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Prospective Measurement of Daily Health Behaviors: Modeling Temporal Patterns in Missing Data, Sexual Behavior, and Substance Use in an Online Daily Diary Study of Gay and Bisexual Men

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Abstract

Daily diary and other intensive longitudinal methods are increasingly being used to investigate fluctuations in psychological and behavioral processes. To inform the development of this methodology, we sought to explore predictors of and patterns in diary compliance and behavioral reports. We used multilevel modeling to analyze data from an online daily diary study of 371 gay and bisexual men focused on sexual behavior and substance use. We found that greater education and older age as well as lower frequency of substance use were associated with higher compliance. Using polynomial and trigonometric functions, we found evidence for circaseptan patterns in compliance, sexual behavior, and substance use, as well as linear declines in compliance and behavior over time. The results suggest potential sources of non-random patterns of missing data and suggest that trigonometric terms provide a similar but more parsimonious investigation of circaseptan rhythms than do third-order polynomial terms.

Keywords

Daily diary; Sexual behavior; Substance use; Missing data; Multilevel modeling; Polynomial

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Introduction

Daily diary methods, like other techniques for capturing daily or momentary data (e.g. ecological momentary assessment, ambulatory assessment) are increasingly being used as research tools to capture behavioral data along with processes that are believed to influence these behaviors [1–3]. These methods are used to assess a myriad of health behaviors and outcomes, ranging from physical activity, diet, medication adherence for chronic health conditions, evaluations of side effects of drugs or vaccines, smoking, stress, emotion, mood, and mental health as a result of their ability to improve upon biases inherent to retrospective data collection [4–15]. The use of diaries is growing, particularly within research that seeks to understand discrete behaviors such as sexual behavior or substance use [16–21]. Research focused on gay and bisexual men (GBM) has suggested that prospective diary methods are a feasible approach and are more likely to accurately capture data on sexual behavior than retrospective assessments that require participants to aggregate and estimate frequency and patterns over as specified period of time [19, 22], particularly for behaviors that occur frequently and may otherwise be forgotten [23].

Diary data collection methods have evolved from paper-and-pencil forms and telephone interviewing systems to more advanced interactive voice response systems and web-based surveys that hold several advantages in improving data collection [4, 11, 22, 24–27]. Web-based data collection tools conveniently capture behavioral data in near real time and are feasible enough to be used repeatedly over long periods of time to gather longitudinal data. Surveys are typically programmable to accommodate various assessment schedules (e.g., daily, weekly), offer ways to improve data quality and minimize missing data and inconsistent self-reports through logic checks and complex branching, and have the potential to minimize socially desirable responses, reduce recall bias, and eliminate back-filling [28]. Data are recorded and accessible instantly and thus can be utilized to develop tailored interventions or provide feedback to participants, when necessary [29]. In addition, web-based systems can capture entries that are verifiable with a date and time stamp, gather geolocation and other location-based data, and even collect environmental (e.g., ambient noise, temperature) and physiological (e.g., heart rate, physical activity) information when combined with appropriate sensors. All of these issues are key in reducing measurement error, particularly within research on topics that are considered personal and sensitive in nature, such as sexual behavior and substance use [22].

Although there are key advantages to using diary methods, they present some unique methodological and statistical issues of importance. One primary concern with diary methods is that of missing data due to non-compliance [29–32]. Although diaries improve upon other biases inherent in retrospective data collection (e.g., recall bias), diary and similar methods can introduce bias through non-random patterns of missingness present in the reports, particularly if the probability of missing data is associated with the behavior of interest (e.g., if people are less likely to complete a diary about drug use on days when they use drugs). Various methods have been implemented to improve compliance, including the use of specific reminder schedules [33], transitioning from traditional paper diaries to web-based surveys [34–36], and carefully considering reporting periods from weekly, daily, and more frequent reporting with diary cycles durations based on the population and topic.

In an attempt to establish whether data are missing at random or in a systematic way that may bias results, a common approach is to examine whether there are any meaningful predictors of diary compliance, such as demographic, behavioral, or psychological variables of interest [32, 37, 38]. Although time is occasionally taken into account in a simple manner such as examining whether data were more commonly missing on weekends, very little research has examined whether there are meaningful patterns in compliance that emerge over the course of the reporting period and whether compliance differs systematically in other cyclical ways such as by day of week. Examining such day-to-day within-person changes in compliance may contribute to our understanding about both diary methodology and behavior more generally [39].

Diaries and other similar methodologies present unique opportunities for examining patterns over time in diary compliance and behavioral outcomes of interest more broadly given their inherent structuring in relation to the course of time. Researchers studying behavior are often interested in patterns that are organized over time, for example the shape of the diurnal cortisol patterns throughout the day [40–44] or the longer-term patterns of craving and withdrawal during recovery from addiction [45, 46]. Testing such patterns in longitudinal psychological research is often done using one of two techniques—either the researcher is simply interested in a general increase or decrease over time and fits data onto a linear trajectory or some degree of non-linearity in these increases or decreases is of interest and polynomial (e.g., quadratic, cubic) functions are investigated. The quadratic function allows for the investigation of a U-shaped curve in which the increase or decrease reverses at some point and the cubic function allows this change in direction to occur twice, resulting in a single inflection point in quadratic slopes and two inflection points in cubic slopes. Modeling these shapes involves one slope parameter for linear functions, two for quadratic functions, three for cubic functions, and so on, depending on the degree of the polynomial.

In contrast to the use of polynomial terms for such cyclical trends, trigonometric (i.e., sine and cosine) functions can be utilized. As described in detail by other authors [47], using only two terms—one sine and one cosine—allows for the investigation of a pattern in which the number of inflection points is unrestricted and based on the coding of time, thus simplifying the number of parameters in the model. As is the case with the polynomial models, the amplitude (i.e., height) and period (i.e., width) of the curves are estimated based on the data. However, despite the apparent flexibility of this trigonometric approach for studying periodicity in behaviors, these functions are rarely taught or used.

