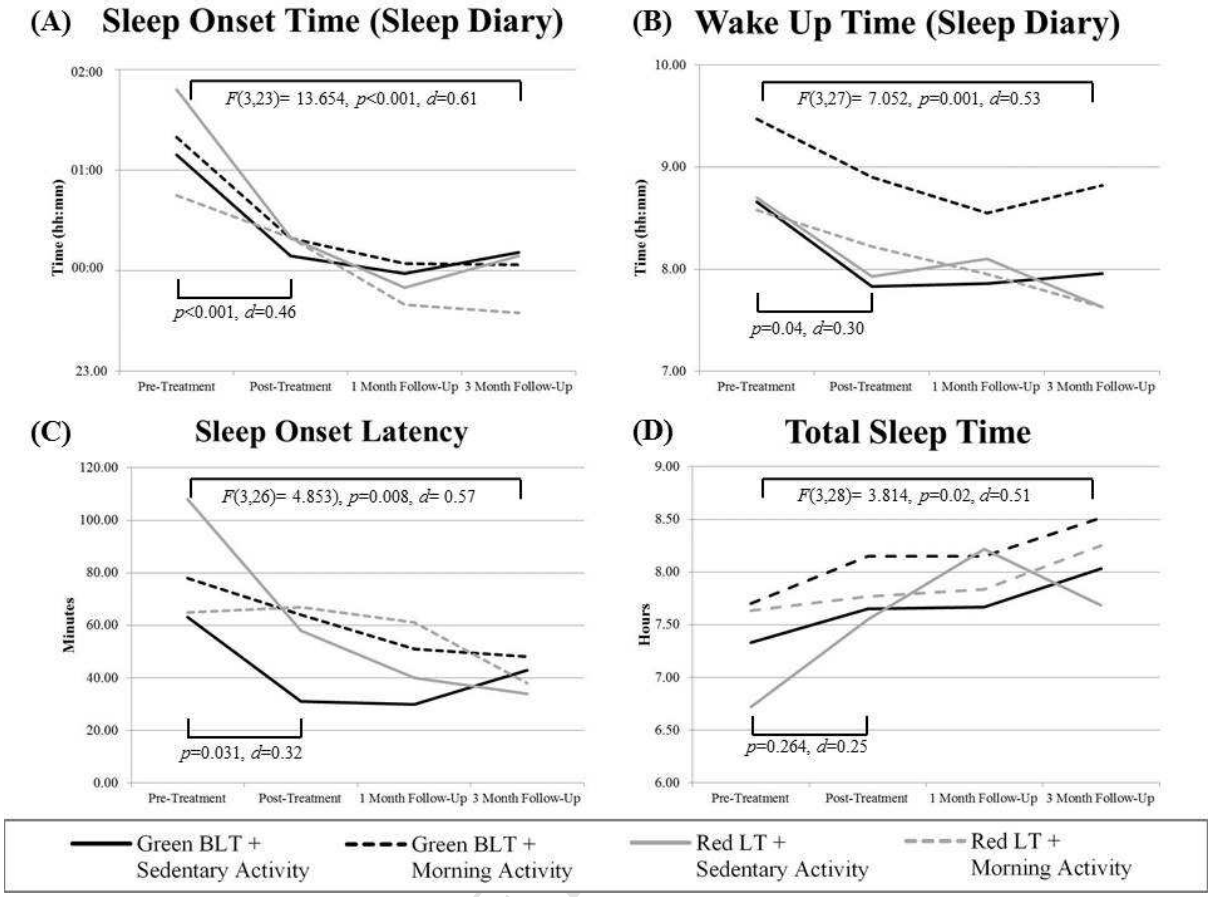

Figure 2 Mean school night sleep diary (A) sleep onset time, (B) wake-up time, (C) sleep onset latency and (D) total sleep time, across treatment and follow-up. Error bars were excluded as there were no between-group differences and inclusion led to visual overcrowding. As there were no between-group differences, inferential statistics reported relate to the main effect of time.

