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Transdiagnostic Sleep and Circadian Intervention for Adolescents Plus Text Messaging: Randomized Controlled Trial 12-month Follow-up

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Abstract

Objective: The Transdiagnostic Sleep and Circadian Intervention for Youth (TranS-C) was developed to improve sleep and circadian functioning in adolescents. This study examined the 12-month effects for TranS-C compared with psychoeducation (PE). We also investigated if a text messaging intervention can promote maintenance of treatment effects.

Method: At baseline, adolescents (58% female, average age = 14.8 years) with an eveningness chronotype were randomized to TranS-C (n = 89) or PE (n = 87). At 6-month follow-up, participants were randomized to receive text messages that repeated treatment information (n = 47), text messages that prompted recall of treatment information (n = 50), or no text messages (n = 47).

Results: Relative to PE, TranS-C was associated with reduced eveningness ($b = 2.06$, $p = 0.005$, $d = 0.29$) from baseline to 12-month follow-up. TranS-C treatment effects, relative to PE, were augmented by receiving text messages, compared to no text messages, for eveningness from baseline to 12-month follow-up ($b = 1.38$, $p = 0.008$, $d = 0.28$) and from 6- to 12- month follow-up ($b = 1.07$, $p = 0.046$, $d = 0.21$). Neither TranS-C nor text messages were significantly associated with other primary outcomes. TranS-C and text messages were significantly associated with improvement on select secondary sleep and health outcomes through follow-up.

Conclusions: For adolescents with an eveningness chronotype, improved sleep and circadian functioning on selected outcomes were maintained over 12 months for TranS-C compared with PE. Text messages boosted effects of TranS-C through 12-month follow-up.

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Keywords

Adolescent; Health; Sleep; Text messages; Eveningness

The transition to adolescence occurs with the onset of puberty, which initiates a cascade of biological, psychological, and social changes that can have far-reaching consequences beyond adolescence and into adulthood (Blakemore et al., 2010; Forbes & Dahl, 2010). Adolescence is a critical period of development with enhanced risk for the onset of a range of physical and mental health problems (Cicchetti & Rogosch, 2002; Dahl et al., 2018). Among the changes that occur during adolescence is a shift toward an eveningness chronotype, which is associated with the onset of puberty and concomitant changes in levels of pubertal hormones (Carskadon et al., 1993; Dolsen et al., 2019; Roenneberg et al., 2004). Eveningness is characterized by delayed sleep and wake patterns and increased physical and mental activity at night relative to the morning (Carskadon et al., 1993). During adolescence, eveningness often combines with early morning school start times, late night technology use, and reduced parental scaffolding of bedtimes (Bruni et al., 2015; Short et al., 2011), and leads to sleep deprivation and daytime sleepiness (Dolsen et al., 2018; Gradisar et al., 2011).

An eveningness chronotype contributes to vicious cycles that escalate vulnerability and risk across multiple domains of health during adolescence. For example, eveningness is associated with emotional distress including higher negative affect and lower positive affect (Dagys et al., 2012; Dolsen & Harvey, 2018; Gau et al., 2007). Eveningness has also been linked to school-related cognitive difficulties including lower grades and academic underperformance (Díaz-Morales & Escribano, 2015; Saxvig et al., 2012). Behavioral and social problems may be influenced by eveningness as well, and include increased alcohol and substance use, sensation seeking and acting out behavior (Díaz-Morales et al., 2014; Dolsen et al., 2018; Gau et al., 2007; Schlarb et al., 2014). There is also evidence that an eveningness chronotype may be related to physical health risk such as higher body mass index and lower physical activity (Arora & Taheri, 2015; Dolsen et al., 2018). Given the multiple consequences of eveningness during adolescence, the Transdiagnostic Sleep and Circadian Intervention (TranS-C) for youth was developed to improve sleep and circadian functioning and thereby reduce health-related risk (Harvey, 2016; Harvey & Buysse, 2017). As a transdiagnostic treatment, TranS-C addresses the wide range of sleep and circadian problems that occur during adolescence instead of focusing on a specific sleep problem (e.g., insomnia) or sleep problems in a particular disorder (e.g., depression).

In the randomized controlled trial (RCT), for which the 12-month follow-up data are reported in this study, we tested whether TranS-C targets eveningness, improves sleep, and reduces risk in health-related domains from baseline to posttreatment. Relative to psychoeducation (PE), TranS-C was associated with reduced eveningness, an earlier endogenous circadian rhythm, decreased weeknight-weekend discrepancy in total sleep time (TST) and wakeup time, reduced daytime sleepiness, and improved self- and parent-reported sleep from baseline to posttreatment (Harvey et al., 2018). TranS-C was not associated with improvement on the primary or secondary outcomes in health-related domains, except that parent-reported risk in the cognitive domain was reduced. At 6-month

follow-up, improvement for TranS-C was maintained for reduced eveningness, decreased weeknight-weekend discrepancy in wakeup time, and better self-reported sleep (Dong et al., 2020). However, TranS-C treatment effects were not maintained for weeknight-weekend discrepancy for TST, daytime sleepiness, or parent-reported sleep problems (Dong et al., 2020). There is a need to assess treatment outcomes across longer follow up periods (Rith-Najarian et al., 2019), particularly given the potential consequences of sleep problems during this vulnerable period of development. The first goal of this investigation was to establish the effects of TranS-C, compared with PE, through 12-month follow-up.

Given the drop-off in efficacy at 6-month follow-up, the second goal of this study was to identify effective and efficient methods to bolster treatment effects with a text messaging intervention. Text messaging interventions may be an effective adjunct to treatment (Hall et al., 2015; Head et al., 2013), and may also support maintenance of treatment improvement (Schlicker et al., 2018). There is growing evidence that text messaging interventions may improve sleep-related outcomes, but findings have been mixed (Gipson et al., 2018). For example, in one study a sleep-related text messaging intervention for adolescents was not associated with sleep improvement in the full sample, but subgroup analyses indicated that non-Hispanic white adolescents had a one hour increase in sleep duration (Tavernier et al., 2017). Text messaging may be an effective and feasible method of improving adolescent sleep, although further investigation is needed.

