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# Improvements of adolescent psychopathology after insomnia treatment: results from a randomized controlled trial over 1 year

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**Background:** Adolescent insomnia can be treated effectively with cognitive behavioural therapy for insomnia (CBTI). However, little is known about effects of CBTI on psychopathology in adolescents. This study aimed to investigate whether (a) CBTI improves psychopathology in Internet- (IT) and face-to-face group treatment (GT) compared to waitlist (WL), (b) improvement in psychopathology can be attributed to reduced insomnia, (c) improvement in psychopathology remains stable for up to 1 year. **Methods:** One hundred and sixteen participants (age = 15.6 years, 25% males) with DSM-5 insomnia, were randomly assigned to IT, GT or WL. Clinical trial registration: <http://www.controlledtrials.com> (ISRCTN33922163). Assessments of psychopathology, insomnia and objectively and subjectively measured sleep occurred at baseline, post-treatment, and at 2-, 6- and 12-month follow-up. Multilevel and mediation analyses were run to test hypotheses. The CBTI protocol, 'Sleeping Smart' for both IT and GT consisted of six weekly sessions and a booster session after 2 months. **Results:** Psychopathology symptoms, insomnia and sleep problems as measured by actigraphy and sleep logs decreased substantially in IT and GT compared with WL at 2-month follow-up with medium to large effect sizes (ESs). Psychopathology symptoms remained stable or further improved for up to 12-month follow-up. ESs at 12-month follow-up for IT and GT were respectively: affective ( $d = -0.87$  and  $-0.97$ ), anxiety ( $d = -0.81$  for IT), somatic ( $d = -0.38$  and  $d = -0.52$ ), oppositional ( $d = -0.42$  for GT) and attention deficit hyperactivity disorder (ADHD) problems ( $d = -0.47$  and  $-0.46$ ). Mediation analyses indicated that reduction of insomnia symptoms after CBTI fully mediated the effects of CBTI on affective and anxiety problems, and partially mediated the effect on ADHD problems. **Conclusions:** This is the first study demonstrating that Internet and face-to-face CBT for insomnia achieves long-term reduction in adolescent psychopathology and does so by improving insomnia. This finding can have profound implications for youth mental health care. **Keywords:** Cognitive behavioural therapy; insomnia; adolescents; sleep; psychopathology; ADHD; depression; anxiety.

## Introduction

Worldwide, insomnia is the most common sleep disorder among adolescents (Johnson, Roth, Schultz, & Breslau, 2006), with point prevalence estimated between 7.8% and 23.8% (Chung, Kan, & Yeung, 2014; Hysing, Pallesen, Stormark, Lunder-vold, & Sivertsen, 2013; Johnson, Roth, Schultz, et al., 2006). Insomnia is defined as a predominant complaint of dissatisfaction with sleep quantity or quality, accompanied by significant daytime impairment, 3 or more days per week, for at least 3 months, despite adequate opportunity to sleep (APA, 2013). It tends to persist over time with high chronicity (Johnson, Roth, Schultz, et al., 2006).

Insomnia has a bi-directional relationship with psychopathology, which implies that it can cause or exacerbate other mental disorders such as depression, anxiety and attention deficit hyperactivity disorder (ADHD) (Gregory & Sadeh, 2016; Johnson, Roth, & Breslau, 2006; Millman, 2005; Owens et al., 2013; Roberts & Duong, 2013). In a meta-analysis, Baglioni et al. (2011) conclude that nondepressed adults with insomnia have a twofold risk to develop

depression compared to adults without sleep problems. In line with these conclusions, in the DSM-5 (APA, 2013) insomnia is regarded as a mental disorder per se (i.e. not necessarily comorbid with another mental disorder) and a target for intervention in itself.

Cognitive behavioural therapy for insomnia (CBTI) generally consists of *stimulus control therapy*, *relaxation training* and *restriction of time in bed* (also known as 'sleep restriction'), each of which individually is an effective intervention, combined with *sleep hygiene education*, *psycho-education* and *cognitive therapy*. CBTI is recommended as first-line treatment for insomnia in adults (Medalie & Cifu, 2017; Morgenthaler et al., 2006; Qaseem, Kansagara, Forcica, Cooke, & Denberg, 2016). A recent review of the effects of CBTI on *adult* insomnia found significant reductions in insomnia symptomatology, but effects measured by sleep logs and actigraphy were mixed and effects on psychiatric symptoms were modest. These mixed results may be attributable to differences between patient groups, CBTI packages and methodological quality of the studies (Jansson-Fröjmark & Norell-Clarke, 2016). In a meta-analysis, Ye et al. (2015) showed that internet-delivered CBTI, in comparison to control

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conditions, had significant but small effects on comorbid anxiety and depression.

For *adolescents*, there appears to be little evidence that depressive symptoms predict the development of sleep disturbances (Lovato & Gradisar, 2014), although prior insomnia in adolescents is associated with a *four* times higher risk of subsequent depression (Johnson, Roth, & Breslau, 2006). Moreover, for adolescents with a sleep problem Shanahan, Cope-land, Angold, Bondy, and Costello (2014) reported an odds ratio of 2.0 for any other psychiatric disorder. In a consensus statement, Owens et al. (2013) conclude that treatment of sleep problems may improve ADHD and decrease the need for stimulant medication. Three randomized studies have shown that a change in adolescent sleep, consisting of experimentally induced sleep deprivation or sleep extension, may affect mood, impulsivity and depression (Dagys et al., 2012; Dewald-Kaufmann, Oort, & Meijer, 2014; Gruber, Cassoff, Frenette, Wiebe, & Carrier, 2012). However, these studies cover a limited range of psychopathology and also have a limited follow-up. Two recent pilot studies focused on the efficacy of CBTI in treating insomnia with co-occurring psychiatric comorbidities. In a randomized pilot study with 41 adolescents, Clarke et al. (2015) indicated that CBTI in combination with depression treatment yielded medium to large effects on some sleep- and depression-outcomes. In a single-arm pilot trial with 40 adolescents, Palermo, Beals-Erickson, Bromberg, Law, and Chen (2017) showed that CBTI resulted in improvements in self-reported insomnia symptoms and sleep variables, psychological symptoms and health-related quality of life.

Interestingly, Clarke et al. (2015) show that, in treating adolescents suffering from insomnia and major depression, CBTI combined with CBT for depression produces better results than sleep hygiene combined with CBT for depression. In adults with insomnia and depression, individual CBTI has been shown to be more effective than self-help CBTI (Ashworth et al., 2015) and group CBTI to be more effective than relaxation training (Norell-Clarke, Jansson-Fröjmark, Tillfors, Holländare, & Engström, 2015). These studies indicate that CBTI is preferable to less intensive sleep treatments, at least in patients with insomnia and comorbid depression. Recently, we demonstrated that treatment efficacy in both group and Internet CBTI for adolescents is similar to that of adults, with significant improvements in several sleep variables including subjective and/or objective sleep efficiency, sleep onset latency (SOL) and total sleep time (TST), and clinically significant improvements in symptoms of insomnia and chronic sleep reduction (De Bruin, Bögels, Oort, & Meijer, 2015). We also showed that CBTI for adolescents has a high probability of being cost-effective compared to no treatment, with Internet CBTI being slightly more cost-effective than group CBTI (De Bruin, van Steensel, & Meijer, 2016).

Considering the bi-directional relationship between sleep and psychopathology, as well as its importance for the scientific and clinical field, the current study aimed to establish whether insomnia treatment improves adolescent psychopathology and, if so, whether reduction of insomnia symptoms mediates this effect. We used a randomized controlled design to test efficacy of treatment compared to a waitlist condition (WL) and applied the CBTI protocol in both a face-to-face group (GT) and an Internet condition (IT). We checked whether symptoms of insomnia and psychopathology, as well as sleep variables from objective and subjective sleep measurements improved after CBTI. Subsequently, we used a mediation analysis to determine whether observed improvements in psychopathology could be attributed to reduction of insomnia. The treatment results for psychopathology are reported at post-treatment and at 2-, 6- and 12-month follow-up. We hypothesized that symptoms of psychopathology would be reduced after CBTI, and that reduction of insomnia would mediate those effects of CBTI.