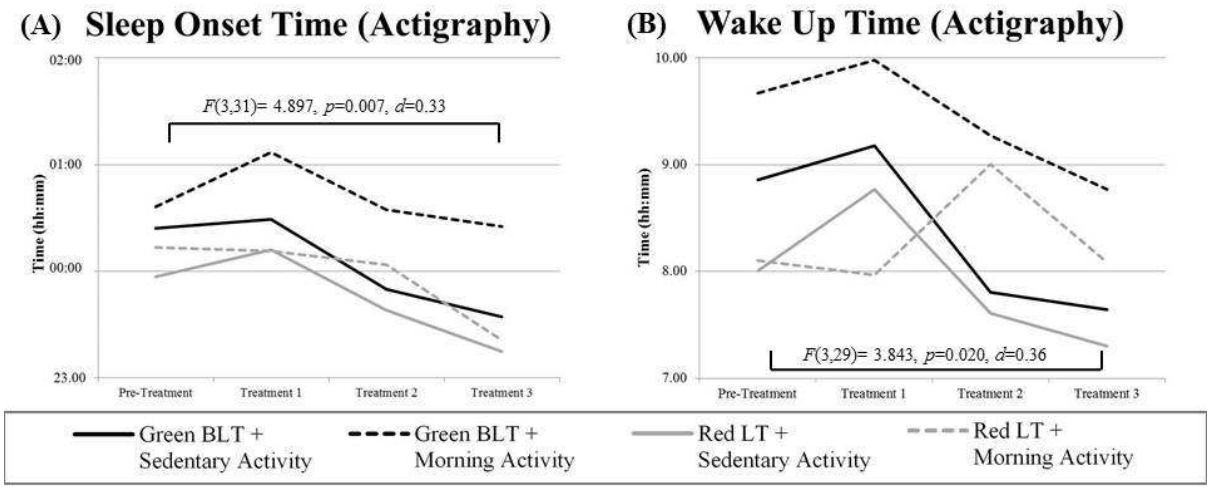

Figure 3 Mean actigraphy school night (A) sleep onset time and (B) wake-up time for treatment groups across treatment. Error bars were excluded as there were no between-group differences and inclusion led to visual overcrowding. As there were no between-group differences, inferential statistics reported relate to the main effect of time.

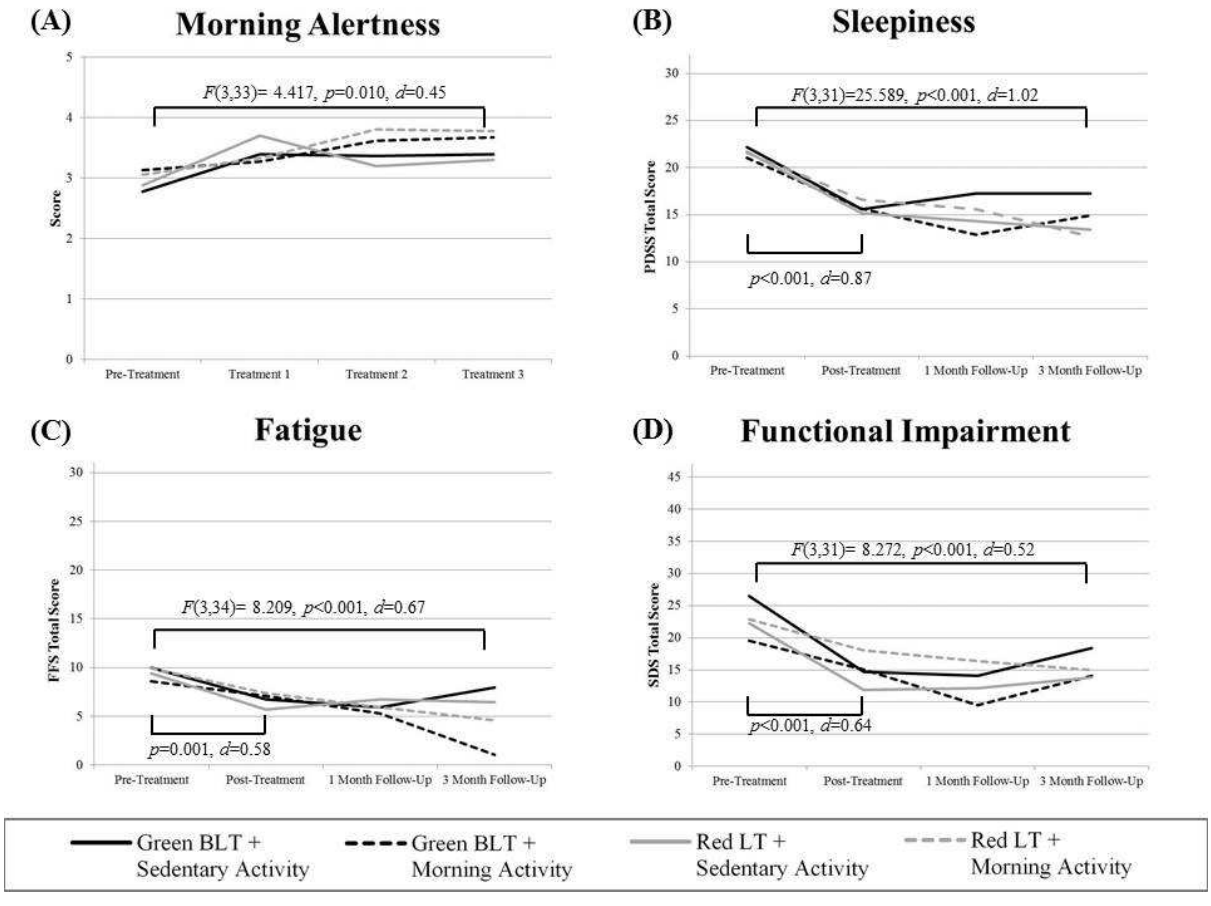

Figure 4 Mean (A) morning alertness across treatment and mean (B) daytime sleepiness, (C) fatigue and (D) functional impairment across treatment and follow-up. Error bars were excluded as there were no between-group differences and inclusion led to visual overcrowding. As there were no between-group differences, inferential statistics reported relate to the main effect of time.