In addition to the methodological difficulty of compliance within diary studies and their methodological advantage of being able to study patterns over time, another methodological issue that can be either a limitation or a benefit of diaries is that of reactivity. Reactivity is a change in behavior resulting from self-observations or increased self-monitoring [1]. Observational studies typically attempt to minimize or statistically control for reactivity as much as possible [19, 22], On the other hand, when utilized as intervention tools, daily diaries tend to harness reactivity as a motivating factor for behavior change [19, 48]. In fact, such studies may maximize the potential for reactivity through techniques such as providing participants feedback about the behaviors they are reporting in real time.

Given the limitations and strengths of diary methodology described above—dealing with compliance and missing data, modeling patterns over time, and examining potential behavioral reactivity—we aimed to investigate these three issues within the present manuscript using a 30-day online daily diary study of sexual behavior and substance use among a sample of highly sexually active GBM. First, we examined demographic and behavioral predictors of diary compliance over the 30-day reporting period. Second, we compared polynomial and trigonometric patterns of periodicity in both diary compliance and behaviors (i.e., sexual behavior and substance use) to examine patterns by the day of week (i.e., Monday through Sunday) and the day of the diary cycle (i.e., day 1 through 30) in these outcomes. In examining the patterns in behavior over the course of the 30-day cycle, we also sought to determine whether any apparent increases or decreases over time were moderated by levels of the outcome behavior reported retrospectively during the baseline visit (i.e., was there evidence of reactivity?).

Method

Analyses for this paper were conducted on data from *Pillow Talk*, a longitudinal study of highly sexually active GBM in New York City (NYC) that included a 30-day diary. Of the 376 men who enrolled in the project, five completed no daily diaries, resulting in an analytic sample of 371 men.

Participants and Procedures

Potential participants completed a phone-based screening interview to assess preliminary eligibility, which was defined as: (1) at least 18 years of age; (2) biologically male and self-identified as male; (3) nine or more male sexual partners in the prior 90 days [49–51]; (4) self-identification as gay or bisexual; and (5) daily access to the Internet in order to complete Internet-based assessments. Participants who met preliminary eligibility were emailed a link to an Internet-based computer-assisted self-interview (CASI), which included informed consent procedures. Men completed this 1-h survey at home via the Internet followed by an in-person baseline appointment. Final eligibility was confirmed during the in-person appointment, with sexual partner criteria confirmed using a timeline follow-back (TLFB) interview.

The data for this paper were collected as part of the CASI conducted at home prior to the baseline appointment, the in-office TLFB interview, and the prospective online daily diary. Participants received a link to complete their diaries starting on the first day following their baseline appointment and continuing for a total of 30 days. Unique links were emailed to participants at 8 p.m. each night and participants were given until 10 a.m. the following morning to complete the survey before their unique link expired. Median completion time for each diary was 4 min. Participants were compensated up to $60 for completing all 30 days of the online diary based on a pay schedule that included bonuses for completion ($1 per day with a $5 bonus for every 5 days completed). All procedures were reviewed and approved by the university-wide Institutional Review Board of the City University of New York.

Measures

Online CASI Measures—Participants reported several demographic characteristics, including sexual identity, age, race/ethnicity, educational background, and relationship status. Participants also self-reported their HIV status which was subsequently confirmed with a rapid HIV test (for HIV-negative or status unknown men) or proof of status such as a medication bottle or lab results (for HIV-positive men) during the baseline appointment.

Timeline Follow-Back Interview—With the help of a research assistant, participants completed a 42-day (i.e., 6 week) digital calendar using a computer. Participants were asked to recall, starting with the day prior to their appointment and going back the full 42 days, any instances of: (1) substance use, which included heavy drinking (five or more standard drinks) and drug use; and (2) sexual activity, which included partner characteristics (e.g., gender, HIV status, relationship type), type of sexual activity, condom use, and whether or not the event occurred under the influence of any of the previously coded substances used on that day. For the purposes of this paper, we calculated the total number of partners, anal sex acts, and condomless anal sex (CAS) acts that the participants had over the 42-day period; we also calculated the number of days on which they engaged in heavy drinking and the number of days on which they used drugs (cocaine/crack, ecstasy, GHB, psychedelics, non-prescription opiates, ketamine, or crystal methamphetamine). Sexual behavior and substance use variables from the TLFB were used only as predictors within models.

Daily Diary Measures—The diary measure was based on previous studies conducted with GBM [17, 25, 52]. Each day, participants reported on their substance use and we calculated one indicator (1 = yes, 0 = no) of whether or not the participant had consumed five or more standard alcoholic drinks (i.e., heavy drinking) or had used drugs (cocaine, crack, crystal meth, ecstasy, heroin, ketamine, GHB, or marijuana). Following those sections, participants were asked whether or not they had engaged in any sexual activity with another person and, if so, were asked a series of questions for each partner they reported for that day. For the purposes of these analyses, we recoded the initial question regarding any sexual activity with another person into an indicator of whether or not (1 = yes, 0 = no) the participant had engaged in any sexual behavior that day.

Statistical Analyses

We first examined basic descriptive statistics regarding demographic variables and the outcomes of interest for the present study. Following this, we fit a series of multilevel models using the SAS 9.2 PROC GLIMMIX procedures with its default settings. We began by testing the null model for the three outcomes—missing data on a given day and, among completed days, whether or not there was sexual behavior and substance use reported—in order to determine the best fitting covariance structure for the repeated measures. In doing so, we compared models using compound symmetry, first-order autoregressive (AR1), Toeplitz, and variance components structures and found that the AR(1) structure had the best fit across the three outcomes. As such, all models were subsequently examined using this AR(1) structure for the repeated covariance. All models also included a random intercept. For the purposes of model comparisons, we utilized the −2 residual log pseudo-likelihood, amount of residual variation remaining, and the parsimony of the model (i.e., number of

effects estimated). Because of issues inherent to multilevel modeling with binary outcomes, the exponentiated regression coefficients are not shown and are not interpreted as odds ratios.