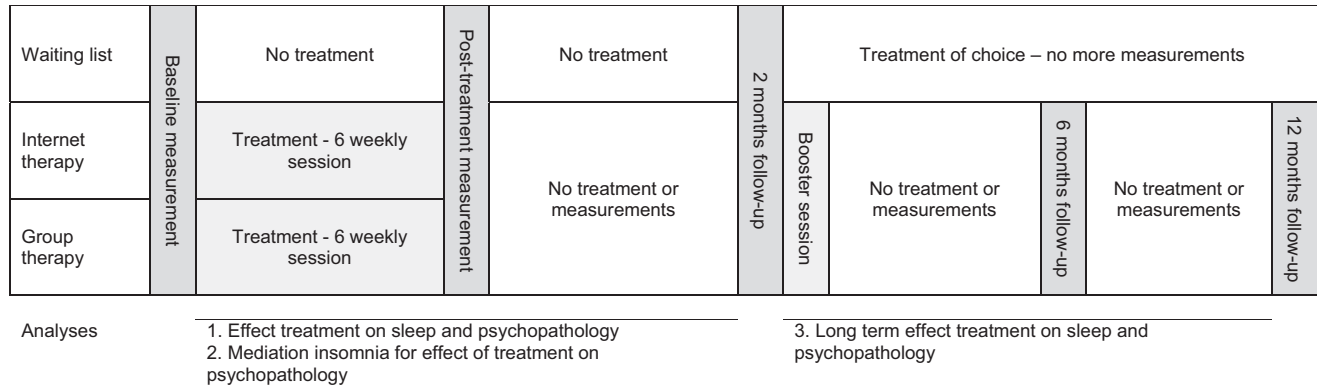
## Methods

### Design and procedure

This study was part of a larger randomized controlled trial (RCT), which was registered at <http://www.controlledtrials.com> (ISRCTN33922163) and approved by the medical ethical committee of the Academic Medical Centre in Amsterdam. The trial design followed the CONSORT 2010 guidelines for RCTs (Moher et al., 2010). Measurements were completed online at baseline, post-treatment and at 2-, 6- and 12-month follow-up from the start of treatment. Participants were recruited by means of advertisements, newsletters, lectures at schools and leaflets for healthcare professionals. The participants registered via a web-form. If they met criteria for inclusion, written informed consent was obtained and they were then randomized to one of the three conditions. Participants who were randomized to WL could choose GT or IT after the 2-month follow-up. Directly before the start of treatment, parents received a booklet with information about the study and treatment (For the design of the study, see Figure 1).

### Participants

After screening the online registration information and subsequent contact emails of 478 potential participants for inclusion and exclusion criteria, 136 were invited for a 1-hr face-to-face interview. Before the interview, these participants completed the *Holland Sleep Disorder Questionnaire* (HSDQ; Kerkhof et al., 2013) and the *Youth Self-Report* (YSR; Achenbach, 1991) online. During the interview, they underwent an assessment for the DSM-5-criteria of insomnia, which included their extensive sleep history, the frequency and duration of their insomnia, and differentiation from other sleep disorders (e.g. Delayed Sleep Phase Disorder) (APA, 2013). Other inclusion criteria were their being between 12 and 19 years old, being in secondary school or after, and living within travelling distance of the treatment centre. The exclusion criteria were other sleep problems or confirmed primary psychiatric disorders, physical problems that interfere with sleep (e.g. pain), substance-related disorders and use of medication (including melatonin) that can affect sleep.



**Figure 1** Design of the study

Twenty adolescents were excluded. (For participant flow through the study, see Figure 2).

Using concealed simple randomization with an equal allocation ratio by referring to a table of random numbers, the resulting 116 adolescents (mean age = 15.6 years,  $SD = 1.6$  years, 25% males) were randomly assigned to WL ( $N = 39$ ), IT ( $N = 39$ ) and GT ( $N = 38$ ) (see Figure 2). There were no significant differences between the groups in terms of age ( $F(2, 113) = 1.23, p = .30$ ) and gender ( $\chi^2(2) = 3.01, p = .22$ ). In most cases, their parents were married or living together (73.3%) (see Table 1).

An a priori power analysis suggested that a sample size of 64 for each group would be necessary to achieve 0.80 power to find medium-sized effects (Cohen's  $d = 0.50$ ). Unfortunately, due to slow recruitment and time constraints of the RCT, we were compelled to terminate inclusion before this number was reached. However, after the pilot phase of this study (De Bruin, Oort, Bögels, & Meijer, 2014) we found a large effect size (ES) improvement in the primary outcome measure sleep efficiency (SE) of Cohen's  $d = 0.70$ . With an autocorrelation of .50, and  $\alpha$  of .05, this ES yielded a power of .86 with the actual sample size.

## Measurements

Baseline and post-treatment measurements were made at fixed times directly before the start and after the end of treatment. Online questionnaires were completed at fixed times, and reminder text-messages were sent to participants whose response was delayed.

At all measurement times, sleep was registered with *wrist actigraphy* (Actiwatch® AW4; Cambridge Neurotechnology Ltd., Cambridge, UK) and sleep logs (Carney et al., 2012) for seven consecutive nights. For actigraphy measurements, 1-min epochs were used, and data were registered with the medium-sensitivity algorithm, which has the highest sensitivity (0.96), specificity (0.42) and accuracy (0.79) for insomnia (Kushida et al., 2001). Validation of actigraphy in adolescents with polysomnography showed a sensitivity of .95 and a specificity of .75 (Meltzer, Montgomery-Downs, Insana, & Walsh, 2012). Participants used the event marker button of the actigraphy to indicate 'lights out' and 'get-up' times, which, together with sleep log variables, were used to calculate TST (i.e. time spent asleep), SOL and sleep efficiency (SE) (percentage TST of time spent in bed).

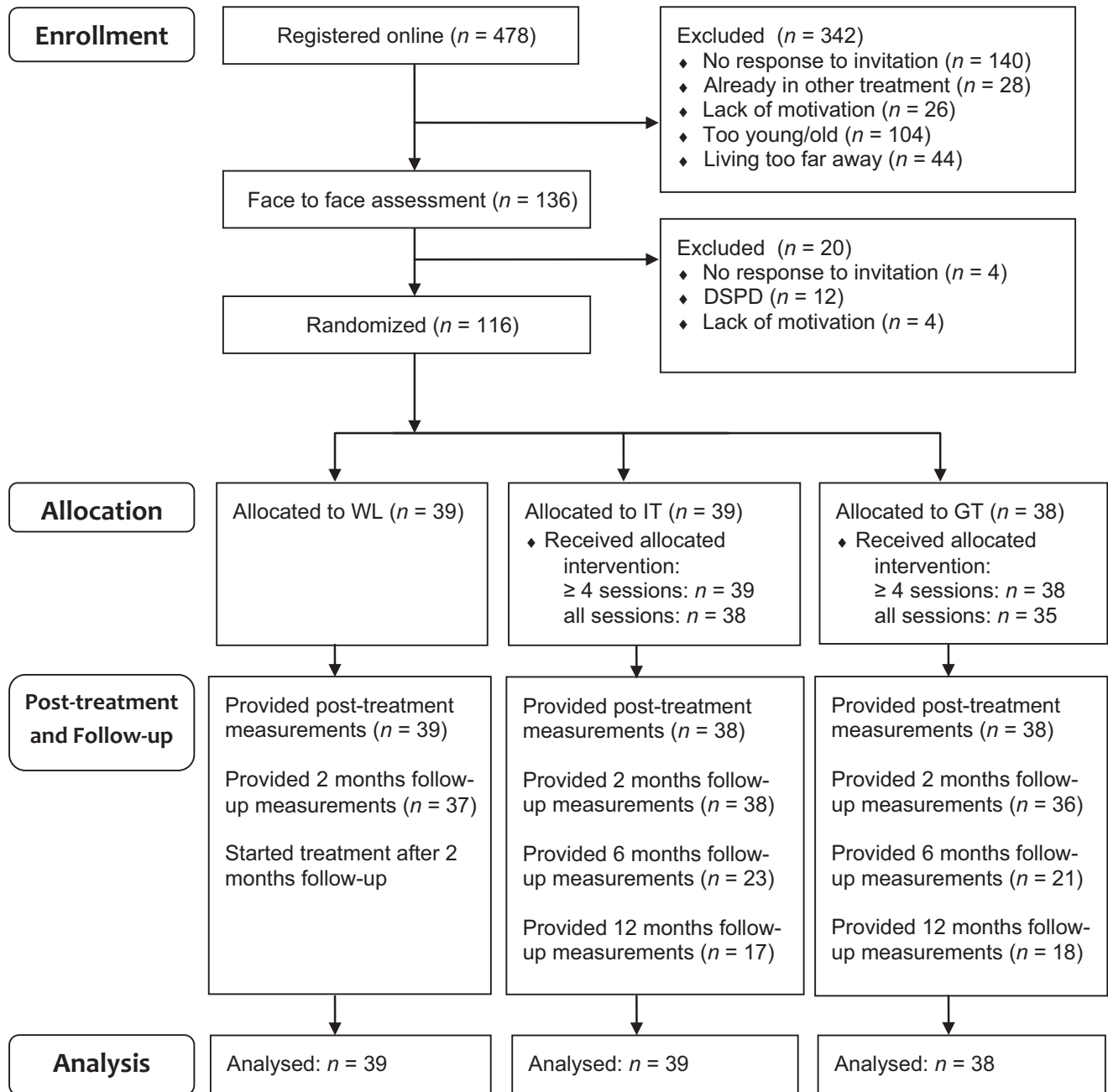
The HSDQ (Kerkhof et al., 2013) consists of 32 items that screen for common sleep disorders based on the six main categories from the International Classification of Sleep Disorders, Second Edition (American Academy of Sleep Medicine, 2005). In a Dutch sample of 1,269 patients and 412 participants without sleep complaints, Cronbach's alpha was .90 and ranged from .73 to .81 for the subscales. Insomnia symptoms

were measured with the insomnia subscale of the HSDQ (HSDQi), which consists of eight items rated on a five-point Likert scale (1–5), with higher scores indicating more symptoms (e.g. 'I have difficulty falling asleep' and 'I feel sleepy during the day'). Based on research from our group, with 951 adolescents from the general population and 210 adolescents from clinical samples (144 cases of delayed sleep phase disorder, and 66 cases of insomnia disorder), we found a Cronbach's alpha of .88 (Van Maanen et al., 2014). In the present sample, Cronbach's alpha ranged from .78–.86 at the different measurement times. According to Youden's criterion, which gives equal weight to sensitivity (.83) and specificity (.87), the optimal cut-off for adolescents is 3.19, with higher scores indicating insomnia. For all measurements using the HSDQi, significant Pearson's correlations were found with the actigraphy-variables SOL ( $r = .37, p < .001$ ), and SE ( $r = -.25, p < .001$ ), and sleep log variables SOL ( $r = .27, p < .001$ ), TST ( $r = -.25, p < .001$ ) and SE ( $r = -.36, p < .001$ ).