The flexibility of text messages provides an opportunity to evaluate how text message characteristics can be optimized to improve outcomes. Existing studies have focused on varying text message frequency or tailoring text messages to participant goals as ways of improving treatment outcome (Hall et al., 2015; Head et al., 2013). Another way of enhancing text messaging interventions may be to incorporate *memory support strategies* within the text messages, which is examined in the current study. There is growing empirical evidence that adding memory support strategies to treatment sessions can improve outcomes (Dong et al., 2017; Harvey et al., 2016). These strategies are then incorporated into treatment-as-usual to support encoding and retrieval of the contents of treatment. Memory support techniques such as *repetition* and *practice remembering* may be especially amenable to the brief format of text messages (Harvey et al., 2014). Repetition text messages could repeat treatment information, which we refer to as PUSH text messages in the current study. Practice remembering text messages could prompt patients to recall a treatment point, which we refer to as PULL text messages in this study. There is some evidence in the cognitive science literature that practice remembering may be more effective than repetition for memory encoding (Karpicke & Roediger, 2007). To the best of our knowledge, previous studies have not systematically compared whether different memory support strategies, such as repetition and practice remembering, can more impact treatment outcomes.

The goal of the present study was to evaluate outcomes from two RCTs conducted in a sample of adolescents with an eveningness chronotype. The first RCT compared TranS-C with PE and the second RCT tested a novel text messaging intervention. The text messaging intervention was tested between the 6- and 12-month follow-up of the TranS-C RCT. The first aim was to examine the effect of TranS-C, compared with PE, on sleep, circadian, and health domain outcomes 12-months following treatment. It was hypothesized that TranS-C

would demonstrate greater improvements than PE on sleep, circadian, and health domain outcomes from baseline to 12-month follow-up. The second aim was to examine the effect of a text messaging intervention on sleep, circadian, and health outcomes for TranS-C compared with PE. Text messages were designed to utilize repetition (PUSH text messages) or practice remembering (PULL text messages). We hypothesized that any text messages (PUSH or PULL text messages), compared with no text messages, would be associated with greater sleep, circadian, and health outcome improvement. We also hypothesized that PULL text messages, compared with PUSH text messages, would be associated with greater sleep, circadian, and health outcome improvement. Given that the text messaging intervention was designed to target memory for treatment, we also evaluated the effect of text messages on treatment recall.

Methods

Participants

The 176 participants for the current study were recruited from January 2013 to February 2016 through advertisements and clinician referrals. Participants and parents/guardians were screened by phone for eligibility. Potentially eligible participants completed an in-person assessment. Eligible participants were randomized in a parallel group design to TranS-C or PE, stratified by age and sex. Assessors were masked to treatment allocation. A computer-generated random number procedure was used to randomize participants and allocations were concealed in individual sealed envelopes. Only the project coordinators involved with the computer-generated randomization and the therapists had knowledge of the treatment allocations. A detailed description of the study procedures can be found elsewhere (Harvey et al., 2018). Participant flow is illustrated in Figure 1. CONSORT requirements for nonpharmacological trials were followed (see Appendix S1; Clinical trials registration: NCT01828320). At the 6-month follow-up assessment, participants were re-randomized using a 3 (PUSH text messages, PULL text messages, or no text messages) by 2 (TranS-C or PE) parallel group design. Only the project coordinator involved with the randomization and the research assistants who sent the text messages had knowledge of the text message treatment allocations and TranS-C and PE treatment allocations. Text messages were sent by research assistants masked to the research hypotheses of this study. Participant flow for the text messaging intervention is illustrated in Figure 2 (Clinical trials registration: NCT02961400).

Inclusion criteria were: (a) age 10–18 years old and attending a class or job by 9:00am at least 3 days per week; (b) fluent in English; (c) able and willing to give informed assent; (d) eveningness for the last 3 months as demonstrated by scoring within the lowest quartile of the Children's Morningness-Eveningness Preferences Scale (CMEP; 27 or lower; Dagys et al., 2012) and a 7-day sleep diary showing a sleep onset time at or later than 10:40pm (10–13 years old), 11:00pm (14–16 years old), and 11:20pm (17–18 years old) at least 3 nights per week (Giannotti et al., 2002; Maslowsky & Ozer, 2014); and (e) 'at-risk' in at least one of the five health domains (see Appendix S2). Exclusion criteria were: (a) physical or neurological illness disease related to the onset of the sleep disturbance; (b) obstructive sleep apnea, restless legs syndrome, or periodic limb movement disorder (those presented with

provisional diagnoses of these disorders were referred for a polysomnography evaluation at the parent's discretion and were enrolled only if the diagnosis was disconfirmed); (c) pervasive developmental disorder; (d) bipolar disorder, schizophrenia, or another current disorder if there was a risk of harm if treatment was delayed; (e) melatonin within 2 weeks of the assessment or any medication changes within 4 weeks of the assessment; and (f) current substance dependence or suicide risk sufficient to preclude treatment on an outpatient basis. The study was approved by the University Institutional Review Board. Guardians of participants provided informed consent and participants provided informed assent.

Treatments

Participants were randomized to TranS-C or PE. Both treatments included six sessions delivered by doctoral or masters-level therapists in a university clinic during the school year. On average, participants in TranS-C attended 5.90 sessions (SD = 0.30) and participants in PE attended 5.89 sessions (SD = 0.37). There were no significant differences in number of sessions attended by treatment condition, $t(125) = 0.20$, $p = 0.842$.

Transdiagnostic Sleep and Circadian Intervention for Youth (TranS-C).—As described elsewhere (Harvey, 2016; Harvey & Buysse, 2017), TranS-C is a modular approach that allows the treatment sessions to be focused on the specific sleep problem experienced by each patient. The goal is to reverse maintaining psychosocial, behavioral and cognitive processes via four cross-cutting modules, four core modules, and seven optional modules. The four Cross Cutting Modules are: case formulation; education; behavior change and motivation; and goal setting. The four Core Modules are: establishing regular sleep−wake times including learning a wind-down and wake-up routine; improving daytime functioning; correcting unhelpful sleep-related beliefs; and maintenance of behavior change. The Optional Modules are: improving sleep efficiency; reducing time in bed; dealing with delayed or advanced phase; reducing sleep-related worry/vigilance; promoting compliance with continuous positive airway pressure or exposure therapy for claustrophobic reactions to continuous positive airway pressure; and negotiating sleep in a complicated environment and reducing nightmares.