Predictors of Missing Data—We began by utilizing generalized linear mixed models to identify demographic and behavioral variables associated with diary completion. We simultaneously entered HIV status, race/ethnicity, education, and age as fixed Level 2 effects into a model predicting diary completion on a given day (1 = yes). Following this, we examined the role of behavioral factors captured in the 6-week TLFB prior to the diary that may have been associated with rates of missing data and adjusted these models for previously identified demographic covariates.

Periodicity Patterns in Missing Data—We next sought to determine whether the day of the week (i.e., Monday through Sunday) or the day of the diary cycle (i.e., day 1 through 30) as fixed Level 1 effects were associated with the probability of completing a diary on a given day, adjusting for significant demographic and behavioral variables identified in the previous section (i.e., college education, age, number of heavy drinking days, and number of drug use days). We began by examining the trend in reporting by day of week and, based on an examination of the observed percentage of diaries completed for each day of week, sought to compare the fit of a third degree polynomial (i.e., cubic) and trigonometric (i.e., sine/cosine) functions. In modeling the trigonometric function, we followed recommendations by Stolwijk et al. [47] and entered the sine and cosine terms simultaneously to obtain an accurate cosine function. The terms were created by taking the sine and cosine of 2π multiplied by the day, where day was equal to 1 through 7 for weekday functions and 1 through 30 for day of cycle. We next utilized the same procedures to examine evidence of periodicity by the day of the diary cycle (i.e., 1 through 30) adjusting for the best-fitting weekly trend identified in the previous model.

Periodicity in Behavioral Reports by Day of Week—We next sought to determine whether there was a weekly pattern in health behaviors by examining whether a certain function fit trends in whether or not participants reported sexual behavior and substance use on each day of the week. In doing so, we tested models for day of week going from Monday to Sunday adjusting all models for age and college education; sexual behavior models were also adjusted for relationship status, a potential confounding variable in reports of sexual behavior. We used all available data for days on which participants reached and answered the question on engaging in sexual behavior (n_{days} = 8238) and substance use (n_{days} = 8264).

Periodicity in Behavioral Reports by Day of Cycle—In the final set of models, we sought to determine whether, adjusting for any observed patterns of periodicity by day of week, reports of sexual and substance use behavior changed over the course of the diary cycle. We tested for differences in the probability of reporting sexual and substance use behavior by day of diary cycle adjusting for the best-fitting function found in the previous section's models for the day of week. As in the previous section, we adjusted all models for age and college education and adjusted sexual behavior models for relationship status. We also sought to examine whether men's levels of the behavior reported at baseline (as

measured in TLFB) moderated any potential differences found over time. To do so, we created a median split of the count of the number of sexual partners (for the sexual behavior model; Mdn 10, M 12.1, SD 7.4) and number of substance use days (for the substance use model; Mdn 7, M 12.5, SD 14.0). We entered the dichotomous variable's main effect and its interaction with the linear term for day of diary cycle in each model to test its moderating effect.

A Note on Producing Plots

Throughout the results, we refer the reader to plots which combine the observed probabilities of the outcome (plotted within a histogram) with the model-predicted probabilities (plotted as a solid line). The estimates were obtained using the LSMEANS option in SAS's PROC GLIMMIX which produced predicted population margins based on the fixed effects of interest holding constant all covariates in the model. As a result of the covariates being held at their sample averages, predicted probabilities may deviate from the observed probabilities. These plots were produced to show the convergence of the trend itself with the observed trend rather than to show a match between the observed and predicted probabilities, which are expected to differ for the reasons just mentioned.

Results

As can be seen in Table 1, the sample was diverse with regards to race/ethnicity, employment status, and educational attainment. The sample was nearly evenly split by HIV status and a majority of the sample identified as gay and was single. Ages ranged from 18 to 73, with an average of 37 and a median of 35 years. For the 371 men in this study, 8,413 diaries were started, from which 8,181 (97.6 %) were completed and submitted. The average number of days completed per participant was 22.1 (Mdn 25.0, SD 7.63), resulting in an average completion rate of 74 % and a median completion rate of 83 %.

Predictors of Missing Data

HIV-positive men did not differ from HIV-negative men (B = −0.27, 95 % CI [−0.62, 0.08], $p = 0.13$) and Black (B = −0.13, 95 % CI [−0.56, 0.30], $p = 0.55$), Latino (B = −0.18, 95 % CI [−0.67, 0.32], $p = 0.49$) and men of other races (B = −0.26, 95 %CI [−0.73, 0.21], $p = 0.28$) did not differ from White men in their probability of diary completion on a given day. Men without a college degree had lower likelihood of completing a diary on a given day than men with a 4-year degree or higher (B = −0.53, 95 % CI [−0.88, −0.19], $p = 0.003$) and older men had a higher likelihood of diary completion than younger men on a given day (B = 0.04, 95 % CI [0.02, 0.05], $p < 0.001$). As such, all further models were adjusted for the influence of college education and age.

Having adjusted for these demographic effects, no sexual behavior variables were significantly associated with missing data—when entered into separate models, having more partners (B = −0.01, 95 % CI [−0.03, 0.01], $p = 0.28$), more anal sex acts (B = 0.00, 95 % CI [−0.01, 0.01], $p = 0.93$), and more CAS acts (B = 0.00, 95 % CI [−0.02, 0.01], $p = 0.63$) in the baseline TLFB were all unassociated with the likelihood of completing a diary entry on a given day. Substance use, however, was associated with missing data even after adjusting for

demographic covariates. Each additional day on which men reported heavy drinking (B = −0.03, 95 % CI [−0.05, −0.01], $p = 0.001$) or drug use (B = −0.07, 95 % CI [−0.09, −0.04], $p < 0.001$) in the baseline TLFB was associated with decreased likelihood of diary completion on a given day. When entered simultaneously, the effect of heavy drinking was reduced to marginal significance (B = −0.02, 95 % CI [−0.03, 0.00], $p = 0.08$) while drug use maintained a strong independent effect (B = −0.06, 95 % CI [−0.09, −0.03], $p < 0.001$). All further models examining missing data were adjusted for the effects of both heavy drinking and drug use from the baseline TLFB data.