The YSR (Achenbach, 1991) is a self-report questionnaire for adolescents' psychopathology. It consists of 119 items scored on a 3-point Likert scale (0 – not true, 1 – somewhat or sometimes true, or 2 – very true or often true). Six subscales exist, which are based on the Diagnostic and Statistical Manual IV (DSM-scales): *Affective problems*, *Anxiety problems*, *Somatic problems*, *ADHD problems*, *Oppositional defiant problems* and *Conduct problems*. For the total score Cronbach's alpha in a Dutch norm sample of 1,026 adolescents ranged from .90 to .92. Analyses of baseline scores for GT, IT and WL revealed that the scores for the DSM-scales *Anxiety problems* and *Oppositional defiant problems* in GT were slightly skewed ( $z = 2.06$ , and  $2.04$  respectively).

## Treatments

The participants randomized to GT or IT received CBTi in six weekly sessions and a booster session after 2 months. All therapists had been trained in behavioural sleep medicine and were supervised by an experienced sleep-psychotherapist. The protocol consisted of psycho-education, sleep hygiene, restriction of time in bed, stimulus control, cognitive therapy and relaxation techniques. During each session, participants received bedtime advice for restriction of time in bed, which was determined as follows: If SE from sleep logs was below 85%, participants were advised to limit their time in bed to roughly their TST, with a minimum of 6 hr in bed. If SE was between 85% and 90%, the time in bed was kept stable. If SE increased to over 90%, the time in bed was increased by 10–15 min. Times in bed were agreed upon with the participants and depended on time constraints (e.g. school start times), personal circumstances (e.g. illness or excessive sleepiness) and therapeutic considerations of the therapists and the supervising CBTi expert. Furthermore, as appropriate,



**Figure 2** Participant flow through the study

exercises of stimulus control, sleep hygiene, relaxation and cognitive therapy were either introduced or continued from the previous sessions. Two months after the sixth session, there was a booster session in which all topics were recapitulated. Participants in the GT condition came to a local youth mental health care centre and received a 90-min session in groups of six to eight participants. Participants in the IT condition logged on to a website where once every week a consultation was made available with personalized bedtime advice, automated feedback and written feedback from a sleep therapist, instruction and explanations of exercises, movies and interactive questionnaires. The order, nature and amount of content of the Internet sessions were similar to those of the group sessions, and the content was presented in a fixed sequence (i.e. participants could access all pages only in a fixed order and could not skip pages). The time needed to engage with the online material of each session was about 90 min, and a session was only marked as 'completed' if all pages had been accessed. Internet sessions could be accessed repeatedly once they had been made accessible to the participant. After the

second Internet CBTI session, participants had a 15-min online chat session with their therapist [For a more detailed description of both treatment modalities and the protocol, see De Bruin et al. (2014, 2015)].

Participants in the WL condition were asked to refrain from using sleep therapy or sleep medication during the entire period of measurements from baseline to 2-month follow-up. They received no information on the (protocol of the) study other than the general information that all participants had received before informed consent was obtained. After the measurements for the 2-month follow-up were concluded, participants from WL could enrol in the treatment of their choice.

#### *Treatment integrity and participant attrition*

To ensure treatment integrity, two therapists executed GT and an independent CBTI expert supervised the treatment. Video recordings of the sessions of five of the groups in GT were rated

**Table 1** Demographic characteristics

| Characteristic                   | Waitlist ( <i>n</i> = 39) | Internet treatment ( <i>n</i> = 39) | Group treatment ( <i>n</i> = 38) | All ( <i>n</i> = 116) |
|----------------------------------|---------------------------|-------------------------------------|----------------------------------|-----------------------|
| Age (mean, <i>SD</i> ) years     | 15.9 (1.6)                | 15.3 (1.4)                          | 15.6 (1.7)                       | 15.6 (1.6)            |
| Gender, No. (%)                  |                           |                                     |                                  |                       |
| Female                           | 28 (71.8)                 | 33 (84.6)                           | 26 (68.4)                        | 87 (75.0)             |
| Male                             | 11 (28.2)                 | 6 (15.4)                            | 12 (31.6)                        | 29 (25.0)             |
| Parent marital status, No. (%)   |                           |                                     |                                  |                       |
| Married or living together       | 24 (61.5)                 | 34 (87.2)                           | 27 (71.1)                        | 85 (73.3)             |
| Single                           | 3 (7.7)                   | 3 (7.7)                             | 5 (13.2)                         | 11 (9.5)              |
| Living apart together            | 2 (5.1)                   | 1 (2.6)                             | 3 (7.9)                          | 6 (5.2)               |
| Other                            | 1 (2.6)                   | 0 (0.0)                             | 0 (0.0)                          | 1 (0.9)               |
| Missing                          | 9 (23.1)                  | 1 (2.6)                             | 3 (7.9)                          | 13 (11.2)             |
| Parent education, No. (%)        |                           |                                     |                                  |                       |
| High school or less              | 1 (2.6)                   | 1 (2.6)                             | 0 (0.0)                          | 2 (1.7)               |
| Some college                     | 11 (28.2)                 | 11 (28.2)                           | 13 (34.2)                        | 35 (30.2)             |
| College graduate                 | 9 (23.1)                  | 12 (30.8)                           | 9 (23.7)                         | 30 (25.9)             |
| Graduate school                  | 9 (23.1)                  | 13 (33.3)                           | 13 (34.2)                        | 35 (30.2)             |
| Other                            | 0 (0.0)                   | 1 (2.6)                             | 0 (0.0)                          | 1 (0.9)               |
| Missing                          | 9 (23.1)                  | 1 (2.6)                             | 3 (7.9)                          | 13 (11.2)             |
| Parent country of birth, No. (%) |                           |                                     |                                  |                       |
| The Netherlands                  | 26 (66.7)                 | 38 (97.4)                           | 29 (76.3)                        | 93 (80.2)             |
| Other                            | 4 (10.3)                  | 0 (0.0)                             | 6 (15.8)                         | 10 (8.6)              |
| Missing                          | 9 (23.1)                  | 1 (2.6)                             | 3 (7.9)                          | 13 (11.2)             |

for integrity by two researchers on a 5-point rating scale (1 = not addressed at all, to 5 = very well addressed) for all the programme elements in the sessions of the treatment protocol (e.g. advice for restriction of time in bed, sleep hygiene discussion, introduction and practice of relaxation exercises, and homework assignments). The mean overall rating was 3.89 ( $SD = 1.47$ ), indicating good integrity. One-way ANOVA showed no significant differences between the groups in GT in terms of average integrity rating ( $F(4, 126) = 1.40, p = .24$ ).

The therapists for IT discussed feedback and bedtime advice and received weekly supervision from a CBTI expert. One-way ANOVA showed that the number of words used for feedback did not differ significantly among the five therapists who guided IT participants (mean number of words per session = 373 ( $SD = 79$ ),  $F(4, 34) = 1.23, p = .32$ ). Furthermore, because the IT sessions consisted of preprogrammed online modules, all IT participants received identical consultations, including the same order of exercises, questionnaires and movies.

At 2-month follow-up, 37 participants in WL (94.9%), 38 in IT (97.4%) and 36 in GT (94.7%) provided measurements. At 6-month follow-up, 23 participants in IT (59.0%) and 21 in GT (55.3%) provided measurements. At 12-month follow-up 17 participants in IT (43.6%) and 18 in GT (47.4%) provided measurements (See Figure 2). All participants in the WL condition were enrolled into treatment after 2-month follow-up and did not provide further measurements. There were no significant differences between the participants who did or did not provide 2-month follow-up measurements, in gender ( $\chi^2(1) = 0.11, p = .74$ ) or age ( $t(114) = 0.77, p = .44$ ). Nor was there a significant difference in gender or age at 12-month follow-up ( $\chi^2(1) = 0.97, p = .33$ ;  $t(75) = 0.86, p = .40$ ). Furthermore, there were no significant baseline differences between the participants who did and those who did not provide post-treatment or follow-up measurements, in insomnia symptoms measured by the HSDQi ( $p$ 's between .57 and .84), and in symptoms of psychopathology measured by the YSR ( $p$ 's between .07 and .90).