Psychoeducation (PE).—PE is an active control condition associated with sleep improvement (Harvey et al., 2015). As described elsewhere (Harvey et al., 2018), PE provided information on the interrelationship between sleep, stress, diet, health, exercise, accidents, and mood. Participants were also given the choice of sampling meditation, yoga, and/or outdoors appreciation activities. PE did not facilitate or plan for behavior change.

Text messaging intervention.—Two text messaging methods were tested. Participants in the PUSH condition were sent text messages that repeated treatment information (e.g., "If your bedtime gets too late, there are ways to get back on track. Try to make your bedtime earlier by 20 to 30 minutes each week."). Participants in the PULL condition were sent text messages that repeated a treatment point and prompted participants to recall a treatment point (e.g., "Relaxing before bed signals to your body and brain that it's time for sleep. What do you do to wind down before bed?"). The text messages were designed by the

first and last author based on the treatment contents of TranS-C and PE. At the 6-month follow-up assessment, participants were randomized using a 3 (PUSH text messages, PULL text messages, or no text messages) by 2 (TranS-C or PE) design.

Twenty-four text messages were sent once per week between the 6-month and 12-month follow-up assessments. Text messages were manually sent by a research assistant between 4pm and 9pm on weekdays and weekends. There were 12 unique text messages for each combination of text messaging condition and treatment condition (see Appendix S3 for text messages). Participants received the same text message twice during the study period. On average, text messages contained 24.6 words and 133.6 characters, and there no differences between text message conditions for word count ($F(3, 44) = 1.47$, $p = 0.24$) or character count ($F(3, 44) = 0.22$, $p = 0.88$). The average reading level for the text messages was grade 3.7 and there were no differences between groups ($F(3, 44) = 1.52$, $p = 0.22$).

Materials and Procedure

Pre-specified outcomes.—For the RCT examining 12-month TranS-C treatment effects (Clinical trials registration: NCT01828320), there were eight primary outcomes (weeknight total sleep time (TST); weeknight bedtime; morningness-eveningness preference measured via CMEP; composite scores for emotional, cognitive, behavioral, social and physical health domains) and 11 secondary outcomes (sleepiness; the Pittsburgh Sleep Quality Index (PSQI); the discrepancy between weeknight and weekends for TST, bedtime, and waketime; Child Behavior Checklist (CBCL) composites for sleep, emotional, cognitive, behavioral, social, and physical health domains). There were six additional secondary outcomes that were collected at baseline and posttreatment only and have been previously reported (Harvey et al., 2018).

For the RCT evaluating the text messaging intervention (Clinical trials registration: NCT02961400), there were four primary outcomes (weeknight TST; weeknight bedtime; morningness-eveningness preference measured via CMEP; free recall) and 12 secondary outcomes (sleepiness; the PSQI; the discrepancy between weeknight and weekends for TST, bedtime, and waketime; CBCL composites for sleep, emotional, cognitive, behavioral, social and physical health domains; text message evaluation).

Measures.—All measures described below were collected at baseline, posttreatment, 6-month follow-up, and 12-month follow-up assessments, except where otherwise specified.

Sleep Diary.: Sleep diary was collected from adolescents each morning by phone for one week. The sleep diary was based on the Expanded Consensus Sleep Diary for Morning (Carney et al., 2012). The following variables were measured using the sleep diary: 1) weeknight TST, calculated as “time getting into bed” - sleep onset latency - wake after sleep onset - terminal wakefulness; 2) weeknight bedtime, using response to “time getting into bed”; 3) weeknight-weekend discrepancy in TST; 4) weeknight-weekend discrepancy in bedtime; and 5) weeknight-weekend discrepancy in wakeup time (time of final awakening). Sleep diary has good-to-excellent reliability for bedtime, sleep onset latency, and TST in adolescents (Short et al., 2017).

Children's Morningness-Eveningness Preference Scale (CMEP).: The CMEP is a 10-item measure of circadian preference (Carskadon et al., 1993). The scores range from 10 to 43 with higher scores indicating greater eveningness. The CMEP has adequate reliability and good validity in adolescent samples (Carskadon et al., 1991, 1993; Kim et al., 2002). The CMEP had excellent internal consistency in the present study (Cronbach's $\alpha = 0.93$).

Sleepiness Scale.: The sleepiness scale contains 10 items from the School Sleep Habits Survey (SSHB; Wolfson & Carskadon, 1998). Items were rated on a 4-point scale (0 = No, 1 = Struggled to Stay Awake, 2 = Fallen Asleep, 3 = Both Struggled to Stay Awake and Fallen Asleep). The SSHB has adequate reliability and has been validated with sleep diary and actigraphy in adolescents (Wolfson et al., 2003; Wolfson & Carskadon, 1998). The SSHB had acceptable internal consistency in the present study (Cronbach's $\alpha = 0.72$).

Pittsburgh Sleep Quality Index (PSQI).: The PSQI is a 19-item measure with 7 component sub-scores, and the sum of these sub-scores produces one global score (Buysse et al., 1989). The global score ranges from 0 to 21 with higher scores indicating worse sleep quality in the past month. The PSQI has adequate internal consistency, adequate test-retest reliability, and good convergent and divergent validity (de la Vega et al., 2015). The PSQI had acceptable internal consistency in the present study (Cronbach's $\alpha = 0.76$).

Child Behavior Checklist (CBCL) Sleep Composite.: A CBCL sleep composite was calculated based on seven items on the parent-reported CBCL that measures sleep functioning (Becker et al., 2015). Items were rated on a 3-point scale (0–2 scale). The CBCL has demonstrated excellent internal consistency, test-retest reliability, and validity (Achenbach & Rescorla, 2001; Gomez et al., 2014). The CBCL had good internal consistency in the present study (Cronbach's $\alpha = 0.86$).

Health domain outcomes.: Youth- and parent-reported health domain composite scores were created to indicate functioning in the emotional, cognitive, behavioral, social, and physical health domains. The Parent-Reported Composite Risk Scores were derived from parent responses to the CBCL and included the five health domains. Further detail and specific measures for each domain are in Appendix S4.

Patient Recall Task (Lee & Harvey, 2015).: A free recall task was completed by participants at posttreatment, 6-month follow-up, and 12-month follow-up. Participants were given a sheet of paper and given 10 minutes to recall treatment information. Two coders rated each free recall response by recall instance, which was defined by a period or paragraph break. Each treatment point was coded and repeated treatment points within the same recall task were counted once. There was 83.4% agreement between two independent coders ($\kappa = 0.68$, ICC = 0.84). A consensus recall score was calculated by averaging the two coder ratings (higher ratings indicate greater recall; range: 0–12.5).