Periodicity Patterns in Missing Data

As can be seen in Table 2, the models for both the cubic function and the trigonometric function had similar fit and terms for each were significant within their respective models. As a result of having one fewer term, similar residual variance, and lower −2 residual log pseudo-likelihood, the trigonometric function was retained for use in later models and is displayed in Fig. 1. As can be seen in the figure, both the observed and model-implied completion rates were highest at the beginning of the week, peaking on Tuesdays, and dipped to their lowest points over the weekend, particularly Friday and Saturday.

Models 3 and 4 display the results of the analyses on the 30-day diary cycle adjusted for the significant weekly trigonometric trend identified previously in Model 2. We found no significant polynomial effect but again found a significant trigonometric effect, even after adjusting for the trigonometric periodicity identified for day of week. However, there was a significant linear effect identified when the two polynomial terms from Model 3 were removed, and this linear effect was subsequently combined with the trigonometric trends from Model 4. The final model (not shown) indicated that, after adjusting for the trigonometric cycle based on day of week as well as demographic and behavioral covariates, the linear trend (B = −0.03, 95 % CI [−0.04, −0.02], $p < 0.001$) was the only independent and significant pattern of diary completion over the course of the full 30-day cycle was a, while both the sine (B = 0.02, 95 % CI [−0.09, 0.14], $p = 0.67$) and cosine terms (B = 0.05, 95 % CI [−0.02, 0.13], $p = 0.14$) for the 30-day cycle became non-significant. Figure 2 plots the combined effects of the non-significant trigonometric trends and the significant linear trend over the 30-day diary cycle that were identified in this final model, holding constant the trigonometric trend for day of week as well as demographic and behavioral characteristics associated with missing data. As can be seen, after adjusting for the weekly trend and the demographic and behavioral covariates, the function suggests predominantly linear decline in completion rates over time, with the predicted probability of completion decreasing by 0.13 over the course of the 30-day cycle.

Periodicity in Behavioral Reports by Day of Week

Given the pattern observed in the histogram in Fig. 3, we tested for linear and quadratic functions predicting the pattern of sexual behavior by day of week (no trigonometric effect was fit to these data given their pattern). As can be seen in Table 3 (Model 5), both the linear and quadratic terms predicting sexual behavior by day of week were significant, and the trend is plotted in Fig. 3 (an exploratory model revealed a non-significant cubic term). As

can be seen in the figure, the odds of sex increased from Monday to Sunday, increasing steadily during the week and more sharply on the weekends.

Based on the pattern observed in the histogram in Fig. 4, we sought to compare polynomial (i.e., cubic) and trigonometric (i.e., sine and cosine) functions in predicting the pattern of substance use behavior over the course of 1 week. As we found previously with patterns of missing data, both the polynomial (not shown in Table 3) and trigonometric (shown as Model 7) effects were significant in separate models, though the trigonometric model utilized fewer terms and had better overall model fit. As such, model with the trigonometric function was retained as the better fitting model and is presented in Table 3 (Model 7). As can be seen in Fig. 4, substance use appeared to increase throughout the week and reach its peak probability on Saturdays, after which it again began to decline, hitting its lowest probability on Tuesdays.

Periodicity in Behavioral Reports by Day of Cycle

Adjusting for the previously reported weekly pattern in sexual activity and substance use, we sought to determine whether there was evidence for an increase or decrease in behavior over time using linear terms for each. We found evidence for a slight but significant decrease in reported sexual activity over time, as shown in Table 3 (Model 6). The model indicated that the probability of reporting sexual activity on a given day decreased by 0.04 over the course of the 30-day diary. We next entered the main and interaction effect of the median split baseline levels of sexual behavior and found that, while increased sexual activity reported in the baseline TLFB had a significant, positive main effect on reports of sexual behavior in the diary (B = 0.84, 95 % CI [0.59, 1.09], $p < 0.001$), there was no interaction indicating differential behavioral change over the course of the diary (B = 0.01, 95 % CI [−0.01, 0.02], $p = 0.38$). It is also worth noting that the autocorrelation coefficient was non-significant, suggesting that engaging in sexual activity on one day had little influence on whether or not individuals subsequently engage in sexual activity the following day. Put another way, men who reported more sexual behavior in their baseline TLFB also had a higher likelihood of engaging in sexual activity on any given day in the diary, but the decrease observed in the likelihood of sexual activity over the course of the 30-day diary was not different based on men's level of sexual activity in the baseline TLFB.

We also found evidence for a slight but significant decrease in reported substance use over time, as shown in Table 3 (Model 8). The model indicated that the probability of reporting substance use on a given day decreased by 0.04 over the course of the 30-day diary. We next entered the main and interaction effect of the median split levels of substance use reported in the baseline TLFB and found that, while increased substance use pre-baseline had a significant, positive main effect on engaging in substance use in the diary (B = 2.96, 95 % CI [2.55, 3.37], $p < 0.001$), there was no interaction indicating differential behavior change over the course of the diary (B = 0.01, 95 % CI [−0.01, 0.02], $p = 0.36$). Put another way, men who reported more drug use in their baseline TLFB also had a higher likelihood of substance use on any given day in the diary, but the decrease observed in the likelihood of substance use over the course of the 30-day diary was not different based on men's frequency of drug use in the baseline TLFB.