Long-Term Outcomes

Adolescents and young adults maintained improvements for SOL, SOT, WUT, TST, sleepiness, fatigue and impairment at follow-up[4]. Forty percent of participants (*N*=24) completed a sleep diary, questionnaires and abridged clinical interview at the three month follow-up. There was no significant difference in proportion of DSWPD diagnosis between the groups (Table 2). However, partial relapse was common, with many adolescents and young adults reporting DSWPD symptomology at follow-up.

Table 2

Proportion of Adolescents and Young Adults who Reported Symptoms of DSWPD at Follow-up.

	Green BLT + SA (*n*=8)	**Green BLT + MA (*n*=8)**	**Red BLT + SA (*n*=5)**	**Red BLT + MA (*n*=3)**	***p***
DSWPD Criteria Met (Clinician Assessed)	25%	25%	0%	0%	0.399
Sleep-Onset Difficulties	38%	38%	40%	33%	1.00
Difficulty Awakening	50%	88%	60%	33%	0.288
Sleep Problem (Participant Reported)	43%	38%	40%	0%	0.596

38% of all participants requested further treatment, in addition to the three sessions of light therapy and activity. Once participants received additional treatment, they were withdrawn from the study and did not complete any further research follow-ups. There were no differences between groups, in terms of the proportion of participants who received additional treatment (Table 3). Additional treatment consisted of further BLT (*n*=4), exogenous melatonin (*n*=3) or both (*n*=9), motivational interviewing (*n*=2), cognitive therapy (*n*=2), sleep restriction therapy (*n*=1), sleep hygiene (*n*=1) and behavioural modification for evening technology use (*n*=1).

[4] Effect sizes were calculated between pre-treatment and three-month follow-up scores.

Table 3

Summary of Adolescents and Young Adults Requiring Additional Treatment.

Received Additional Treatment Following:	**Green BLT + SA (*n*=14)**	**Green BLT + MA (*n*=13)**	**Red BLT + SA (*n*=14)**	**Red BLT + MA (*n*=15)**
Post-Treatment	*n*=3	*n*=2	*n*=1	*n*=5
1-Month Follow-Up	*n*=1	*n*=0	*n*=4	*n*=1
3-Month Follow-Up	*n*=2	*n*=1	*n*=0	*n*=1
Total	43%*	23%*	36%*	47%*

***** $\chi^2(3, N = 56) = 0.18$, $p = 0.60$.

Discussion

A randomised controlled design evaluated the efficacy of bright light therapy, delivered by portable LED glasses (ie Re-Timers), and morning activity for the treatment of adolescent DSWPD. There were no differences between the active and control conditions; however, over time, improvements were found across a range of night time and daytime variables (13 out of 15). Sleep timing was advanced and sleep quality and daytime functioning also improved, with these changes maintained at follow-up.

Given adolescents and young adults had experienced their sleep problem for ~three years, five months, with significant associated daytime consequences, these results suggest that brief sleep therapy can result in rapid improvements in adolescent's sleep and wellbeing.

Light Therapy

These findings are consistent with results from previous RCTs of LT for adolescent DSWPD (Danielsson et al., 2015; Gradisar, Dohnt, et al., 2011; Saxvig et al., 2014). However, these studies used either light lamps/ boxes (ie 10,000 lux lamp, with 18 x 28 x 44 cm surface, at 50 cm distance for 30-45 min, (Danielsson et al., 2015); 10,000 lux light box, with 47 x 17.5 x 29cm surface, at 50cm distance for 30-45 mins (Saxvig et al., 2014), or natural ambient light supplemented by light lamps (Gradisar, Dohnt, et al., 2011). Therefore, the present study extends upon previous knowledge, by being the first to evaluate newly

developed portable light glasses for the treatment of DSWPD in young people and additionally, by being the first RCT for DSWPD to compare the efficacy of short green wavelength light therapy with long red wavelength light therapy.