### Statistical analyses

One-way ANOVAs and chi-square tests were used to compare demographic variables. Within-group ESs were calculated for the outcome variables (psychopathology, actigraphy, sleep logs

and insomnia symptoms) to indicate the degree of change after treatment, using Cohen's  $d$  [ $d = (M2 - M1) / SD_{pooled}$ , where  $M1$  = baseline mean,  $M2$  = post-treatment mean or follow-up mean and  $SD_{pooled}$  = pooled standard deviation, obtained by pooling the baseline  $SD$  across groups (see Table 2)]. We used multilevel regression analysis, with repeated measurements nested within participants, to test significant differences in outcomes between the groups. Multilevel regression analysis allows inclusion of participants with missing data at one or more measurement times (Snijders & Bosker, 1999), so all participants were included in the analyses. Because for the YSR outcomes a significant differential effect of treatment outcomes according to gender appeared for most DSM-scales, all models also included main and interaction effects of gender.

All predictor and outcome variables were standardized, which allows for interpretation of the  $\beta$  coefficients from the multilevel regression analyses, which are shown in Tables 3–5, as Cohen's  $d$  effect sizes (ESs), with .20, .50, and .80 indicating small, medium and large ESs respectively (Cohen, 1988). Regression coefficients represent differences of each effect compared to WL at baseline. As the independent variables were binary coded (0, 1), separate ESs for both GT and IT can be deduced from ESs for the main effects of GT and IT and ESs for interaction effects. When there is a significant interaction of condition (GT or IT)\*time (e.g. post-treatment), the ES for GT or IT is the sum of the ES of GT or IT, and the ES of the interaction.

To test effects of treatment on psychopathology and sleep, models were analysed for baseline, post-treatment and 2-month follow-up measurements for GT, IT and WL. To test long-term effects of treatment, models were analysed for 6- and 12-month follow-up measurements compared to 2-month follow-up measurements for IT compared to GT only, as WL participants provided measurements only until 2-month follow-up.

To test whether reduction of insomnia symptoms mediates the significant effects of treatment on psychopathology, we conducted multilevel regression analyses to test criteria for mediation (Hayes, 2013; MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002; Preacher & Hayes, 2004). As there were no significant differences between GT and IT in effects of CBTI for insomnia symptoms, we created one group of all treated participants from both GT and IT and then compared this group to WL in the mediation analyses. (For details of the

**Table 2** Means, standard deviations and Cohen's *d* within-group effect sizes of outcome variables from baseline to 12-month follow-up

|                                   | Baseline<br>Mean (SD) | Post-treatment |                       | Follow-up    |                       | 6 months    |                       | 12 months   |                       |
|-----------------------------------|-----------------------|----------------|-----------------------|--------------|-----------------------|-------------|-----------------------|-------------|-----------------------|
|                                   |                       | Mean (SD)      | <i>d</i> <sup>a</sup> | Mean (SD)    | <i>d</i> <sup>a</sup> | Mean (SD)   | <i>d</i> <sup>a</sup> | Mean (SD)   | <i>d</i> <sup>a</sup> |
| <b>Psychopathology</b>            |                       |                |                       |              |                       |             |                       |             |                       |
| Affective problems                |                       |                |                       |              |                       |             |                       |             |                       |
| WL                                | 10.97 (4.42)          | 9.89 (3.75)    | -0.25                 | 10.35 (3.57) | -0.14                 | -           | -                     | -           | -                     |
| IT                                | 8.85 (3.31)           | 5.95 (3.11)    | -0.86                 | 5.45 (2.92)  | -1.03                 | 5.44 (2.23) | -1.08                 | 5.63 (3.22) | -0.87                 |
| GT                                | 8.89 (3.68)           | 6.11 (2.86)    | -0.80                 | 6.11 (3.72)  | -0.71                 | 5.50 (3.03) | -0.90                 | 5.27 (2.82) | -0.97                 |
| Anxiety problems                  |                       |                |                       |              |                       |             |                       |             |                       |
| WL                                | 4.15 (2.11)           | 3.92 (2.07)    | -0.10                 | 4.06 (2.19)  | -0.04                 | -           | -                     | -           | -                     |
| IT                                | 3.85 (2.05)           | 2.59 (1.82)    | -0.62                 | 2.42 (1.50)  | -0.75                 | 2.17 (1.54) | -0.83                 | 2.19 (1.52) | -0.81                 |
| GT                                | 3.45 (2.10)           | 2.86 (1.93)    | -0.28                 | 2.79 (1.81)  | -0.32                 | 2.22 (2.02) | -0.54                 | 2.47 (2.00) | -0.42                 |
| Somatic problems                  |                       |                |                       |              |                       |             |                       |             |                       |
| WL                                | 3.97 (2.12)           | 4.14 (2.25)    | 0.07                  | 4.41 (2.15)  | 0.18                  | -           | -                     | -           | -                     |
| IT                                | 3.21 (1.95)           | 2.54 (2.21)    | -0.31                 | 1.97 (1.74)  | -0.63                 | 2.11 (2.00) | -0.50                 | 2.44 (1.67) | -0.38                 |
| GT                                | 3.32 (1.80)           | 2.36 (1.79)    | -0.51                 | 2.32 (1.93)  | -0.51                 | 1.89 (1.78) | -0.72                 | 2.13 (2.17) | -0.52                 |
| ADHD problems                     |                       |                |                       |              |                       |             |                       |             |                       |
| WL                                | 6.00 (2.33)           | 6.35 (2.23)    | 0.15                  | 6.59 (2.27)  | 0.23                  | -           | -                     | -           | -                     |
| IT                                | 6.18 (2.76)           | 5.51 (3.08)    | -0.22                 | 4.94 (2.44)  | -0.45                 | 4.78 (2.67) | -0.46                 | 4.88 (2.09) | -0.47                 |
| GT                                | 6.53 (1.84)           | 6.17 (2.05)    | -0.18                 | 5.54 (2.17)  | -0.47                 | 5.78 (2.78) | -0.29                 | 5.20 (3.03) | -0.46                 |
| Oppositional defiant problems     |                       |                |                       |              |                       |             |                       |             |                       |
| WL                                | 3.00 (1.76)           | 2.92 (1.61)    | -0.05                 | 2.47 (1.59)  | -0.28                 | -           | -                     | -           | -                     |
| IT                                | 3.38 (2.06)           | 2.95 (1.94)    | -0.20                 | 2.42 (1.86)  | -0.46                 | 2.22 (1.83) | -0.53                 | 2.25 (2.02) | -0.49                 |
| GT                                | 3.39 (1.84)           | 2.50 (1.58)    | -0.49                 | 2.64 (1.52)  | -0.42                 | 2.83 (1.62) | -0.29                 | 2.87 (1.55) | -0.27                 |
| Conduct problems                  |                       |                |                       |              |                       |             |                       |             |                       |
| WL                                | 3.08 (2.02)           | 3.00 (1.93)    | -0.04                 | 2.06 (2.36)  | -0.41                 | -           | -                     | -           | -                     |
| IT                                | 2.56 (2.08)           | 2.59 (1.96)    | 0.01                  | 2.36 (1.93)  | -0.09                 | 1.83 (1.82) | -0.34                 | 2.13 (2.31) | -0.17                 |
| GT                                | 3.05 (1.79)           | 2.33 (1.69)    | -0.39                 | 2.46 (1.62)  | -0.33                 | 2.28 (1.23) | -0.45                 | 2.53 (1.46) | -0.28                 |
| Actigraphy sleep measurements     |                       |                |                       |              |                       |             |                       |             |                       |
| Sleep efficiency, %               |                       |                |                       |              |                       |             |                       |             |                       |
| WL                                | 76.1 (7.3)            | 74.6 (8.7)     | -0.18                 | 75.7 (5.9)   | -0.06                 | -           | -                     | -           | -                     |
| IT                                | 76.5 (6.3)            | 82.5 (5.3)     | 0.96                  | 82.7 (5.0)   | 1.00                  | 83.9 (4.0)  | 1.24                  | 83.8 (4.9)  | 1.12                  |
| GT                                | 75.6 (8.0)            | 80.8 (6.7)     | 0.67                  | 81.9 (5.9)   | 0.84                  | 83.1 (4.9)  | 1.02                  | 84.7 (5.0)  | 1.18                  |
| Sleep onset latency, min          |                       |                |                       |              |                       |             |                       |             |                       |
| WL                                | 44 (30)               | 48 (33)        | 0.12                  | 41 (25)      | -0.10                 | -           | -                     | -           | -                     |
| IT                                | 39 (24)               | 20 (15)        | -0.89                 | 18 (15)      | -0.96                 | 17 (14)     | -0.99                 | 20 (19)     | -0.76                 |
| GT                                | 47 (31)               | 25 (24)        | -0.75                 | 18 (14)      | -1.13                 | 17 (17)     | -1.08                 | 19 (15)     | -1.00                 |
| Total sleep time, min             |                       |                |                       |              |                       |             |                       |             |                       |
| WL                                | 421 (73)              | 413 (86)       | -0.09                 | 401 (70)     | -0.26                 | -           | -                     | -           | -                     |
| IT                                | 418 (73)              | 436 (66)       | 0.24                  | 427 (56)     | 0.13                  | 441 (47)    | 0.33                  | 437 (58)    | 0.25                  |
| GT                                | 409 (69)              | 415 (79)       | 0.08                  | 417 (75)     | 0.10                  | 426 (69)    | 0.22                  | 422 (51)    | 0.19                  |
| Sleeplogs and Insomnia scale HSDQ |                       |                |                       |              |                       |             |                       |             |                       |
| Sleep efficiency, %               |                       |                |                       |              |                       |             |                       |             |                       |
| WL                                | 80.4 (16.0)           | 80.7 (15.8)    | 0.02                  | 80.0 (17.8)  | -0.02                 | -           | -                     | -           | -                     |
| IT                                | 84.3 (10.3)           | 90.1 (7.7)     | 0.61                  | 90.1 (6.9)   | 0.62                  | 90.8 (5.7)  | 0.70                  | 89.5 (7.5)  | 0.51                  |
| GT                                | 80.2 (14.2)           | 86.6 (9.6)     | 0.70                  | 89.1 (7.7)   | 0.73                  | 87.0 (11.8) | 0.47                  | 89.2 (11.8) | 0.60                  |
| Sleep onset latency, min          |                       |                |                       |              |                       |             |                       |             |                       |
| WL                                | 52 (48)               | 53 (51)        | 0.02                  | 53 (53)      | 0.02                  | -           | -                     | -           | -                     |
| IT                                | 49 (43)               | 30 (27)        | -0.50                 | 33 (25)      | -0.43                 | 30 (23)     | -0.49                 | 35 (36)     | -0.31                 |
| GT                                | 57 (49)               | 39 (31)        | -0.42                 | 31 (22)      | -0.64                 | 35 (29)     | -0.49                 | 35 (30)     | -0.47                 |
| Total sleep time, min             |                       |                |                       |              |                       |             |                       |             |                       |
| WL                                | 441 (117)             | 438 (117)      | -0.02                 | 438 (131)    | -0.02                 | -           | -                     | -           | -                     |
| IT                                | 456 (87)              | 471 (74)       | 0.18                  | 477 (72)     | 0.25                  | 498 (63)    | 0.50                  | 473 (86)    | 0.17                  |
| GT                                | 435 (107)             | 450 (90)       | 0.14                  | 467 (90)     | 0.30                  | 471 (95)    | 0.32                  | 457 (74)    | 0.21                  |
| HSDQ – insomnia symptoms          |                       |                |                       |              |                       |             |                       |             |                       |
| WL                                | 3.58 (0.63)           | 3.74 (0.62)    | 0.24                  | 3.72 (0.63)  | 0.21                  | -           | -                     | -           | -                     |
| IT                                | 3.44 (0.54)           | 2.86 (0.71)    | -0.86                 | 2.58 (0.73)  | -1.21                 | 2.46 (0.38) | -1.91                 | 2.54 (0.41) | -1.63                 |
| GT                                | 3.62 (0.54)           | 3.01 (0.59)    | -1.02                 | 2.62 (0.69)  | -1.46                 | 2.46 (0.46) | -2.24                 | 2.47 (0.51) | -1.93                 |