Discussion

Overall, diary completion in this study was relatively high given the 30-day length of the cycle, though we found that GBM with higher levels of education and those who were older had higher rates of completion. Adjusting for these demographic effects, we also found that completion was not associated with how sexually active men were at enrollment, though amount of both heavy drinking and drug use at baseline—particularly drug use—were associated with lower completion rates. Adjusting for these variables, we found meaningful trigonometric patterns in missing data (i.e., compliance) over the course of a week, suggesting that completion peaks toward the middle of the week and declines most on the weekends, as well as having a predominantly linear decline in compliance over the course of the 30-day cycle. With regard to behavior, we found that sexual activity increased in a primarily quadratic trend over the course of the week with a peak on Sunday, while drug use showed evidence of a predominantly trigonometric pattern peaking on Saturdays. Finally, with regard to behavioral change over time, we found evidence for a relatively small but significant linear decline in reports of sexual behavior and substance use over the 30-day cycle, though these changes were not significantly different for men with higher or lower levels of the behavior reported at baseline, calling into question whether these represent reactivity or some other process.

Overall, the findings regarding predictors and patterns of missing data are likely to be the most meaningful to consider for future research. We found that missing data were predicted by both age and education, suggesting that these data do not meet the criteria for being missing completely at random (MCAR). Levels of sexual activity were unassociated with missing data, though higher frequency of substance use was associated with increased probability of missing data on a given day. These data suggest that, when analyzing sexual behavior data, the assumption of the data being missing at random (MAR) may be met (i.e., missing data on sexual behavior do not depend on how sexually active participants are), while analyses of substance use outcomes may need to assume the data are missing not at random (MNAR; i.e., the missing data may be associated with the outcome of interest).

With the increasing use of diaries and similar methods to assess substance use [53], the finding that more frequent substance users were less compliant to the diary protocol is worth highlighting. Just as retrospective recall of substance use may be more problematic for heavier users, it appears that prospective reporting on it may also be biased. That being said, lower compliance for heavier substance users is likely to underrepresent substance use days and thus is more likely to be biased toward null rather than significant associations. Individual differences in compliance by demographic characteristics—in this case, educational attainment and age—underscore the importance of examining data for such patterns and adjusting not only based on variables that may confound a certain outcome or association but also those which may lead to non-random patterns of missingness. These findings also highlight the necessity of considering the sample under consideration, as diaries may not always be the best choice for certain groups (e.g., those with very low levels of education).

Having accounted for demographic and behavioral predictors of missing data, we still found significant evidence for a trigonometric pattern in missing data over the course of the week. Specifically, diary compliance peaked on Tuesdays, declined until reaching the lowest point on Fridays and Saturdays, and began to improve again on Sundays, beginning the cycle anew. For studies in which diaries are completed less than daily, the implications may be that diaries on Fridays and Saturdays should be avoided or tailored to individuals' unique schedules. Among studies that include daily assessments or use a random sample of days, it seems critical to examine the effect of weekend reporting and adjust for it within models. As is typically expected, compliance to the diary also declined somewhat from the beginning to the end of the 30-day cycle. Unlike patterns based on the day of week, compliance over the course of the cycle was primarily linear. In this study, we utilized a compensation schedule in which participants received bonuses after every five completed diaries. In contrast, these results suggest that compensation schedules in which later diaries are rewarded more strongly may help to ameliorate the drop off in completion that occurs over time. Some studies have included completion bonuses for a high overall completion rate (e.g., $15 if 90 % or more of diaries are completed), which may aid in completion through to the end of the study [17, 52]. However, this technique has the potential to disincentivize any completion after falling below the threshold for compensation. Similarly, compensation might be increased or content might be adapted (e.g., made briefer) on the weekends in such a way as to encourage completion on days that show lower response rates.

In addition to the findings regarding diary compliance, a secondary aim was to examine patterns in health behaviors themselves—research has rarely if ever been undertaken to examine the periodic patterns in sexual and substance use behavior over the course of each week, and the results of this study were relatively clear. The likelihood of sexual behavior remained relatively steady from Monday through Thursday and inclined sharply from Friday until Sunday in a quadratic fashion. In contrast to this, substance use remained relatively steady from Monday to Thursday and peaked on Saturdays in a trigonometric fashion. A variety of biological, behavioral, and psychological variables show evidence of circadian, circaseptan, or seasonal rhythms that follows a trigonometric trend, and these data support the use of such a function for investigating these patterns. Importantly, while the investigation of polynomial—particularly quadratic and cubic—patterns is common in psychological research, trigonometric patterns appear less often. Despite this, the current study provides evidence that they represent a more parsimonious method of representing cyclical trends than third-degree polynomials and would be particularly useful in instances where two or more inflection points over time are expected. As a result, these functions should be considered more often in research training and practice for behavioral scientists. That being said, these types of patterns are not the only ways to assess time series trends, and we acknowledge the importance of considering alternatives such as those which account for seasonal trends and those in which additive and multiplicative trends are compared. It is important for researchers to take these temporal trends into account when investigating these behavioral outcomes, particularly if the predictor of interest may also follow temporal trends (i.e., if the day of the week may be a confounding factor that explains the observed association between the predictor and the outcome).

Finally, we found evidence for a slight linear decline in both sexual behavior and substance use over the course of the 30-day diary suggesting the possibility of behavioral reactivity. It is important to point out that the source of this behavior change cannot be determined and thus it is unknown whether this resulted from the baseline assessment (i.e., the surveys or timeline follow-back interview which both also focused on sexual behavior and substance use), the diary itself, or some other factor. Nonetheless, these findings do point to the potential role that assessment might play in increasing self-monitoring and behavior change. To the extent that diary and other similar methods are to be used for intervention, these findings suggest that one might be able to harness this potential increase in behavioral self-monitoring to induce desired behavior change within a diary-based or other form of mobile intervention [19]. More importantly, they suggest that intervention studies both with and without daily assessment methods may wish to utilize a "washout" period between assessment and intervention due to the fact that behavior change may ensue immediately following assessment even without intervention. Finally, these results demonstrate the importance of accounting for behavior change via the effect of time within intensive longitudinal designs—even after adjusting for autocorrelation in responses and utilizing a random intercept, the linear effect of time was still significant and may need to be adjusted for in other analyses with behavioral outcomes.