Experimental studies have provided convincing evidence for the superiority of short wavelengths of light (relative to long) in advancing the human circadian rhythm (Warman et al., 2003; Wright et al., 2004). However, clinical practice guidelines have called for the replication of experimental research findings in clinical samples, within less tightly controlled environments (Auger et al., 2015). Initial data (Saxvig et al., 2014) suggest the wavelength of LT, when administered in accordance with practice guidelines, may not significantly influence the outcome of treatment for young people with DSWPD. Notably, experimental studies have administered shorter wavelength light (ie blue light, 470nm, Wright et al., 2004), compared to the present study (507nm). However, there is some concern that short wavelength light below 500nm may cause photochemical damage to the retina (Bullough, 2000). Therefore, commercially available light emitting devices, such as the Re-Timer, emit light above 500nm to avoid potential hazard, whilst also maximising the degree of phase advance (Wright et al., 2004). The Re-Timer glasses have shown to phase delay the circadian rhythm of good sleepers, however experimental studies investigating phase advance are lacking (Lovato, Lack, 2015). It is possible this methodological difference (ie the wavelength of short wave light administered) may go some way to explaining the inconsistency in results between experimental and clinical research. However, it is also possible that changes in behavioural patterns alone (ie fixed earlier sleep-wake routine, evening light restriction) contributed to advanced circadian and sleep timing (Dewald-Kaufmann et al., 2014; Saxvig et al., 2014; Sharkey et al., 2011) and/or that the three weekly sessions with a psychologist (including psychoeducation), in itself, provided benefit (Bowers, Clum, 1988). Saxvig and colleagues (2014) have also suggested that sleep pressure could drive phase advances;

however, total sleep time increased across treatment in the present study, so evidence for this hypothesis is limited.

Morning Activity

This is the first study to investigate the efficacy of scheduled physical activity for the treatment of adolescent DSWPD. However, there was no objective evidence for increases in physical activity. Interactive motion-sensing video gaming has been considered more enjoyable than traditional physical activity for young adults (ie walking, running) (Graves et al., 2010). Although participants reported complying with morning activity, it is possible that daily physical activity was not of sufficient intensity or duration to have a therapeutic effect. Experimental studies have administered a three hr pulse of moderate (Baehr et al., 2003; Buxton et al., 1997; Van Reeth et al., 1994) or high intensity (Youngstedt et al., 2002) exercise, which is impractical to implement in clinical practice. However, there is some evidence that shorter durations of high intensity exercise could be as effective (Buxton et al., 1997). Therefore, future studies could evaluate physical activity of a longer duration (eg 45-60 min) and higher intensity (eg moderate-high intensity). Furthermore, future clinical trials could evaluate more practical forms of physical activity (ie walking/ cycling to school).

Treatment of DSWPD

Although there is convincing evidence for the short-term efficacy of chronobiological treatments for DSWPD, partial treatment success and relapse are common (Abu-Salah, Auger, 2013; Alvarez et al., 1992; Saxvig et al., 2014). 38% of our sample required additional treatment by the three month follow-up. As additional treatment was commonly chronobiological in nature (ie re-implementation of light therapy, evening exogenous melatonin, or a combination therof), it is possible that the continuation of light therapy may result in better long-term outcomes, as was shown by Saxvig and colleagues (2014).

Although treatment produced meaningful improvements in sleep and functioning, further research is needed to refine clinical practice guidelines for the treatment of DSWPD in young people.

Limitations and Future Directions

The limitations of our study are as follows: measures of circadian timing were not taken (ie dim light melatonin onset, core body temperature nadir). Moreover, although participants were instructed to minimise natural light during LT, ambient light levels within participants' homes were not measured. Although this data might have elucidated why there were no differences between the green and red LT conditions, the clinical application of this data is questionable. Additionally, wrist actigraphy was used to measure movement frequency, rather than more robust measures of physical activity, such as heart rate, or maximal oxygen consumption. Thus, although wrist actigraphy is an ecologically valid way of measuring activity, potential pitfalls may have included the ability of actigraphy to detect small differences in physical activity between the treatment groups.

This trial recruited the largest number of adolescents and young adults to date, however, due to attrition, analyses conducted at the one and three month follow-ups may have been underpowered. As it is difficult to recruit a large number of adolescents for clinical research trials, it may be beneficial to conduct multicentre trials in the future.

Future research could compare the relative effectiveness of portable light devices with empirically established modes of bright light delivery (ie light boxes/ lamps) (Auger et al., 2015). Alternatively, it would be worthwhile knowing whether the inclusion of an artificial light source (eg light box, lamp or glasses) in BLT is necessary. For example, dismantling research designs may help to elucidate what components of bright light therapy (eg evening light restriction, fixed earlier wake up times, post-awakening light therapy, wavelength of

light therapy) drive improvements in sleep and daytime functioning for adolescents and young adults with DSWPD.