Text Message Evaluation.: A seven-item measure assessing participant experiences with the text messaging intervention was administered at the 12-month follow-up assessment (Table S1). Each item was rated on a 9-point Likert scale (1 = Not at all, 9 = Very much). The text messaging evaluation had good internal consistency (Cronbach's $\alpha = 0.87$). A total

evaluation score was created by calculating the mean of all 7 items. Table S1 displays means and standard deviations for the text message evaluation. Participants in the no text message condition did not complete the text message evaluation.

Statistical analysis

For the RCT comparing TranS-C and PE (Clinical trials registration: NCT01828320), an a priori power analysis indicated that 69 participants per condition were needed to achieve at least 80% power to observe an average effect size of $d = 0.48$ and two-sided significance of 0.05. The recruitment allowed for at least 20% more for potential attrition. The final sample size for the analysis was 176 for intent-to-treat analysis.

This study used multilevel modeling (MLM) with restricted maximum likelihood estimation using the *lmer* function in R (Bates et al., 2015). All analyses were adjusted for age and sex, which were the stratification factors used during the randomization. An intent-to-treat method was used and missing at random was assumed. For aim one, the fixed component of the MLM included covariates (age and sex), a categorical indicator for time (Baseline, Posttreatment, 6-month follow-up, 12-month follow-up), a categorical indicator for treatment condition (PE, TranS-C), a categorical indicator for any text messaging condition (No text messages = −2, PUSH text messages = 1, PULL text messages = 1), a categorical indicator for PULL vs. PUSH text messages (No text messages = 0, PUSH text messages = −1, PULL text messages = 1), and a two-way treatment by time interaction term. For aim two, the MLM included the same fixed effects as aim one and also included two three-way time by treatment by text messaging interaction terms for each text messaging contrast as well as all lower order two-way interaction terms. The random part of the model included a subject-specific random intercept and a subject-specific error term.

Multiple comparisons were corrected using the Benjamini-Hochberg (1995) procedure with a 15% false discovery rate for six subgroups of analyses for aim 1: effects of TranS-C vs. PE on change from baseline to 12-month follow-up for primary outcomes (1) and secondary outcomes (2), effects of TranS-C vs. PE on change from posttreatment to 12-month follow-up for primary (3) and secondary outcomes (4), and effects of TranS-C vs. PE on change from 6- to 12-month follow-up for primary (5) and secondary outcomes (6). There were eight subgroups of analyses for aim 2: effects of receiving text messages on change from 6- to 12-month follow-up for primary outcomes (1) and secondary outcomes (2), effects of PULL vs. PUSH text messages on change from 6- to 12-month follow-up for primary (3) and secondary outcomes (4), effects of any text messages on change from baseline to 12-month follow-up for primary outcomes (5) and secondary outcomes (6), and effects of PULL vs. PUSH text messages on change from baseline to 12-month follow-up for primary (7) and secondary outcomes (8). The Benjamini-Hochberg critical values are reported in Tables S2, S3, and S4.

Results

Participant characteristics

Table 1 presents baseline demographic and clinical characteristics. Table S5 displays means and standard deviations for primary and secondary outcomes for TranS-C relative to PE. Tables S6 and S7 present means and standard deviations for primary and secondary outcomes for the text messaging intervention. The attrition rate was 5.68% (n = 10) following treatment, 7.95% (n = 14) between posttreatment and 6-month follow-up, and 13.64% (n = 24) between the 6-month and 12-month follow-up (Figure 1). Attrition was not significantly different between treatment groups at 12-month follow-up (TranS-C: 13 [14.61%], PE: 11 [12.64%]; $\chi^2(1) = 0.03$, $p = 0.873$). The attrition rate from the text messaging intervention was 4.2% (n = 8; Figure 2) and was not significantly different between text messaging groups at 12-month follow-up (PUSH: 3 [2.08%], PULL: 5 [3.47%], No text messages: 0 [0.0%]; $\chi^2(2) = 4.71$, $p = 0.096$).

Aim one: TranS-C 12-month follow-up effects

Primary outcomes.—Relative to PE, TranS-C was associated with a greater reduction in eveningness as measured by the CMEP from baseline through 12-month follow-up ($b = 2.06$, $p = 0.005$, $d = 0.29$, 95% confidence interval (CI) = 0.09, 0.49). There was an advantage of PE relative to TranS-C for weeknight bedtime from baseline to 12-month follow-up ($b = 0.38$, $p = 0.032$, $d = 0.22$, 95% CI = 0.02, 0.42). There were no significant differences between TranS-C and PE through 12-month follow-up for weeknight TST, the emotional domain composite, cognitive domain composite, behavioral domain composite, social domain composite, and the physical health domain composite (Table S2).

Secondary outcomes.—Weeknight-weekend discrepancy for wakeup time showed a significant improvement for TranS-C relative to PE from baseline to 12-month follow-up ($b = 1.02$, $p = 0.001$, $d = 0.35$, 95% CI = 0.15, 0.56). There was an advantage of PE relative to TranS-C for parent-reported cognitive domain risk from posttreatment to 12-month follow-up ($b = 0.48$, $p = 0.022$, $d = 0.24$, 95% CI = 0.03, 0.44). There were no significant differences between TranS-C and PE through 12-month follow-up for sleepiness, the PSQI, weeknight-weekend discrepancy for TST and bedtime, or the parent reported CBCL composites (Table S2).

Aim two: Text messaging intervention

Primary outcomes.—TranS-C treatment effects, relative to PE, for reduced eveningness were further enhanced for participants who received text messages (PUSH or PULL text messages), compared to no text messages, from baseline through 12-month follow-up ($b = 1.38$, $p = 0.008$, $d = 0.28$, 95% CI = 0.07, 0.48) and from 6- to 12-month follow-up ($b = 1.07$, $p = 0.046$, $d = 0.21$, 95% CI = 0.00, 0.41). There was no significant effect of receiving PUSH or PULL text messages, compared with no text messages, for weeknight TST, weeknight bedtime, or free recall (Table S3). There were no significant differences for PULL relative to PUSH text messages for the four primary outcomes (Table S4).