WL, Waitlist; IT, Internet therapy; GT, Group therapy; HSDQ, Holland Sleep Disorder Questionnaire.

<sup>a</sup>Cohen's *d* effect size relative to Baseline: with .20, .50, and .80 indicating small, medium and large effect sizes (Cohen, 1988).

mediation analyses for GT and IT separately, see Tables S3 and S4 in the Supplement). We tested for significance of the mediation effect by reduction of insomnia symptoms on psychopathology at 2-month follow-up compared to baseline, including the HSDQi scores (for insomnia symptoms) at post-treatment as predictor for psychopathology at 2-month

follow-up (i.e. temporal precedence). The effects of treatment on YSR scores (mediation criterion 1) and on HSDQi scores (mediation criterion 2) were analysed according to the analyses described in the previous paragraphs of this section. For YSR scales that had improved significantly after treatment, we conducted multilevel regression analyses for mediation criteria

**Table 3** Multilevel regression analyses for effects of group CBTI and Internet CBTI compared to waitlist on psychopathology, from baseline to 2-month follow-up

| Parameter   | Affective<br>$\beta$ (SE) | Anxiety<br>$\beta$ (SE) | Somatic<br>$\beta$ (SE) | ADHD<br>$\beta$ (SE) | Oppositional<br>defiant $\beta$ (SE) | Conduct<br>$\beta$ (SE) |
|---|---------------------------|-------------------------|-------------------------|----------------------|--------------------------------------|-------------------------|
| Group effects at baseline   |                           |                         |                         |                      |                                      |                         |
| Gender (difference of girls compared to boys, at baseline)  | 0.62 (.18)**              | 0.79 (.20)***           | 0.62 (.18)**            | 0.30 (.21)           | -0.13 (.21)                          | -0.49 (.21)*            |
| Internet CBTI (difference with waitlist, at baseline)   | -0.61 (.19)**             | -0.25 (.21)             | -0.44 (.21)*            | 0.04 (.22)           | 0.23 (.22)                           | -0.20 (.22)             |
| Group CBTI (difference with waitlist, at baseline)  | -0.50 (.19)*              | -0.32 (.21)             | -0.29 (.21)             | 0.23 (.22)           | 0.22 (.22)                           | -0.03 (.22)             |
| Treatment effects   |                           |                         |                         |                      |                                      |                         |
| Post-treatment (change of waitlist from baseline to post-treatment)   | -0.01 (.14)               | 0.15 (.15)              | 0.08 (.12)              | 0.13 (.15)           | -0.03 (.17)                          | -0.07 (.19)             |
| 2-month follow-up (change of waitlist from post-treatment to 2-month follow-up)   | 0.26 (.19)                | 0.29 (.20)              | 0.03 (.16)              | 0.57 (.21)**         | 0.09 (.23)                           | -0.24 (.25)             |
| Gender*post-treatment (additional change of girls from baseline to post-treatment, compared to boys)                                | -0.32 (.14)*              | -0.37 (.15)*            | 0.10 (.16)              | 0.07 (.15)           | 0.01 (.17)                           | 0.08 (.18)              |
| Gender*2-month follow-up (additional change of girls from post-treatment to 2-month follow-up, compared to boys)                    | -0.36 (.16)*              | -0.16 (.17)             | -0.25 (.19)             | -0.37 (.18)*         | -0.03 (.20)                          | -0.11 (.22)             |
| Internet CBTI*post-treatment (additional change of Internet CBTI from baseline to post-treatment, compared to waitlist)             | -0.44 (.14)**             | -0.45 (.15)**           | -0.37 (.17)*            | -0.50 (.16)**        | -0.24 (.17)                          | -0.02 (.19)             |
| Group CBTI*post-treatment (additional change of group CBTI from baseline to post-treatment, compared to waitlist)                   | -0.45 (.14)**             | -0.22 (.15)             | -0.53 (.17)**           | -0.32 (.16)*         | -0.42 (.17)*                         | -0.32 (.19)             |
| Internet CBTI*2-month follow-up (additional change of Internet CBTI from post-treatment to 2-month follow-up, compared to waitlist) | -0.12 (.17)               | -0.20 (.19)             | -0.34 (.21)             | -0.43 (.19)*         | -0.33 (.21)                          | 0.19 (.24)              |
| Group CBTI*2-month follow-up (additional change of group CBTI from post-treatment to 2-month follow-up, compared to waitlist)       | 0.07 (.18)                | -0.08 (.19)             | 0.13 (.21)              | -0.55 (.20)**        | -0.02 (.22)                          | 0.28 (.24)              |

CBTI = cognitive behavioural therapy for insomnia. All predictor and outcome variables were standardized, which allows for interpretation of the  $\beta$  coefficients as Cohen's *d* effect sizes (ESs), with .20, .50, and .80 indicating small, medium and large ESs, respectively (Cohen, 1988). Regression coefficients represent differences of each effect compared to waitlist at baseline. Separate ESs for group and Internet CBTI can be deduced from ESs for the main effects of group and Internet CBTI and ESs for interaction effects. When there is a significant interaction of condition (group or Internet CBTI)\*time (e.g. post-treatment), the total ES for group or Internet CBTI over time is the sum of the ES of group or Internet CBTI, and the ES of the interaction.

\* $p < .05$ ; \*\* $p < .01$ .

3 and 4, with models with HSDQi scores as predictors for the YSR scores (criterion 3), and models with both treatment and HSDQi scores as predictors for YSR scores (criterion 4). If criteria 1–3 are met (i.e. treatment is a significant predictor for YSR and HSDQi scores, and HSDQi is a significant predictor for YSR, including matching signs of the effects), there is an indication of either partial or complete mediation. If criterion 4 is also met (i.e. significant direct effect of predictor treatment is no longer significant in a model with HSDQi as predictor for YSR), there is an indication of complete mediation. We used a bootstrapping procedure with 1,000 replications to investigate the statistical significance of the mediation effects (i.e. the product of coefficients) (Hayes, 2013; Preacher & Hayes, 2004).