Limitations

The results of the current study should be considered in light of their limitations. The sample was engaging in higher than average levels of sexual activity prior to baseline and thus the decline in sexual activity over the course of the diary may have at least partially resulted from regression to the mean and may not have been seen in less active samples; however, this sample included men who were not selected based on high substance use levels and the decline in substance use was similar to the decline in sexual behavior, suggesting regression to the mean may not have been the primary factor in any potential behavior change observed. The behavioral outcomes focused on in this study—sexual behavior and substance use—showed different weekly rhythms but similar patterns of decline, though these patterns may not generalize to other behaviors. Moreover, though we accounted for weekly and cyclical trends in behavior, other trends such as seasonal effects were not investigated. Although we attempted to focus on important individual differences in demographic and behavioral factors that may lead to differences in diary completion, we by no means exhausted the potential list, and did not examine any psychosocial variables despite some evidence from previous research that these may play a role [19]. Finally, though we do not believe these processes are specific to our sample, we nonetheless relied on a sample of NYC-based GBM and thus additional research is needed to determine the extent to which these findings would be replicated among other groups.

Conclusions

In this 30-day online diary study of GBM focused on sexual behavior and substance use, we found that both demographic (i.e., educational attainment and age) and behavioral (i.e., frequency of substance use prior to baseline) factors were associated with diary compliance, suggesting such factors may bias results of similar studies. We found discernible patterns of

missing data and behavior utilizing weekly trigonometric and polynomial trends and demonstrated that trigonometric functions captured cyclical trends more parsimoniously than a third-degree (i.e., cubic) polynomial and might be useful in future psychological and behavioral research on phenomena that may display cyclical rhythms over time; this would be particularly true in trends that are expected to have multiple inflection points (i.e., third-order and higher polynomials) for which the trigonometric pattern can model these with only two coefficients rather than the added coefficient for each additional degree of the polynomial effect. Finally, over the course of the 30-day diary cycle we found slight declines in diary compliance as well as in the report of the behaviors themselves, indicating drop-off in completion and suggesting potential reactivity in behavior. Statistical methods of adjustment, including autocorrelation effects, random effects, and accounting for the effect of time within analyses may help to reduce potential biases, and researchers should consider adjusting for variables that not only confound the outcome or associations with the outcome but also that may lead to biases in the extent of missing data. Future studies should examine these issues among other populations and with different behaviors, and simulation studies should be conducted to better understand the potential impact of these issues on the results of diary and other intensive longitudinal designs.

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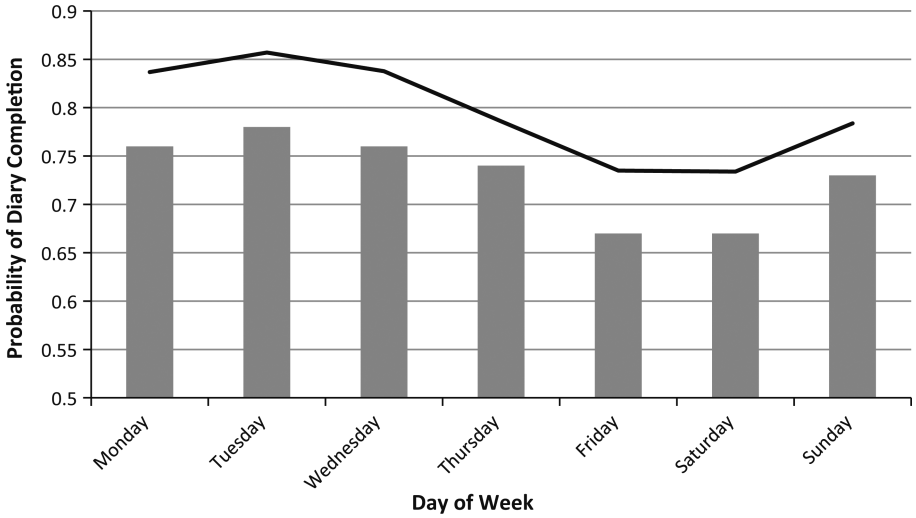

Fig. 1.

This figure displays the trigonometric function demonstrating periodicity in the missing data by day of week holding constant demographic and behavioral confounding variables. The gray histogram demonstrates the observed percentage of completed diaries by day of week; the black line is a plot of the estimated probability of completion based on the marginal fixed effects in the trigonometric model presented in Table 2; the difference between the observed and predicted probabilities is largely the result of adjusting for demographic confounding within the model

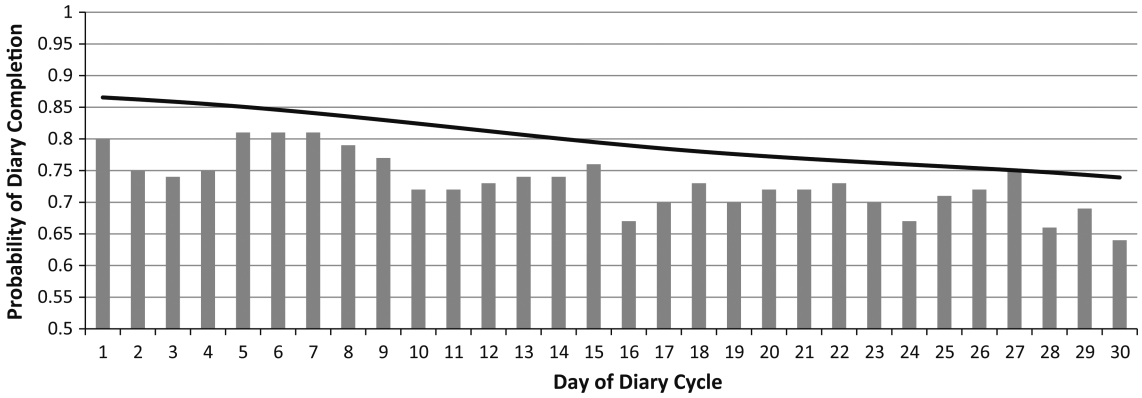

Fig. 2.