Secondary outcomes.—For participants who received text messages (PUSH or PULL text messages), compared with no text messages, weeknight-weekend discrepancy for bedtime showed an improvement for TranS-C relative to PE from posttreatment to 12-month follow-up ($b = -0.48$, $p = 0.029$, $d = -0.23$, 95% CI = −0.43, −0.02). TranS-C, compared with PE, was associated with lower risk on the parent-reported physical health composite for participants who received text messages (PUSH or PULL text messages), compared with no text messages, from baseline to 12-month follow-up ($b = -0.35$, $p = 0.001$, $d = -0.34$, 95% CI = −0.55, −0.14) and from 6- to 12-month follow-up ($b = -0.24$, $p = 0.029$, $d = -0.23$, 95% CI = −0.43, −0.02). There was an advantage of PE over TranS-C for reduced sleepiness for participants who received text messages (PUSH or PULL), compared with no text messages, from posttreatment to 12-month follow-up ($b = 1.20$, $p = 0.032$, $d = 0.22$, 95% CI = 0.02, 0.43). There was no additional benefit of TranS-C relative to PE for participants who received PUSH or PULL text messages, compared with, no text messages through 12-month follow-up for the PSQI, the discrepancy between weeknight and weekends for TST, bedtime, and waketime, and the parent reported CBCL composites (Table S3). Additionally, there were no significant differences for PULL relative to PUSH text messages for the eleven secondary outcomes (Table S4).

Table S1 displays means, standard deviations, and test statistics for the text message evaluation. The overall acceptability score was 5.07 (SD = 1.78). There were no significant differences between text messaging conditions for the total evaluation score, $F(1, 70) = 3.06$, $p = 0.085$. There was a significant text messaging by treatment interaction for text message approval, $F(1,69) = 6.10$, $p = 0.016$. Participants in PE+PULL liked receiving text messages significantly less than PE+PUSH ($t(69) = -3.48$, $p = 0.001$, $d = -0.84$, 95% CI = −1.34, −0.34), TranS-C+PULL ($t(69) = -2.927$, $p = 0.005$, $d = -0.71$, 95% CI = −1.20, −0.22), or TranS-C+PUSH ($t(69) = -2.999$, $p = 0.004$, $d = -0.73$, 95% CI = −1.22, −0.23). There was a significant text messaging by treatment interaction for the acceptability of being sent a text message after each session, $F(1,69) = 8.31$, $p = 0.005$. Participants in PE+PULL rated receiving text messages after each session as less acceptable than PE+PUSH ($t(70) = -2.576$, $p = 0.012$, $d = -0.62$, 95% CI = −1.09, −0.13) or TranS-C+PULL ($t(70) = -2.739$, $p = 0.008$, $d = -0.65$, 95% CI = −1.13, −0.17).

Discussion

This study reports on findings from two different RCTs conducted in a sample of adolescents with an eveningness chronotype. The first RCT compared TranS-C with PE, and the current study examined the 12-month treatment effects of TranS-C for the first time (aim one). The second RCT tested a novel text messaging intervention for sleep and circadian functioning (aim two), and the present study is the first to report outcomes of this RCT. The text messaging intervention was tested within the TranS-C RCT between the 6- and 12-month follow-up.

Regarding aim one primary outcomes, TranS-C, compared with PE, maintained improvement for eveningness through 12-month follow-up with a small-medium effect size. An eveningness chronotype contributes to risk across multiple physical and mental health domains critical to adolescent development. We have previously shown that TranS-C reduces

eveningness at posttreatment and 6-month follow-up (Dong et al., 2020; Harvey et al., 2018). In this RCT, we demonstrated that eveningness is modifiable and that improvement persists 12-months following treatment. This study adds to the growing literature on the long-term benefits of cognitive and behavioral treatments for adolescent sleep problems (Blake et al., 2016, 2017; de Bruin et al., 2018). These data suggest that a psychosocial approach, like TranS-C, holds promise for promoting lasting change in circadian preference.

TranS-C, relative to PE, was not associated with improvement on the other primary outcomes for aim one through 12-month follow-up including weeknight TST, weeknight bedtime, or the five health domains. Regarding weeknight TST, average change may not best reflect treatment improvement given that we included youth who exhibited long and short TST, which are both associated with risk (Liu et al., 2020). Although TranS-C did not significantly impact weeknight bedtime, there was significant improvement on this measure for PE. PE was an active control condition that provided sleep-related information and has previously been shown to improve sleep and mood outcomes (Harvey et al., 2015). Regarding the primary health outcomes, TranS-C may indirectly reduce risk in the five health domains by improving sleep and circadian functioning. In a mediation analysis there was evidence that improving eveningness has important downstream benefits for reducing risk across the five health domains (Dong et al., 2019).

For the secondary outcomes for aim one, TranS-C treatment effects were maintained through 12-month follow-up with a small-medium effect size for sleep diary measured weeknight-weekend discrepancy for wakeup time. The difference between weeknight and weekend wakeup time decreased by 29.4 minutes from baseline to 12-month follow-up for TranS-C and increased by 23.6 minutes during the same period for PE. A discrepancy between sleep timing on weeknights relative to weekends (i.e., social jetlag) has been linked to lower grades and depression symptoms among adolescents (Levandovski et al., 2011). TranS-C treatment effects, compared with PE, were associated with small, non-significant effect sizes through 12-month follow-up for the other secondary outcomes.

Overall, TranS-C was associated with modest sustained improvement for select sleep and circadian outcomes through 12-month follow-up. However, TranS-C was not significantly associated with most of the primary and secondary outcomes following treatment or through 12-month follow-up. As noted, TranS-C was compared with an active control condition (Harvey et al., 2015), which may have contributed to fewer between-group effects. In the current study PE was associated with improved weeknight bedtime and parent-reported cognitive risk. Additionally, TranS-C was designed as a 6-session intervention in order to balance an effective “dose” of psychotherapy with the multiple familial, social, and academic obligations of adolescents. A review of RCTs suggests that an average of 12.7 sessions may be needed for at least half of patients to demonstrate improvement (Hansen et al., 2002). Thus, it was notable that any improvement was observed given the length of TranS-C. There may be some adolescents who differentially benefit from treatment. In a secondary analysis of this RCT, we examined baseline levels of inflammation as moderators of treatment and observed that adolescents with lower baseline inflammation had improved treatment response (Dolsen & Harvey, 2021). More generally, this pattern of findings highlights a need for innovations focused in sustaining outcomes longer term.