## Results

### Results for psychopathology

Table 2 shows means, standard deviations and within-group ESs from baseline to 12-month

follow-up. (For the range of the scores of all participants for the DSM-scales of the YSR at each measurement time, and the percentage of participants with scores in the nonclinical, borderline or clinical range, see Table S1 in the supplement).

At baseline, a lower score was found for *Affective problems* for both GT and IT compared to WL ( $\beta = -0.61$  and  $\beta = -0.50$  respectively), and for *Somatic problems* for IT only ( $\beta = -0.44$ ). There were no significant differences for any of the other DSM-scales from the YSR. For *Affective*, *Somatic* and *ADHD problems*, multilevel regression analyses showed significant treatment effects at post-treatment for both IT and GT compared to WL (see Table 3), indicating that the treated adolescents improved significantly on these scales, with ESs ranging from -0.32 to -0.53. For *Anxiety problems*,



**Table 4** Multilevel regression analyses for effects of Internet CBTI compared to group CBTI on psychopathology, from 2-month follow-up to 12-month follow-up

| Parameter   | Affective<br>$\beta$ (SE) | Anxiety<br>$\beta$ (SE) | Somatic<br>$\beta$ (SE) | ADHD<br>$\beta$ (SE) | Oppositional<br>defiant $\beta$ (SE) | Conduct<br>$\beta$ (SE) |
|---|---------------------------|-------------------------|-------------------------|----------------------|--------------------------------------|-------------------------|
| Group effects at 2-month follow-up (for group and Internet CBTI only)   |                           |                         |                         |                      |                                      |                         |
| Gender (difference of girls compared to boys at 2-month follow-up)  | -0.62 (.27)*              | 0.53 (.25)*             | -0.15 (.26)             | -0.40 (.25)          | -0.13 (.27)                          | -0.43 (.28)             |
| Internet CBTI (difference with group CBTI at 2-month follow-up)   | -0.11 (.26)               | -0.41 (.25)             | -0.20 (.26)             | -0.16 (.25)          | -0.13 (.26)                          | 0.02 (.26)              |
| Treatment effects   |                           |                         |                         |                      |                                      |                         |
| 6-month follow-up (change of group CBTI from 2- to 6-month follow-up)   | -0.55 (.19)**             | -0.24 (.17)             | -0.33 (.17)             | 0.02 (.16)           | -0.25 (.21)                          | -0.45 (.23)             |
| 12-month follow-up (change of group CBTI from 6- to 12-month follow-up)   | -0.12 (.22)               | -0.06 (.20)             | -0.08 (.20)             | -0.06 (.18)          | 0.36 (.24)                           | 0.47 (.27)              |
| Gender*6-month follow-up (additional change of girls from 2- to 6-month follow-up)  | 0.41 (.24)                | 0.20 (.21)              | 0.37 (.21)              | 0.04 (.19)           | 0.47 (.25)                           | 0.48 (.28)              |
| Gender*12-month follow-up (additional change of girls from 6- to 12-month follow-up)  | 0.21 (.29)                | 0.29 (.25)              | 0.29 (.26)              | -0.04 (.23)          | -0.36 (.31)                          | -0.41 (.35)             |
| Internet CBTI*6-months (additional change of Internet CBTI from 2- to 6-month follow-up, compared to group CBTI)            | 0.32 (.21)                | 0.00 (.18)              | 0.05 (.19)              | -0.01 (.17)          | -0.22 (.23)                          | -0.17 (.25)             |
| Internet CBTI*12-month follow-up (additional change of Internet CBTI from 6- to 12-month follow-up, compared to group CBTI) | -0.17 (.24)               | -0.24 (.21)             | -0.32 (.22)             | 0.04 (.20)           | -0.08 (.26)                          | -0.02 (.30)             |

CBTI = cognitive behavioural therapy for insomnia. All predictor and outcome variables were standardized, which allows for interpretation of the  $\beta$  coefficients as Cohen's *d* effect sizes (ESs), with .20, .50, and .80 indicating small, medium and large ESs, respectively (Cohen, 1988). Regression coefficients represent differences of each effect compared to group CBTI at 2-month follow-up. When there is a significant interaction of Internet CBTI\*time (e.g. 6-month follow-up), the total ES for Internet CBTI over time is the sum of the ES of Internet CBTI, and the ES of the interaction.

\* $p < .05$ ; \*\* $p < .01$ .

a significant decrease was found for IT ( $\beta = -0.45$ ) but not for GT. For *Oppositional defiant problems*, a significant decrease was found for GT only ( $\beta = -0.42$ ).

For *ADHD problems*, significant effects were also found at 2-month follow-up for both IT and GT ( $\beta = -0.43$  and  $-0.55$  respectively), indicating further improvements in both treatment groups compared to WL 2 months after treatment was concluded. Analyses of follow-up measurements at 6 and 12 months after treatment (see Table 4) showed a significant further decrease of *Affective problems* for both treatment groups compared to 2-month follow-up ( $\beta = -0.55$ ). The analyses indicated that this effect was smaller for IT than for GT, though this difference was not significant ( $\beta = -0.55 + 0.32 = -0.23$ ,  $p = .13$ ).

Using an alternative parameterization in the multilevel regression analyses, we checked whether changes at 2-month follow-up were significant if directly compared to baseline measurements. These results are available in Table S2 in the Appendix. In short, all results from the analyses for outcomes on psychopathology as described above were confirmed, with improvements at post-treatment maintained or further increased at 2-month follow-up in comparison to baseline. For IT and GT respectively the ESs at 2-month follow-up compared to baseline were:

*Affective problems*  $\beta = -0.56$  and  $-0.38$ , *Anxiety problems*  $\beta = -0.65$  (significant for IT only), *Somatic problems*  $\beta = -0.71$  and  $-0.43$ , *ADHD problems*  $\beta = -0.93$  and  $-0.87$ , *Oppositional defiant problems*  $\beta = -0.57$  and  $-0.44$ .

As indicated in the section on statistical analyses, gender was included in the models. Compared to boys, at baseline, post-treatment and at 2-month follow-up girls scored significantly higher overall for *Affective*, *Anxiety* and *Somatic problems* ( $\beta = 0.62$ – $0.79$ ), and lower for *Conduct problems* ( $\beta = -0.49$ ). There were also significant interaction effects for gender on *Affective* and *Anxiety problems* at post-treatment, and on *Affective* and *ADHD problems* at 2-month follow-up, indicating that after treatment there was a larger decrease of these problems for girls, with ESs ranging from  $\beta = -0.32$  to  $-0.37$ .

At 6- and 12-month follow-up, there were no significant interactions with gender for any of the scales, indicating that the improvements between baseline and 2-month follow-up were maintained similarly over the course of 12 months.

### Results for sleep

For all sleep variables, the means, standard deviations, and within-group ESs from baseline to 12-month follow-up are shown in Table 2. In addition,

**Table 5** Mediation multilevel regression analyses of effects from treatment and insomnia symptoms on psychopathology, with all treated participants compared to waitlist

| Parameter   | Affective $\beta$ (SE) | Anxiety $\beta$ (SE) | Somatic $\beta$ (SE) | ADHD $\beta$ (SE) | Oppositional defiant $\beta$ (SE) |
|---|------------------------|----------------------|----------------------|-------------------|-----------------------------------|
| Step 3 <sup>a</sup> – Model including insomnia symptoms as predictor for psychopathology  |                        |                      |                      |                   |                                   |
| Insomnia symptoms (from baseline to post-treatment as predictor for psychopathology from baseline to 2 months follow-up)                                  | 0.45 (.08)***          | 0.18 (.08)*          | 0.16 (.09)           | 0.19 (.09)*       | 0.25 (.09)**                      |
| 2-month follow-up (changes in psychopathology from baseline to 2-month follow-up for all participants)  | -0.27 (.09)**          | -0.13 (.09)          | -0.12 (.11)          | 0.01 (.10)        | -0.17 (.11)                       |
| Insomnia symptoms*2-month follow-up (different change of psychopathology for different insomnia symptoms)   | -0.06 (.09)            | 0.16 (.09)           | 0.18 (.10)           | 0.14 (.10)        | -0.09 (.10)                       |
| Step 4 <sup>a</sup> – Model including treatment and insomnia symptoms as predictor for psychopathology  |                        |                      |                      |                   |                                   |
| Insomnia symptoms (at post-treatment as predictor for psychopathology at 2-month follow-up)   | 0.42 (.08)***          | 0.17 (.08)*          | 0.13 (.09)           | 0.19 (.08)*       | 0.24 (.09)*                       |
| Treatment <sup>b</sup> (compared to waitlist at baseline)   | -0.50 (.16)**          | -0.24 (.18)          | -0.33 (.18)          | 0.16 (.18)        | 0.23 (.20)                        |
| 2-month follow-up (compared to baseline)  | -0.31 (.19)            | -0.06 (.19)          | 0.15 (.22)           | 0.61 (.21)**      | 0.03 (.22)                        |
| Insomnia symptoms*2-month follow-up (differential effects of treatment at 2-month follow-up for different changes in insomnia symptoms at post-treatment) | -0.05 (.10)            | 0.13 (.10)           | 0.09 (.12)           | -0.06 (.11)       | -0.13 (.12)                       |
| Treatment <sup>b</sup> *2-month follow-up (direct effect of treatment on psychopathology from baseline to 2-month follow-up)                              | 0.02 (.24)             | -0.12 (.25)          | -0.44 (.28)          | -0.88 (.27)**     | -0.31 (.29)                       |

\* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .001$ .