Although the *method* and *wavelength* of light therapy were the focus of the present study, future clinical trials could vary the *duration* of daily light exposure. The duration of light therapy in the current study (ie 30-60 min) was in accordance with previous randomised controlled trials (Danielsson et al., 2015; Gradisar, Dohnt, et al., 2011; Saxvig et al., 2014) and clinical guidelines (Gradisar et al., 2014). Additionally, a recent trial has shown the duration of light therapy did not predict treatment outcomes (Danielsson et al., 2016). However, with a paucity of research investigating the effect of daily light therapy duration on the degree of circadian advance, further research is needed to increase our confidence in this standalone finding.

Researchers could also aim to identify 'risk factors' (eg DSWPD severity, low motivation to change, repetitive negative thinking) for poor treatment outcome. The addition of cognitive behavioural therapy (Danielsson et al., 2015) to LT shows promise. However, identifying "risk factors" for poor treatment outcome, might allow for more effective case conceptualised treatment of DSWPD (ie treatment which focuses on the unique experience of the individual) (Dudley et al., 2011). Further refinement of treatment components should be a priority, with particular importance placed upon measuring long term outcomes, including relapse.

Summary

In recent years, momentum is gaining for the evaluation of efficacious sleep treatments for adolescents and young adults. Findings from the present study add to existing literature supporting the use of light therapy for adolescent DSWPD (Danielsson et al., 2015; Gradisar, Dohnt, et al., 2011; Saxvig et al., 2014; Wilhelmsen-Langeland et al., 2013). However, short wavelength light therapy was no more effective than long wavelength light

therapy (ie control conditions). Therefore, it is unclear what components of light therapy are the "active ingredients" of treatment and dismantling studies may be needed. As participants did not meaningfully increase physical activity, we cannot yet draw conclusions about the potential utility of morning physical activity. Notably, results suggest that relapse was common for many adolescents and young adults with DSWPD. Consequently, a number of priorities for future research have been highlighted.

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References

Abu-Salah, T., & Auger, R. (2013). Adolescent delayed sleep phase disorder: clinical features and response to treatment. *Sleep, 36*, A189-A190.

Acebo, C., Sadeh, A., Seifer, R., Tzischinsky, O., Wolfson, A., Hafer, A., & Carskadon, M. (1999). Estimating sleep patterns with activity monitoring in children and adolescents: how many nights are necessary for reliable measures? *Sleep, 22*(1), 95-103.

Alvarez, B., Dahlitz, M., Vignau, J., & Parkes, J. (1992). The delayed sleep phase syndrome: clinical and investigative findings in 14 subjects. *Journal of Neurology, Neurosurgery & Psychiatry, 55*(8), 665-670.

American Academy of Sleep Medicine. (2014). *International Classification of Sleep Disorders: Diagnostic and coding manual (3rd ed.)*. Westchester, IL: American Academy of Sleep Medicine.

Ancoli-Israel, S., Cole, R., Alessi, C., Chambers, M., Moorcroft, W., & Pollak, C. (2003). The role of actigraphy in the study of sleep and circadian rhythms. American Academy of Sleep Medicine Review Paper. *Sleep, 26*(3), 342-392.

Auger, R., Burgess, H., Emens, J., Deriy, L., Thomas, S., & Sharkey, K. (2015). Clinical practice guideline for the treatment of intrinsic circadian rhythm sleep-wake disorders: advanced sleep-wake phase disorder (ASWPD), delayed sleep-wake phase disorder (DSWPD), non-24-hour sleepwake rhythm disorder (N24SWD), and irregular sleep-wake rhythm disorder (ISWRD). *Journal of Clinical Sleep Medicine, 11*(10), 1199-1236.

Baehr, E., Eastman, C., Revelle, W., Olson, S., Wolfe, L., & Zee, P. (2003). Circadian phase-shifting effects of nocturnal exercise in older compared with young adults. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 284*(6), R1542-R1550. doi: 10.1152/ajpregu.00761.2002

Baehr, E., Fogg, L., & Eastman, C. (1999). Intermittent bright light and exercise to entrain human circadian rhythms to night work. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 277*(6), R1598-R1604.

Barger, L., Wright, K., Hughes, R., & Czeisler, C. (2004). Daily exercise facilitates phase delays of circadian melatonin rhythm in very dim light. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 286*(6), R1077-R1084.

Bonnar, D., Gradisar, M., Moseley, L., Coughlin, A., Cain, N., & Short, M. (2015). Evaluation of novel school-based interventions for adolescent sleep problems: does parental involvement and bright light improve outcomes? *Sleep Health, 1*(1), 66-74.

Bowers, T., & Clum, G. (1988). Relative contribution of specific and nonspecific treatment effects: meta-analysis of placebo-controlled behavior therapy research. *Psychological bulletin, 103*(3), 315.