Example include infusing the intervention with the science of habit formation (Harvey et al., 2021) and improving memory for treatment (Harvey et al., 2016).

The second aim of this study was to evaluate a text messaging intervention as an adjunctive treatment to TranS-C. At the outset, we acknowledge that the text messaging intervention was conducted in the context of a study not originally designed or powered to evaluate multiple randomizations. Overall, participants rated the acceptability of the text messaging intervention as greater than neutral with no differences between text message conditions. Regarding the four primary outcomes, text messages were associated with a small-medium effect size improvement in eveningness above and beyond the advantage of TranS-C compared to PE from baseline to 12-month follow-up as well as from 6- to 12-month follow-up, which was the active period of the text messaging intervention. Adolescence is a developmental period of enhanced vulnerability for physical and mental health problems (Cicchetti & Rogosch, 2002; Dahl et al., 2018), and an eveningness chronotype is associated with increased risk for behavioral problems, alcohol and substance use, and depressive symptoms (Dagys et al., 2012; Dolsen & Harvey, 2018; Gau et al., 2007). This study adds to the literature on the efficacy of text messaging interventions (Hall et al., 2015; Head et al., 2013; Tavernier et al., 2017), and extends prior research by showing that the addition of text messages to a transdiagnostic sleep and circadian intervention can promote reduced eveningness among adolescents.

For the secondary outcomes, there was an advantage of text messages over no text messages on change for weeknight-weekend discrepancy for bedtime and parent-reported physical health. The text messaging intervention did not enhance TranS-C treatment effects for the other secondary outcomes. These findings are notable because TranS-C did not have an impact on weeknight-weekend discrepancy for bedtime or the physical health domain (Dong et al., 2020; Harvey et al., 2018), and may suggest that a text messaging intervention can boost treatment non-response for select outcomes.

Text messages may also boost the efficacy of PE. Participants in PE, compared with TranS-C, who received text messages, compared with no text messages, had a greater reduction in sleepiness from posttreatment to 12-month follow-up. PE provided sleep education but did not facilitate behavior change. It is possible that adolescents in PE developed their own sleep-related goals, and text messages containing reminders of sleep and health information may have cued behavioral change for these participants. Additional research is needed regarding the types of text messages that may be most beneficial for individuals in a psychoeducation-only treatment given that participants in PE rated receiving PULL text messages as less acceptable than receiving PUSH text messages.

The text messaging RCT also evaluated whether text message characteristics can be optimized to improve outcome. The design of the PULL and PUSH text message conditions was informed by the growing literature demonstrating that memory support strategies may enhance treatment outcomes (Dong et al., 2017; Harvey et al., 2016). We did not find significant differences between PULL and PUSH text messages for primary or secondary outcomes. Furthermore, memory for treatment does not appear to be the mechanism of action for the text messaging intervention, as change in treatment recall (primary outcome)

was associated with non-significant, small-medium effect size decreases between 6- and 12-month follow-up. One potential explanation is that participants responded to only 28.0% of text message prompts to recall treatment information (i.e., PULL text messages), and thus many participants may not have benefited from practice remembering. Additionally, all PULL text messages included a prompt to recall treatment information, and participants may have habituated to receiving a recall prompt in every text message. Future studies should examine if varying the frequency of recall prompts can increase participant response rate and subsequent memory for treatment.

There were several limitations. First, the text messaging intervention occurred during the follow-up period for the RCT that compared TranS-C and PE. Although statistical analyses comparing TranS-C and PE controlled for the text messaging intervention, it is not possible to completely separate the TranS-C and PE treatment effects from the text messaging intervention effects. Second, the text messaging intervention was conducted in the context of a study that was powered for comparisons between two treatment groups. The text messaging intervention may be underpowered given that participants in TranS-C and PE were further randomized to three text messaging conditions. Hence, caution is warranted regarding the interpretation and generalizability of the text messaging effects. Third, participants in each treatment condition received the same standardized text messages rather than text messages tailored to their individual sleep goals. Although standardized text messages have been shown to more effectively maintain treatment effects compared with individually-tailored text messages in adults with depression (Schlicker et al., 2018), future studies should compare standardized text messages to personalized text messages for sleep outcomes among adolescents. Last, this study had multiple inclusion and exclusion criteria that may limit the generalizability of the present findings to more heterogenous samples.