<sup>a</sup>Mediation analysis showing results for steps 3 (insomnia symptoms are a significant predictor for psychopathology) and 4 (significant direct effect of predictor treatment is no longer significant in a model with insomnia symptoms as predictor for psychopathology) of the 4-step approach (Hayes, 2013; MacKinnon et al., 2002; Preacher & Hayes, 2004).

<sup>b</sup>Treatment = all participants from group and Internet CBTI together.

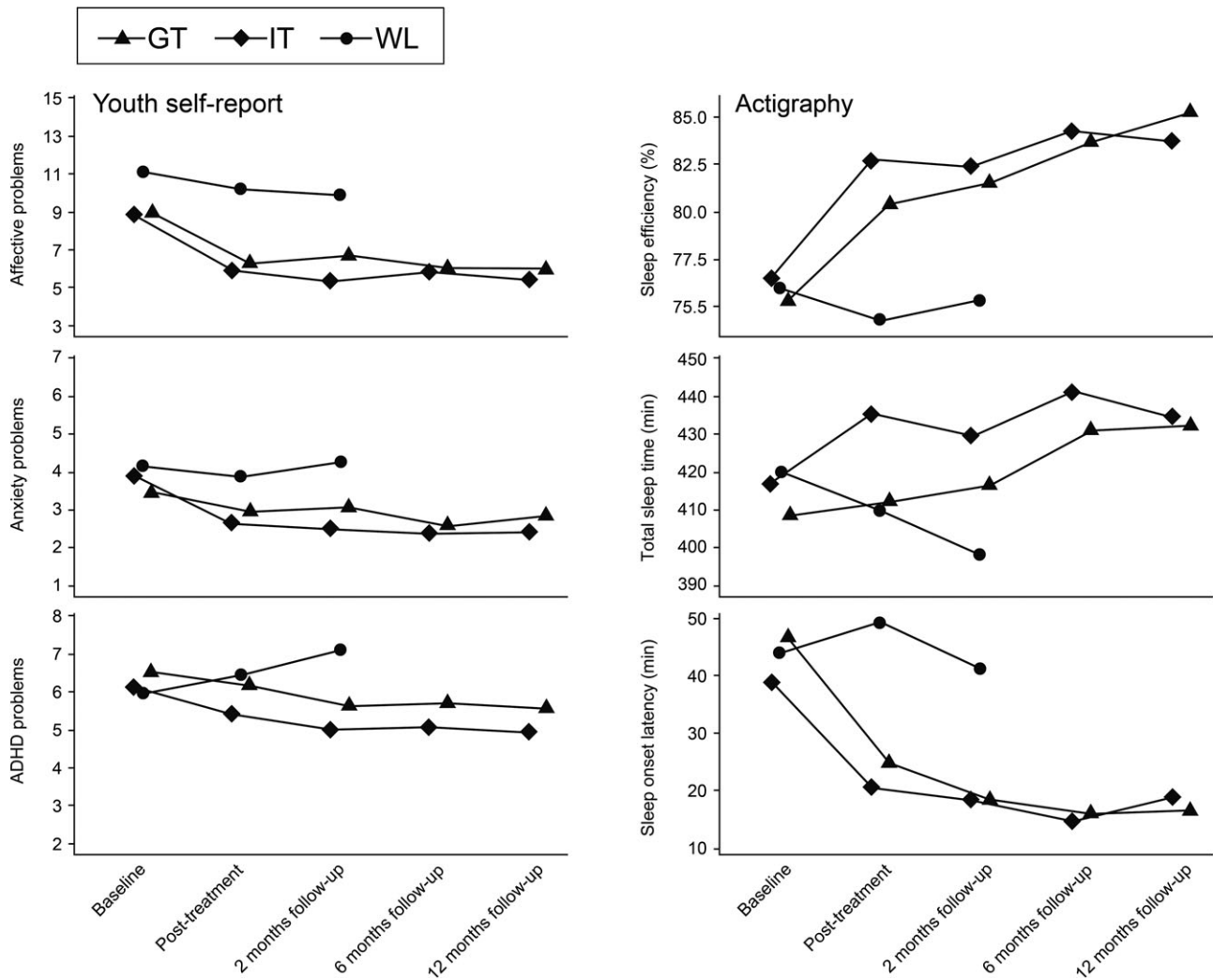
multilevel regression analyses indicated that at post-treatment insomnia symptoms (as measured by the HSDQi) decreased significantly in IT and GT compared to WL (IT:  $\beta = -0.98$ , GT:  $\beta = -1.04$ ,  $p$ 's  $< .001$ ). The actigraphy measurements from adolescents in both IT and GT, compared to WL, showed significant improvements for SE (IT:  $\beta = 1.09$ , GT:  $\beta = 0.91$ ,  $p$ 's  $< .001$ ), and SOL ( $\beta = -0.87$ , GT:  $\beta = -0.99$ ,  $p$ 's  $< .001$ ). TST increased, although this was significant at the 0.05-level for IT only (IT:  $\beta = 0.37$ ,  $p < .01$ , GT:  $\beta = 0.24$ ,  $p = .09$ ). Variables from sleep logs showed significant improvements at post-treatment for SE (IT:  $\beta = 0.41$ , GT:  $\beta = 0.47$ ,  $p$ 's  $< .001$ ) and SOL (IT:  $\beta = -0.44$ , GT:  $\beta = -0.44$ ,  $p$ 's  $< .001$ ), though not for TST (IT:  $\beta = 0.14$ ,  $p = .22$ , GT:  $\beta = 0.15$ ,  $p = .20$ ). Within-group Cohen's  $d$  ESs for all improvements ranged from medium to large (see Table 2 and Figure 3). There were no significant interactions of time and condition from post-treatment to 2-month follow-up, indicating that the improvements at post-treatment were maintained at 2-month follow-up.

Multilevel regression analyses of effects at 6- and 12-month follow-up, compared to 2-month follow-up

yielded no significant interactions of time and condition. This indicates that the improvements in sleep at post-treatment were maintained up to 12-month follow-up (see Tables 2 and 3, and Figure 3).

### Mediation of insomnia for treatment effects on psychopathology

We tested mediation at 2-month follow-up, because for that measurement-period we could compare to WL. We conducted the analyses with both treated groups (IT and GT) together compared to WL. In the previous sections, criterion 1 (i.e. direct effect of treatment on the YSR scales) and criterion 2 (i.e. direct effect of the treatment on the HSDQi insomnia scale) of the mediation analysis were confirmed. To summarize: for all DSM-scales, except *Conduct problems*, there was an improvement after treatment in IT, GT or both at 2-month follow-up, indicating that criterion 1 was met. Also, reduction of insomnia symptoms after CBTI for both IT and GT indicated that criterion 2 was met. Further multilevel regression analyses showed that reduction of insomnia symptoms was a significant predictor for improvement of



**Figure 3** Estimated marginal means for Youth Self-Report scales for affective, anxiety and ADHD problems, and for sleep measurements

*Affective, Anxiety, ADHD and Oppositional defiant problems*, indicating that, for these scales, also criterion 3 was also met, though not for *Somatic problems*. Furthermore, our analyses showed that when controlling for the effect of reduction of insomnia symptoms, treatment effects decreased to nonsignificant levels for *Anxiety, Affective* and *Oppositional defiant problems* (see Table 5). These results indicate full mediation by reduction of insomnia symptoms for effects of CBTI on *Affective, Anxiety* and *Oppositional defiant problems*, as well as partial mediation for *ADHD problems*.

The product of coefficients and bootstrapping procedure showed that the indirect (mediation) effect was significant for *Affective problems* ( $z = -3.47, p < .001$ ), *Anxiety problems* ( $z = -2.05, p < .05$ ) and *ADHD problems* ( $z = -2.94, p < .01$ ), though not for *Oppositional defiant problems* ( $z = -0.74, p = .46$ ). The results of our multilevel regression analyses for mediation, product of coefficients and bootstrapping procedures for GT and IT separately are included in the Appendix (Tables S3 and S4). In brief, the analyses showed that for GT and IT significant full mediation effects were found for *Affective problems*

( $z = -2.65$  and  $z = -3.07, p$ 's  $< .01$ , respectively), and for GT a significant full mediation effect was found for *Somatic problems* ( $z = -3.44, p < .001$ ).

**Discussion**

In a sample of 116 Dutch adolescents aged between 12 and 19 years, we investigated whether insomnia treatment reduced adolescent psychopathology and whether observed improvement of psychopathology could be attributed to a reduction of insomnia symptoms. The results of this study indicate that group and Internet treatment led to improvements in most categories of psychopathology (*Affective, Anxiety, Somatic, ADHD* and *Oppositional defiant problems*) but not in *Conduct problems*. Symptoms of insomnia showed a considerable decrease with (very) large ESs, and there was a concomitant considerable improvement of objectively and subjectively measured sleep. It is important to note that the observed improvements in mental health and sleep followed both group and Internet CBTI and were sustained over 1 year. Furthermore, we found strong indications of full mediation by reduction of insomnia

symptoms for treatment effects on *Affective* and *Anxiety problems*, as well as partial mediation for *ADHD problems*. These findings appear to indicate, first, that sleep problems play an important role in causing and maintaining psychopathology in adolescents, and, second, that CBT for insomnia may be an effective additional instrument in treating certain types of psychopathology.