Bullough, J. (2000). The blue-light hazard: A review. *Journal of the Illuminating Engineering Society, 29*(2), 6-14.

Buxton, O., Frank, S., L'Hermite-Balériaux, M., Leproult, R., Turek, F., & Van Cauter, E. (1997). Roles of intensity and duration of nocturnal exercise in causing phase delays of human circadian rhythms. *The American journal of physiology, 273*(3 Pt 1), E536-542.

Cajochen, C., Munch, M., Kobialka, S., Krauchi, K., Steiner, R., Oelhafen, P., . . . Wriz-Justice, A. (2005). High Sensitivity of Human Melatonin, Alertness, Thermoregulation, and Heart Rate to Short Wavelength Light. *The Journal of Endocrinology and Metabolism, 9*(3), 1311-1316.

Cameron, K., Williamson, P., Short, M., & Gradisar, M. (2017). Validation of the Flinders Fatigue Scale as a measure of daytime fatigue. *Sleep Medicine, 30*, 105-112.

Carskadon, M. (2011). Sleep in adolescents: the perfect storm. *Pediatric Clinics of North America, 58*(3), 637.

Crowley, S., Acebo, C., & Carskadon, M. (2007). Sleep, circadian rhythms, and delayed phase in adolescence. *Sleep Medicine, 8*(6), 602-612.

Crowley, S., & Eastman, C. (2017). Human Adolescent Phase Response Curves to Bright White Light. *Journal of Biological Rhythms*, 0748730417713423.

Danielsson, K., Jansson-Fröjmark, M., Broman, J.-E., & Markström, A. (2015). Cognitive Behavioral Therapy as an Adjunct Treatment to Light Therapy for Delayed Sleep Phase Disorder in Young Adults: A Randomized Controlled Feasibility Study. *Behavioral Sleep Medicine*, 1-21.

Danielsson, K., Jansson-Fröjmark, M., Broman, J., & Markström, A. (2016). Light Therapy With Scheduled Rise Times in Young Adults With Delayed Sleep Phase Disorder: Therapeutic Outcomes and Possible Predictors. *Behavioral Sleep Medicine*, 1-15.

Dewald-Kaufmann, J., Oort, F., & Meijer, A. (2014). The effects of sleep extension and sleep hygiene advice on sleep and depressive symptoms in adolescents: a randomized controlled trial. *Journal of Child Psychology and Psychiatry, 55*(3), 273-283.

Drake, C., Nickel, C., Burduvali, E., Roth, T., Jefferson, C., & Badia, P. (2003). The Pediatric Daytime Sleepiness Scale (PDSS): sleep habits and school outcomes in middle-school children. *Sleep: Journal of Sleep and Sleep Disorders Research, 26*(4), 455-458.

Dudley, R., Kuyken, W., & Padesky, C. (2011). Disorder specific and trans-diagnostic case conceptualisation. *Clinical Psychology Review, 31*(2), 213-224.

Eastman, C., Hoese, E., Youngstedt, S., & Liu, L. (1995). Phase-shifting human circadian rhythms with exercise during the night shift. *Physiology & Behavior, 58*(6), 1287-1291.

Eckerberg, B., Lowden, A., Nagai, R., & Åkerstedt, T. (2012). Melatonin treatment effects on adolescent students' sleep timing and sleepiness in a placebo-controlled crossover study. *Chronobiology International, 29*(9), 1239-1248.

Gangwisch, J., Babiss, L., Malaspina, D., Turner, J., Zammit, G., & Posner, K. (2010). Earlier parental set bedtimes as a protective factor against depression and suicidal ideation. *Sleep, 33*(1), 97.

Geerdink, M., Beersma, D., Hommes, V., & Gordijn, M. (2016). Short Blue Light Pulses (30 Min.) in the Morning are Able to Phase Advance the Rhythm of Melatonin in a Home Setting. *Journal of Sleep Disorder Therapy, 5*(242), 2167-0277.1000242.

Giannotti, F., Cortesi, F., Sebastiani, T., & Ottaviano, S. (2002). Circadian preference, sleep and daytime behaviour in adolescence. *Journal of Sleep Research, 11*(3), 191-199.

Gradisar, M., & Crowley, S. (2013). Delayed sleep phase disorder in youth. *Current Opinion in Psychiatry, 26*(6), 580-585.

Gradisar, M., Dohnt, H., Gardner, G., Paine, S., Starkey, K., Menne, A., . . . Trenowden, S. (2011). A Randomized Controlled Trial of Cognitive-Behavior Therapy Plus Bright Light Therapy for Adolescent Delayed Sleep Phase Disorder. *Sleep, 34*(12), 1671-1680.