This figure displays the combined trigonometric (non-significant) and linear (significant) functions underlying the periodicity in diary completion by day of the 30-day diary cycle holding constant the trigonometric function identified in completion by day of week (i.e., Fig. 1) as well as demographic and behavioral confounding variables. The gray histogram demonstrates the observed percentage of completed diaries by day of diary cycle, while the black line is a plot of the estimated probability of completion based on the marginal fixed effects of the final model. The difference between the observed and predicted probabilities is largely the result of adjusting for demographic confounding within the model

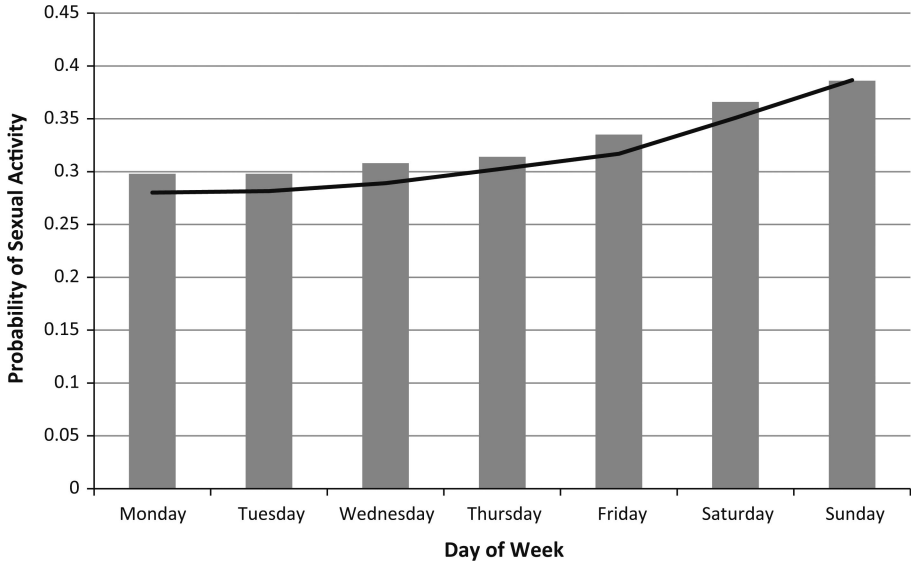

Fig. 3.

This figure displays the quadratic trend for day of week in predicting the probability of reporting sexual activity on a given day. The gray histogram demonstrates the observed percentage of days on which sexual activity occurred by day of week, while the black line is a plot of the estimated marginal probability of sexual activity based on the fixed effects of the model adjusted for demographic characteristics. The difference between the observed and predicted probabilities is largely the result of adjusting for demographic confounding within the model

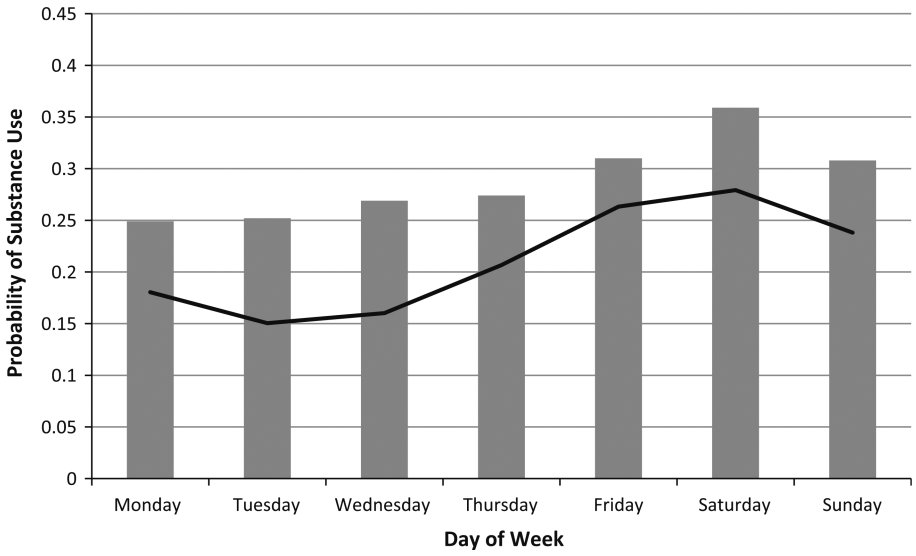

Fig. 4.

This figure displays the trigonometric trend for day of week in predicting the probability of reporting substance use on a given day. The gray histogram demonstrates the observed percentage of days on which substance use occurred by day of week, while the black line is a plot of the estimated marginal probability of substance use based on the fixed effects of the model adjusted for demographic characteristics. The difference between the observed and predicted probabilities is largely the result of adjusting for demographic confounding within the model

Table 1

Demographic characteristics of the sample

Variable	*n*	%
Race/ethnicity		
Black	74	19.9
Latino	50	13.5
White	191	51.5
Multiracial/other	56	15.1
Sexual orientation		
Gay, queer, or homosexual	327	88.1
Bisexual	44	11.9
HIV status		
Positive	165	44.5
Negative	206	55.5
Employment status		
Full-time	117	31.5
Part-time	94	25.3
Student (unemployed)	31	8.4
Unemployed	127	34.2
Not answered	2	0.5
Highest educational attainment		
High school diploma/GED or less	42	11.3
Some college or Associate's degree	113	30.5
Bachelor's or other 4-year degree	124	33.4
Graduate degree	92	24.8
Relationship Status		
Single	297	80.1
Partnered	74	19.9
	M	SD
Age (Mdn 35.0)	37.0	11.5

Table 2

Modeling the pattern of missing data by day of week (Models 1 and 2) and day of diary cycle (Models 3 and 4) using polynomial and trigonometric functions