These findings are in line with previous research that has shown that insomnia can cause and aggravate psychopathology, including depression, anxiety and ADHD (Baglioni et al., 2011; Johnson, Roth, & Breslau, 2006; Millman, 2005; Owens et al., 2013; Roberts & Duong, 2013; Shanahan et al., 2014). In adults, insomnia treatment produces large effects on insomnia symptoms and small-to-moderate effects on psychopathology symptoms (Jansson-Fröjmark & Norell-Clarke, 2016; Ye et al., 2015). Studies comparing online to face-to-face or group treatments show similar results for group and online treatment for diminishing depressive symptoms (Blom et al., 2015) and better results for face-to-face treatment in diminishing depressive and anxiety symptoms (Lancee, Van Straten, Morina, Kaldò, & Kamphuis, 2016).

Our findings indicate that also in adolescents, insomnia treatment may similarly mitigate symptoms of insomnia and certain types of psychopathology. As has been hypothesized for emotional disturbances in general (Riemann et al., 2010), and depression and ADHD in particular (Johnson, Roth, & Breslau, 2006; Owens, 2005), common neural and/or behavioural mechanisms underlying insomnia and psychopathology may explain the effectiveness of CBTI in treating psychopathology. Another interesting hypothesis is that components of CBTI, such as cognitive therapy or relaxation, target behaviour that is prevalent in both insomnia and psychopathology. Both of these hypotheses merit further investigation.

Concerning the bi-directional relationship between insomnia and psychopathology, an important question is whether it is best (a) first to treat the insomnia and then to assess the effect of that treatment on the psychopathology (and only treat the latter if still necessary), (b) first to treat the psychopathology and then to assess the effect of that treatment on the insomnia (and only treat the latter if still necessary), or (c) to combine both treatments from the outset. As Clarke and Harvey (2012) have hypothesized, insomnia in adolescents may interfere with depression treatment, and residual insomnia may be a major component of incompletely remitted depression. In the present study, we have shown that insomnia treatment per se can improve adolescent psychopathology. In the interests of youth mental health, we therefore urge that further studies in this area be given the highest priority.

The aforementioned results are also of great significance for clinical practice. The prevalence of psychopathology is high among adolescents (Roberts,

Roberts, & Xing, 2007). Moreover, abundant evidence shows that most mental disorders in adults originate before adulthood (Kessler et al., 2007; Kim-Cohen et al., 2003; Reef, Van Meurs, Verhulst, & Van der Ende, 2010). As only about one in five adolescents suffering from anxiety and/or depression uses mental healthcare services (Essau, 2005), it can be concluded that many adolescents are deprived of the mental healthcare that they need. Our study shows that a relatively short treatment programme for insomnia can have a strongly positive influence on mental health problems in the young. Moreover, we have found broadly similar results for Internet and group therapy, in line with the meta-analysis of Zachariae, Lyby, Ritterband, and O'Toole (2016), who also reported effects of Internet treatments on adult sleep problems, which are comparable to face-to-face insomnia treatments. Internet CBTI could therefore be considered as an accessible and efficacious intervention. The present study indicates that such therapy not only directly improves sleep but can also ameliorate other serious psychological problems. Regarding the effects of insomnia treatment on psychopathology for the two treatment modalities Internet and group CBTI together or separately, two results stand out: the similar significant full mediation for *Affective problems* in all mediation analyses, and the absence of partial mediation for *ADHD problems* when analysing mediation in Internet and group CBTI separately. These differences may be due to different pathways and/or time courses of change of *Affective problems* and *ADHD problems*, which may in turn be due to different aetiologies of psychopathological disorders, and different treatment mechanisms in Internet and group CBTI. However, the present study design and sample size may not have been suitable to fully address these findings, and we recommend further studies into working mechanisms of CBTI and of different treatment modalities.

The relatively low dropout in our study is comparable with the mean dropout of 14.5% that Ho et al. (2015) reported in their meta-analysis of *self-help* CBTI among adults with insomnia. However, it compares favourably with the dropout in studies of other Internet and face-to-face treatments of adolescent psychopathologies (Fernandez, Salem, Swift, & Ramtahal, 2015; Rooksby, Elouafkaoui, Humphris, Clarkson, & Freeman, 2015). This may be attributable not only to the weekly personal and detailed feedback the adolescents received on their sleep logs and homework tasks, but also to the high motivation of the self-selected participants to engage in treatment.

Despite its strengths, including the randomized controlled design, the reasonable number of participants, the objective measurements, and the 1-year follow-up, our study also has some limitations. Notwithstanding the low dropout after treatment and at 2-month follow-up, only about 45% of the participants provided measurements at 12-month follow-up. However, the data that are missing due to

attrition may be not ‘missing completely at random’, but conditional on all variables that we included in the models, we believe that the missing data can be considered as ‘missing at random’. This implies that the estimates of the parameters that represent CBTI effects in the multilevel regression analyses are unbiased, and that conclusions regarding CBTI effects at follow-ups until 12 months are robust. For other measurements, however, including treatment evaluation, a higher percentage of responders is desirable. Furthermore, despite the randomization we found baseline differences between the groups in two of the psychopathology outcomes. We consider this a coincidental effect, which could have been prevented by using a randomization-after-matching procedure, but such a procedure would not have been feasible in this study. We did not include participants with comorbid mental disorders and, therefore, cannot generalize our results to this group. However, this may also have caused a floor-effect for psychopathology outcomes, thus reducing the possible decrease of psychopathology after CBTI. By excluding participants with medical and psychiatric comorbidities and by using an experimental setting, our sample may be atypical of a clinical population. Therefore, we recommend additional studies in a clinical setting. Further, low specificity of actigraphy measurements (Meltzer et al., 2012) may underestimate results in terms of objective sleep time and sleep efficiency. Comparison with sleep logs suggests that this also played a role in our study. However, this limitation does not interfere with our result that group and Internet CBTI led to improvements in most of the tested categories of psychopathology. Finally, although the YSR (Achenbach, 1991) is a reliable, valid and widely used instrument to measure symptoms of mental disorders, clinical ratings of mental disorders may be necessary to further validate our results.

Based on the results of our study, we recommend that sleep interventions be promoted in mental health prevention and care for adolescents. This recommendation is in accordance with the DSM-5 guidelines (APA, 2013; Reynolds & O’Hara, 2013) in which insomnia is considered a target for intervention itself. Furthermore, we recommend further studies in adolescents on the working mechanisms of CBTI and its separate components, such as restriction of time in bed, and on their relation with

improvements in psychopathology. In our study, even though we did not involve parents, teachers or peers in the treatment, the results show that with this relatively simple approach significant improvements in insomnia, sleep and psychopathology can be achieved. As CBTI is a relatively short-term treatment, it is feasible in healthcare centres and, as in our study, over the Internet. By using Internet treatment, the threshold for many adolescents to seek therapeutic help can be lowered (De Bruin et al., 2014) and this modality should therefore be considered as a good alternative for face-to-face insomnia treatment among people of this age group.

To conclude, our study demonstrates the importance of sleep for healthy adolescent functioning and the possibility of improving both sleep and psychopathology by applying a relatively short and accessible treatment programme.

### Supporting information

Additional Supporting Information may be found in the online version of this article:

**Table S1.** Range of scores and percentage clinical scores for the DSM-scales of the Youth Self-Report at each measurement time.

**Table S2.** Multilevel regression analyses for effects of group CBTI and Internet CBTI compared to waitlist on psychopathology, with treatment effects at post-treatment and 2-month follow-up compared to baseline.

**Table S3.** Mediation multilevel regression analyses of effects from group treatment and insomnia symptoms on psychopathology, with participants from group CBTI compared to waiting list.

**Table S4.** Mediation multilevel regression analyses of effects from Internet treatment and insomnia symptoms on psychopathology, with participants from Internet CBTI compared to waiting list.

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The authors have declared that they have no competing or potential conflicts of interest.

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### Key points

- This randomized controlled trial investigated the effects of cognitive behavioural therapy for insomnia (CBTI) on adolescent sleep and psychopathology and whether improvements in psychopathology could be attributed to reduced insomnia.
- Adolescents with insomnia benefited from both group and Internet CBTI for insomnia and sleep complaints, for up to 1 year after treatment, with medium to large ESs.

- Anxiety, depression, ADHD symptoms and oppositional defiant problems were also reduced for up to 1 year after treatment, with large ESs.
- Improvements in several symptoms of psychopathology appeared to be fully or partially mediated by reduced insomnia, indicating that psychopathology can be reduced by improved sleep.
- The conclusion that CBTi for youth can reduce symptoms of both insomnia and psychopathology, provides promising new opportunities for adolescent mental healthcare.

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