Adolescence is a developmental period associated with significant risk as well as opportunities to thrive. The delay in sleep and wake patterns toward an eveningness chronotype is a potentially modifiable contributor to risk and vulnerability. This study reports on RCT outcomes from two interventions designed to target sleep, eveningness, and risk across multiple health domains relevant to adolescent development. This study provides evidence for the first time that TranS-C treatment gains were maintained through 12-month follow-up, compared with PE, for improved eveningness and reduced weeknight-weekend discrepancy for wakeup time. TranS-C treatment effects were not significant through 12-month follow-up for the other primary and secondary outcomes. This study is also the first to report findings from an RCT that tested a novel text messaging intervention conducted between the 6- and 12-month follow-up of the TranS-C RCT. There was evidence that receiving text messages may promote maintenance of improved eveningness as well as boost treatment effects for the weeknight-weekend discrepancy in bedtime and parent-reported physical health risk. The text messaging intervention was not associated with significant change on other primary or secondary outcomes. The possible benefits of text messaging interventions for augmenting interventions, such as TranS-C, are far-reaching given that text messaging is inexpensive, simple, and ubiquitous.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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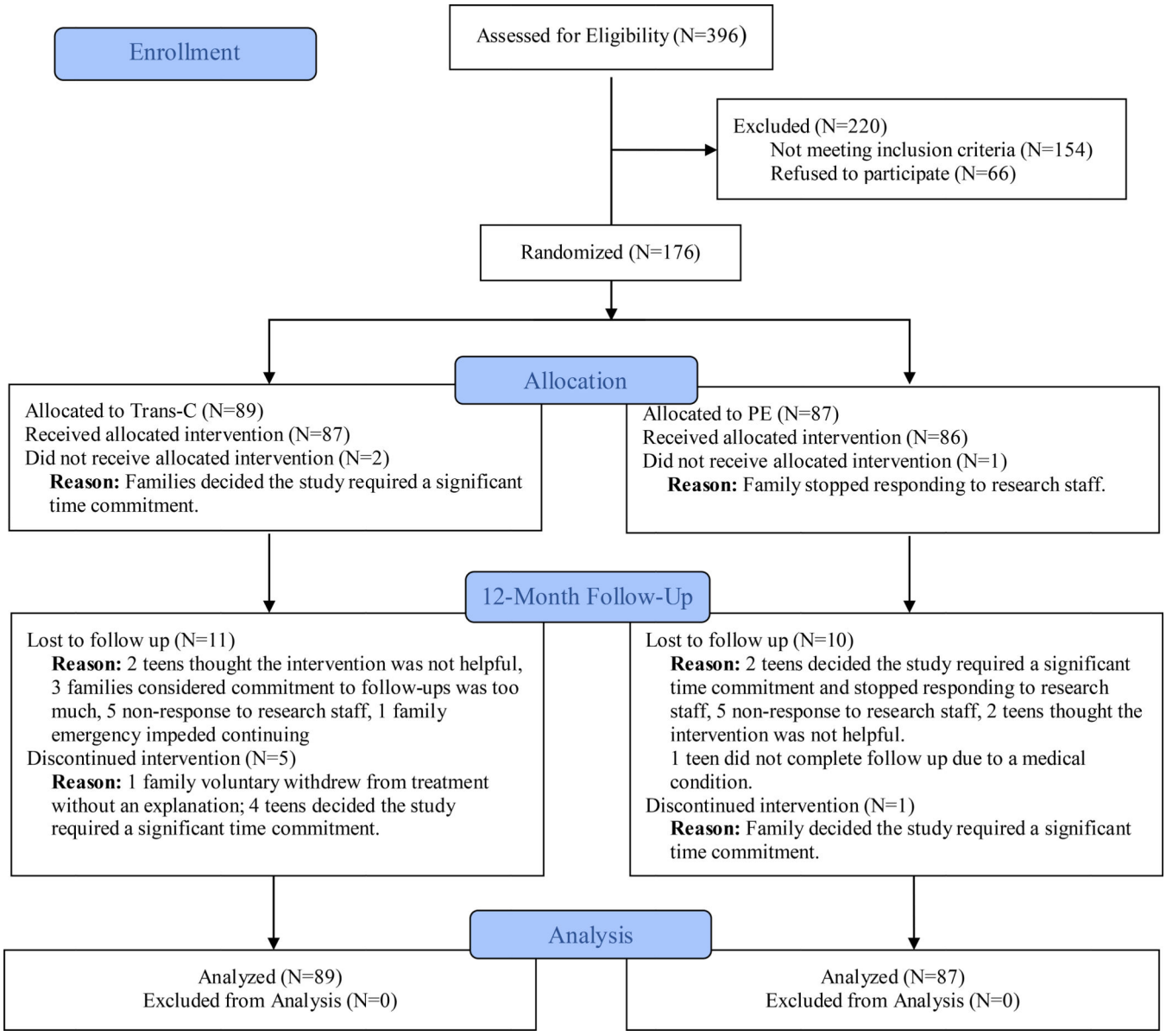

Figure 1.
CONSORT diagram illustrating the flow of participants through the study.

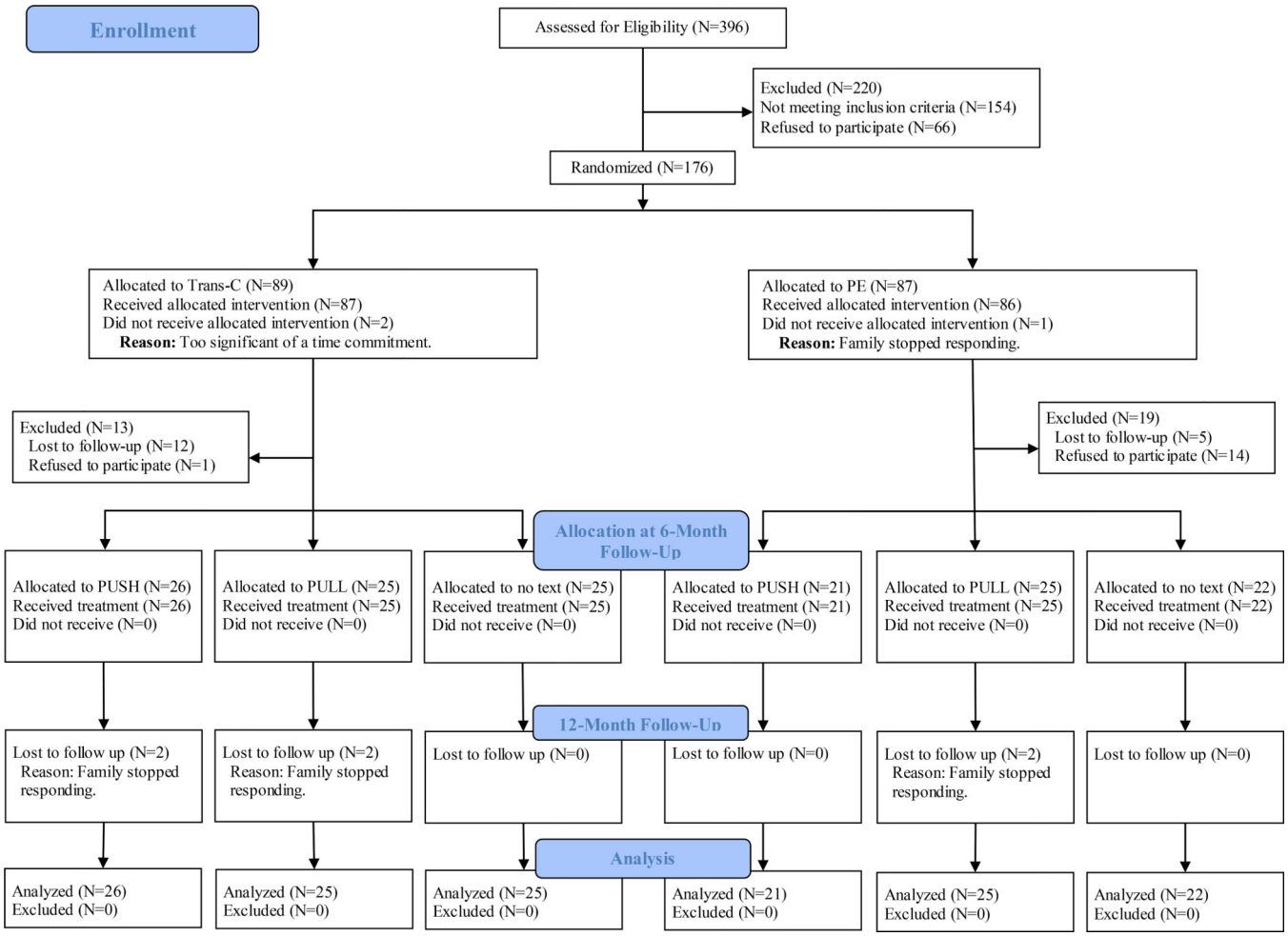

Figure 2.
CONSORT diagram illustrating the flow of participants in the text messaging intervention.