Gradisar, M., Gardner, G., & Dohnt, H. (2011). Recent worldwide sleep patterns and problems during adolescence: A review and meta-analysis of age, region, and sleep. *Sleep Medicine, 12*, 110-118.

Gradisar, M., Lack, L., Richards, H., Harris, J., Gallasch, J., Boundy, M., & Johnston, A. (2007). The Flinders Fatigue Scale: preliminary psychometric properties and clinical sensitivity of a new scale for measuring daytime fatigue associated with insomnia.

Journal of clinical sleep medicine: JCSM: official publication of the American Academy of Sleep Medicine, 3(7), 722.

Gradisar, M., Smits, M., & Bjorvatn, B. (2014). Assessment and Treatment of Delayed Sleep Phase Disorder in Adolescents: Recent Innovations and Cautions. *Sleep Medicine Clinics, 9*(2), 199-210.

Graves, L., Ridgers, N., Williams, K., Stratton, G., Atkinson, G., & Cable, N. (2010). The physiological cost and enjoyment of Wii Fit in adolescents, young adults, and older adults. *Journal of Physical Activity and Health, 7*(3), 393-401.

Graves, l., Stratton, G., Ridgers, N., & Cable, T. (2008). Energy expenditure in adolescents playing new generation computer games. *British journal of sports medicine, 42*(7), 592-594.

Joo, E., Abbott, S., Reid, K., Wu, D., Kang, J., Wilson, J., & Zee, P. (2017). Timing of light exposure and activity in adults with delayed sleep-wake phase disorder. *Sleep Medicine, 32*, 259-265.

Kalak, N., Gerber, M., Kirov, R., Mikoteit, T., Yordanova, J., Pühse, U., . . . Brand, S. (2012). Daily Morning Running for 3 Weeks Improved Sleep and Psychological Functioning in Healthy Adolescents Compared With Controls. *Journal of Adolescent Health, 51*(6), 615-622.

Khalsa, S., Jewett, M., Cajochen, C., & Czeisler, C. (2003). A phase response curve to single bright light pulses in human subjects. *The Journal of physiology, 549*(3), 945-952.

Krauchi, K., Cajochen, C., & Wirz-Justice, A. (1997). A relationship between heat loss and sleepiness: effects of postural change and melatonin administration. *Journal of Applied Physiology, 83*(1), 134-139.

Landau, S., & Everitt, B. (2004). *A handbook of statistical analyses using SPSS* (Vol. 1): Chapman & Hall, Boca Raton, FL.

Lovato, N., Gradisar, M., Short, M., Dohnt, H., & Micic, G. (2013). Delayed sleep phase disorder in an Australian school-based sample of adolescents. *Journal of Clinical Sleep Medicine, 9*(9), 939-944.

Lovato, N., & Lack, L. (2015). Circadian phase delay using the newly developed re-timer portable light device. *Sleep and Biological Rhythms*, 1-8.

Maldonado, C., Bentley, A., & Mitchell, D. (2004). A pictorial sleepiness scale based on cartoon faces. *Sleep, 27*(3), 541-550.

Meltzer, L., Walsh, C., Traylor, J., & Westin, A. (2012). Direct comparison of two new actigraphs and polysomnography in children and adolescents. *Sleep, 35*(1), 159-166.

Micic, G., Lovato, N., Gradisar, M., Burgess, H., Ferguson, S., Kennaway, D., & Lack, L. (2015). Nocturnal melatonin profiles in patients with delayed sleep-wake phase disorder and control sleepers. *Journal of Biological Rhythms, 30*(5), 437-448.

Miyazaki, T., Hashimoto, S., Masubuchi, S., Honma, S., & Honma, K. (2001). Phase-advance shifts of human circadian pacemaker are accelerated by daytime physical exercise. *American Journal of Physiology- Regulatory, Integrative and Comparative Physiology, 281*, R197-R205.

Peng, W., Lin, J., & Crouse, J. (2011). Is playing exergames really exercising? A meta-analysis of energy expenditure in active video games. *Cyberpsychology, Behavior, and Social Networking, 14*(11), 681-688.

Rajaratnam, S., Licamele, L., & Birznieks, G. (2015). Delayed sleep phase disorder risk is associated with absenteeism and impaired functioning. *Sleep Health, 1*(2), 121-127.

Reid, K. J., Jaksa, A. A., Eisengart, J. B., Baron, K. G., Lu, B., Kane, P., . . . Zee, P. C. (2012). Systematic evaluation of Axis-I DSM diagnoses in delayed sleep phase disorder and evening-type circadian preference. *Sleep Medicine, 13*(9), 1171-1177.

Richardson, C., Gradisar, M., Short, M., & Lang, C. (2017). Can exercise regulate the circadian system of adolescents? Novel implications for the treatment of delayed sleep-wake phase disorder. *Sleep Medicine Reviews, 34*, 122-129.