Term	Model 1: 7-day polynomial function			Model 2: 7-day trigonometric function			Model 3: 30-day polynomial function			Model 4: 30-day trigonometric function		
	B	95 %CI	*p*	B	95 %CI	*p*	B	95 %CI	*p*	B	95 %CI	*p*
Fixed effects												
Intercept	1.63	[1.46, 1.80]	<0.001	1.38	[1.23, 1.54]	<0.001	1.85	[1.61, 2.09]	<0.001	1.39	[1.24, 1.55]	<0.001
No college degree	–0.61	[–0.93, –0.31]	<0.001	–0.63	[–0.94, –0.32]	<0.001	–0.64	[–0.95, –0.32]	<0.001	–0.63	[–0.95, –0.32]	<0.001
Age	0.04	[0.02, 0.05]	<0.001	0.04	[0.02, 0.05]	<0.001	0.04	[0.02, 0.05]	<0.001	0.04	[0.02, 0.05]	<0.001
Heavy drinking days	–0.02	[–0.04, 0.00]	0.08	–0.02	[–0.04, 0.00]	0.08	–0.02	[–0.04, 0.00]	0.08	–0.02	[–0.04, 0.00]	0.08
Club drug use days	–0.06	[–0.09, –0.03]	<0.001	–0.06	[–0.09, –0.03]	<0.001	–0.06	[–0.09, –0.03]	<0.001	–0.06	[–0.09, –0.03]	<0.001
Linear	–0.28	[–0.33, –0.23]	<0.001	–	–	–	–0.03	[–0.09, 0.02]	0.25	–	–	–
Quadratic	–0.08	[–0.11, –0.05]	<0.001	–	–	–	0.00	[0.00, 0.00]	0.94	–	–	–
Cubic	0.03	[0.03, 0.04]	<0.001	–	–	–	0.00	[0.00, 0.00]	0.83	–	–	–
Sine	–	–	–	0.40	[0.33, 0.47]	<0.001	–	–	–	0.29	[0.22, 0.36]	<0.001
Cosine	–	–	–	–0.10	[–0.16, –0.03]	0.005	–	–	–	0.02	[–0.05, 0.09]	0.64
Random effects	Est.	SE		Est.	SE		Est.	SE		Est.	SE	
Intercept	1.88	0.17		1.89	1.17		1.93	0.18		1.92	0.18	
AR(1)	0.09	0.01		0.09	0.01		0.08	0.01		0.08	0.01	
Residual	0.85	0.01		0.85	0.01		0.86	0.01		0.86	0.01	
–2 Residual LPL	54829.18			54812.55			55310.46			55126.94		

Although not shown, models 3 and 4 were adjusted for the 7-day trigonometric effects identified in Model 2. The polynomial and trigonometric effects refer to those effects that are coded for the time frame named above each model (i.e., for the 7-day models, these are the weekly polynomial or trigonometric effects while for the 30-day models, these are day of cycle effects); the weekly effects within the 30-day models are not shown but were consistent in both magnitude and significance with those found in the 7-day models

AOR adjusted odds ratio, *CI* confidence interval, *LPL* log pseudo-likelihood

Table 3

Modeling the pattern of sexual and drug use behavior by day of week (Models 5 and 7) and day of diary cycle (Models 6 and 8)

Term	Model 5: 7-day pattern of sexual behavior			Model 6: 30-day pattern of sexual behavior			Model 7: 7-day pattern of substance use			Model 8: 30-day pattern of substance use		
	B	**95 %CI**	***p***	**B**	**95 %CI**	***p***	**B**	**95 %CI**	***p***	**B**	**95 %CI**	***p***
Fixed effects												
Intercept	–0.90	[–1.02, –0.78]	<0.001	–0.81	[–0.95, –0.67]	<0.001	–1.34	[–1.58, –1.10]	<0.001	–1.22	[–1.47, –0.97]	<0.001
No college degree	0.07	[–0.15, 0.29]	0.54	0.07	[–0.15, 0.29]	0.55	0.35	[–0.13, 0.83]	0.15	0.35	[–0.13, 0.83]	0.16
Age	0.00	[–0.01, 0.01]	0.37	0.00	[–0.01, 0.01]	0.39	–0.02	[–0.04, 0.00]	0.06	–0.02	[–0.04, 0.00]	0.07
In relationship	0.44	[0.17, 0.71]	<0.001	0.45	[0.18, 0.71]	0.001	–	–	–	–	–	–
Linear effect	0.05	[0.01, 0.09]	0.007	–0.01	[–0.01, 0.00]	0.02	–	–	–	–0.01	[–0.02, 0.00]	0.007
Quadratic effect	0.01	[0.00, 0.03]	0.04	–	–	–	–	–	–	–	–	–
Cubic effect	–	–	–	–	–	–	–	–	–	–	–	–
Sine effect	–	–	–	–	–	–	–0.36	[–0.44, –0.28]	<0.001	–	–	–
Cosine effect	–	–	–	–	–	–	0.18	[0.10, 0.25]	<0.001	–	–	–
Random effects	Est.	SE		Est.	SE		Est.	SE		Est.	SE	
Intercept	0.84	0.09		0.84	0.09		4.65	0.43		4.64	0.43	
AR(1)	0.02	0.01		0.02	0.01		0.08	0.01		0.08	0.01	
Residual	0.92	0.01		0.92	0.01		0.71	0.01		0.71	0.01	
–2 Residual LPL	37269.86			37291.72			42497.56			42543.50		

Although not shown, models 6 and 8 were adjusted for the 7-day patterns identified in Models 5 and 7. The polynomial and trigonometric effects refer to those effects that are coded for the time frame named above each model (i.e., for the 7-day models, these are the weekly polynomial or trigonometric effects while for the 30-day models, these are day of cycle effects); the weekly effects within the 30-day models are not shown but were consistent in both magnitude and significance with those found in the 7-day models

AOR adjusted odds ratio, *CI* confidence interval, *LPL* log pseudo-likelihood