Table 1.

Baseline demographic and clinical characteristics of study participants.

Characteristic	PUSH text messages		PULL text messages		No text messages	
	TranS-C	PE	TranS-C	PE	TranS-C	PE
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
Female	15 (57.7%)	12 (57.1%)	15 (60.0%)	12 (48.0%)	11 (44.0%)	13 (59.1%)
Male	11 (42.3%)	9 (42.9%)	10 (40.0%)	13 (52.0%)	14 (56.0%)	9 (40.9%)
Ethnicity						
Hispanic or Latino	5 (19.2%)	5 (25.0%)	5 (20.0%)	1 (4.5%)	2 (8.3%)	3 (13.6%)
Not Hispanic or Latino	21 (80.8%)	15 (75.0%)	20 (80.0%)	21 (95.5%)	22 (91.7%)	19 (86.4%)
Race (adolescent)						
Caucasian	14 (58.3%)	10 (50.0%)	16 (66.7%)	18 (75.0%)	18 (72.0%)	14 (66.7%)
African American/Black	1 (4.2%)	3 (15.0%)	2 (8.3%)	0 (0.0%)	0 (0.0%)	4 (19.0%)
American Indian or Alaskan Native	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Asian	3 (12.5%)	2 (10.0%)	4 (16.7%)	2 (8.3%)	3 (12.0%)	1 (4.8%)
Native Hawaiian or Other Pacific Islander	1 (4.2%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (4.0%)	0 (0.0%)
Refused to answer	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Unknown	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Mixed Race	5 (20.8%)	5 (25.0%)	2 (8.3%)	4 (16.7%)	3 (12.0%)	2 (9.5%)
Family annual income						
1–10,000	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (4.2%)	0 (0.0%)	0 (0.0%)
10,001–20,000	0 (0.0%)	1 (5.0%)	1 (4.2%)	0 (0.0%)	0 (0.0%)	2 (9.1%)
20,001–30,000	1 (3.8%)	2 (10.0%)	0 (0.0%)	1 (4.2%)	1 (4.3%)	0 (0.0%)
30,000–40,000	0 (0.0%)	1 (5.0%)	0 (0.0%)	1 (4.2%)	0 (0.0%)	1 (4.5%)
40,001–50,000	2 (7.7%)	1 (5.0%)	3 (12.5%)	0 (0.0%)	2 (8.7%)	2 (9.1%)
50,001–60,000	3 (3.8%)	0 (10.0%)	1 (4.2%)	1 (4.2%)	2 (4.3%)	0 (0.0%)
60,001–70,000	1 (7.7%)	2 (0.0%)	1 (8.3%)	1 (12.5%)	1 (0.0%)	0 (0.0%)
70,001–80,000	2 (7.7%)	0 (0.0%)	2 (4.2%)	3 (8.3%)	0 (0.0%)	0 (0.0%)
80,001–90,000	2 (11.5%)	0 (0.0%)	1 (4.2%)	2 (8.3%)	0 (4.3%)	0 (9.1%)
90,001–100,000	3 (46.2%)	0 (65.0%)	1 (58.3%)	2 (50.0%)	1 (69.6%)	2 (68.2%)
100,000+	12 (42.3%)	13 (45.0%)	14 (54.2%)	12 (54.2%)	16 (39.1%)	15 (36.4%)

Characteristic	PUSH text messages		PULL text messages		No text messages	
	TranS-C	PE	TranS-C	PE	TranS-C	PE
Current grade (at baseline)						
5	2 (7.7%)	0 (0.0%)	1 (4.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
6	2 (7.7%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (4.0%)	2 (9.1%)
7	3 (11.5%)	1 (4.8%)	0 (0.0%)	3 (12.0%)	2 (8.0%)	1 (4.5%)
8	3 (11.5%)	5 (23.8%)	5 (20.0%)	3 (12.0%)	2 (8.0%)	4 (18.2%)
9	5 (19.2%)	3 (14.3%)	8 (32.0%)	5 (20.0%)	2 (8.0%)	4 (18.2%)
10	8 (30.8%)	4 (19.0%)	5 (20.0%)	9 (36.0%)	5 (20.0%)	8 (36.4%)
11	1 (3.8%)	3 (14.3%)	3 (12.0%)	3 (12.0%)	6 (24.0%)	1 (4.5%)
12	2 (7.7%)	5 (23.8%)	3 (12.0%)	2 (8.0%)	6 (24.0%)	2 (9.1%)
College	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (4.0%)	0 (0.0%)
Any current KSADS Dx (teen report)	11 (45.8%)	9 (50.0%)	13 (54.2%)	13 (59.1%)	9 (39.1%)	8 (36.4%)
Any past KSADS Dx (teen report)	10 (41.7%)	12 (66.7%)	16 (66.7%)	12 (52.2%)	10 (43.5%)	8 (36.4%)
Any current KSADS Dx (parent report)	6 (25.0%)	9 (45.0%)	11 (44.0%)	14 (60.9%)	6 (26.1%)	9 (40.9%)
Any past KSADS Dx (parent report)	6 (24.0%)	8 (44.4%)	12 (48.0%)	11 (47.8%)	6 (27.3%)	11 (50.0%)
Age (years)	14.0 (2.0)	15.3 (1.8)	14.9 (1.6)	14.8 (1.4)	15.4 (1.9)	14.4 (1.5)

Note: K-SADS: Schedule for Affective Disorders and Schizophrenia for School-Age Children.

[a] teen report

[b] parent report.