Roenneberg, T., Kuehnle, T., Pramstaller, P., Ricken, J., Havel, M., Guth, A., & Merrow, M. (2004). A marker for the end of adolescence. *Current Biology, 14*(24), R1038.

Sadeh, A., Sharkey, K., & Carskadon, M. (1994). Activity-Based Sleep—Wake Identification: An Empirical Test of Methodological Issues. *Sleep, 17*(3), 201-207.

Saxvig, I., Pallesen, S., Wilhelmsen-Langeland, A., Molde, H., & Bjorvatn, B. (2012). Prevalence and correlates of delayed sleep phase in high school students. *Sleep Medicine, 13*, 193-199.

Saxvig, I., Wilhelmsen-Langeland, A., Pallesen, S., Vedaa, Ø., Nordhus, I., & Bjorvatn, B. (2014). A randomized controlled trial with bright light and melatonin for delayed sleep phase disorder: Effects on subjective and objective sleep. *Chronobiology International, 31*(1), 72-86.

Sharkey, K., Carskadon, M., Figueiro, M., Zhu, Y., & Rea, M. (2011). Effects of an advanced sleep schedule and morning short wavelength light exposure on circadian phase in young adults with late sleep schedules. *Sleep Medicine, 12*, 685-692.

Sheehan, D., Harnett-Sheehan, K., & Raj, B. (1996). The measurement of disability. *International Clinical Psychopharmacology, 11*, 89-95.

Shen, J., Barbera, J., & Shapiro, C. (2006). Distinguishing sleepiness and fatigue: focus on definition and measurement. *Sleep Medicine Reviews, 10*(1), 63-76.

Shochat, T., Cohen-Zion, M., & Tzischinsky, O. (2014). Functional consequences of inadequate sleep in adolescents: a systematic review. *Sleep Medicine Reviews, 18*(1), 75-87.

Short, M., Gradisar, M., Lack, L., & Wright, H. (2013). The impact of sleep on adolescent depressed mood, alertness and academic performance. *Journal of Adolescence, 36*(6), 1025-1033.

Short, M., Gradisar, M., Wright, H., Lack, L., Dohnt, H., & Carskadon, M. (2011). Time for bed: parent-set bedtimes associated with improved sleep and daytime functioning in adolescents. *Sleep, 34*(6), 797.

Sivertsen, B., Harvey, A., Pallesen, S., & Hysing, M. (2015). Mental health problems in adolescents with delayed sleep phase: results from a large population-based study in Norway. *Journal of Sleep Research, 24*(1), 11-18.

van Geijlswijk, I., Korzilius, H., & Smits, M. (2010). The use of exogenous melatonin in delayed sleep phase disorder: a meta-analysis. *Sleep, 33*(12), 1605-1614.

van Maanen, A., Dewald-Kaufmann, J., Smits, M., Oort, F., & Meijer, A. (2013). Chronic sleep reduction in adolescents with Delayed Sleep Phase Disorder and effects of melatonin treatment. *Sleep and Biological Rhythms, 11*, 99-104.

Van Reeth, O., Sturis, J., Byrne, M., Blackman, J., L'Hermite-Balériaux, M., LeProult, R., . . . Van Cauter, E. (1994). Nocturnal exercise phase delays circadian rhythms of melatonin and thyrotropin secretion in normal men. *American Journal of Physiology-Endocrinology And Metabolism, 266*(6), E964-E974.

Warman, V., Dijk, D., Warman, G., Arendt, J., & Skene, D. (2003). Phase advancing human circadian rhythms with short wavelength light. *Neuroscience Letters, 342*(1–2), 37-40.

Wilhelmsen-Langeland, A., Saxvig, I., Pallesen, S., Nordhus, I., Veeda, O., Lundervold, A., & Bjorvatn, B. (2013). A Randomized Controlled Trial with Bright Light and Melatonin for the Treatment of Delayed Sleep Phase Disorder: Effects on Subjective and Objective Sleepiness and Cognitive Function. *Journal of Biological Rhythms, 28*(8), 306-321.

Wright, H., Lack, L., & Kennaway, D. (2004). Differential effects of light wavelength in phase advancing the melatonin rhythm. *Journal of Pineal Research, 36*, 140-144.

Youngstedt, S., Kripke, D., & Elliott, J. (2002). Circadian phase-delaying effects of bright light alone and combined with exercise in humans. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 282*(1), R259-R266.

- The trial compared short and long wavelength light therapy, with adjunct activity.
- Adolescents had improved sleep timing, SOL and daytime functioning post-treatment.
- There were no significant differences in outcomes between treatment groups.
- Improvements were maintained, or improved upon (TST), at the three month follow-up.
- However, long-term relapse of DSWPD symptomology was common.