Behaviour Research and Therapy 123 (2019) 103477

Contents lists available at ScienceDirect

Behaviour Research and Therapy

journal homepage: www.elsevier.com/locate/brat

Alexithymia – Not autism – is associated with frequency of social interactions in adults

Alan H. Gerber[a], Jeffrey M. Girard[b], Stacey B. Scott[a], Matthew D. Lerner[a,*]

[a] Department of Psychology, Stony Brook University, Stony Brook, NY, USA
[b] Language Technologies Institute, Carnegie Mellon University, Pittsburgh, PA, USA

ARTICLE INFO

Keywords:
Alexithymia
Autism
ASD
EMA
Social interaction

ABSTRACT

Objective: While much is known about the *quality* of social behavior among neurotypical individuals and those with autism spectrum disorder (ASD), little work has evaluated *quantity* of social interactions. This study used ecological momentary assessment (EMA) to quantify *in vivo* daily patterns of social interaction in adults as a function of demographic and clinical factors.
Method: Adults with and without ASD ($N_{ASD} = 23$, $N_{Neurotypical} = 52$) were trained in an EMA protocol to report their social interactions via smartphone over one week. Participants completed measures of IQ, ASD symptom severity and alexithymia symptom severity.
Results: Cyclical multilevel models were used to account for nesting of observations. Results suggest a daily cyclical pattern of social interaction that was robust to ASD and alexithymia symptoms. Adults with ASD did not have fewer social interactions than neurotypical peers; however, severity of alexithymia symptoms predicted fewer social interactions regardless of ASD status.
Conclusions: These findings suggest that alexithymia, not ASD severity, may drive social isolation and highlight the need to reevaluate previously accepted notions regarding differences in social behavior utilizing modern methods.

Social interaction provides vital opportunities for individuals to achieve goals through collaboration and represents one of the most fundamental aspects of human life (Coan & Sbarra, 2015; Tomasello, 1999). Psychology has long been interested in understanding various aspects of social interaction (i.e., back and forth communication), including the important role it plays in psychological health (Horowitz & Strack, 2010; Leary & Hoyle, 2009). Numerous psychological disorders have been linked with differences in social and interpersonal functioning (e.g., Girard et al., 2017), but perhaps some of the most salient differences are those evident in Autism Spectrum Disorder (ASD). Research indicates that individuals with ASD experience considerable difficulty with social communication and interaction such as making eye-contact, having conversations, and sending and receiving nonverbal signals (American Psychiatric Association, 2013; Lord, Elsabbagh, Baird, & Veenstra-Vanderweele, 2018; Volkmar, Lord, Bailey, Schultz, & Klin, 2004).

Two important aspects of social interactions are their *quality* (e.g., reciprocity and flexibility) and their *quantity* (e.g., frequency and temporal patterning). Differences in the quality of social interactions in ASD have been well-studied. For instance, ASD has been associated with reduced social reciprocity (e.g., back-and-forth conversation) and difficulties adjusting to social context, such as understanding sarcasm (Lord et al., 2018). Less is known about the quantity of social interactions in ASD. For example, it is not clear what frequency of social interactions is common in ASD, and almost nothing is known about their temporal patterning (e.g., are there cyclical rises and falls over time and are aspects of these patterns characteristic of ASD?). Careful study of the quantity of social interactions in ASD has the potential to improve scientific understanding of how the daily experiences of individuals with ASD unfold and can help identify potential targets for intervention. For example, individuals with ASD may seek out social interactions at times when neurotypical peers are not as available (e.g., late at night), suggesting a need to focus on potential differences in temporal patterning of interactions. Likewise, it would be illuminating to study which psychological factors explain differences in social interaction quantity (e.g., alexithymia or difficulty with emotional awareness; Bird & Cook, 2013). Previous research on adults with ASD suggests that they engage in few social interactions overall (Bishop-Fitzpatrick, DaWalt, Greenberg, & Mailick, 2017; Orsmond, Krauss, & Seltzer, 2004; Orsmond, Shattuck, Cooper, Sterzing, & Anderson, 2013). However,

* Corresponding author. Department of Psychology, Stony Brook University, Stony Brook, NY, 11794-2500, USA.
E-mail address: matthew.lerner@stonybrook.edu (M.D. Lerner).

https://doi.org/10.1016/j.brat.2019.103477
Received 18 January 2019; Received in revised form 26 June 2019; Accepted 9 September 2019
Available online 10 September 2019
0005-7967/

these studies have been limited by almost exclusively relying on secondhand (e.g., caregiver) accounts, not examining behavior in real-world settings, and not directly comparing the behavior of adults with ASD to that of their neurotypical peers.

Ecological momentary assessment (EMA; Stone & Shiffman, 1994) has the potential to address these limitations by enabling the collection of firsthand accounts of social behavior in real-world settings from comparable ASD and neurotypical groups. EMA typically uses smart phones or other electronic devices that can be easily carried around by participants. Participants are prompted to fill out surveys or provide other information at pre-selected intervals, time-points, and/or following specific events such as an interpersonal interaction or a change in symptoms (Stone & Shiffman, 1994). The present study used EMA to quantify daily patterns of social interaction in adults as a function of both demographic (e.g., age and gender) and clinical (e.g., ASD status and alexithymia severity) factors with the aim of providing a foundation for a new approach to understanding patterns of social behavior.

Evidence indicates that, in neurotypical adults, patterns of several relevant social behaviors (i.e., behaviors impacting other individuals) distinct from social interaction follow predictable daily or weekly nonlinear cycles, similar to those of biological mechanisms such as the sleep and cortisol cycles (Warner, 1988). For example, sexual activity demonstrates a consistent weekly cycle that peaks on the weekend (Bodenmann, Atkins, Schar, & Poffet, 2010) and interactions on social media seems to follow a daily cycle with lower activity on the weekend (Golder, Wilkinson, & Huberman, 2007). A few studies have suggested that neurotypical adults average between six and seven in-person social interactions per day (Brown & Moskowitz, 1998; Moskowitz, 1994; Wheeler & Nezlek, 1977), but the temporal patterning of these interactions has rarely been examined.

Several studies have examined the quantity of social interactions in young and middle-age adults (i.e., 21 to 55 year-olds) with ASD and generally concluded that ASD is associated with fewer social interactions (Bishop-Fitzpatrick et al., 2017; Orsmond et al., 2004, 2013). However, these studies have been limited in several important ways. First, most participants in these studies had cognitive or intellectual impairments and lived in their family home, which may have led to fewer interactions being reported than might be found in ASD populations who do not exhibit intellectual disability (ID) and/or are living independently. Second, previous work has not reported data on participants' ASD symptom severity, precluding comparisons across the range of clinical presentation. Furthermore, these studies largely relied on caregiver accounts of the previous year, which may have been subject to recall bias and other questionnaire-related biases (Shiffman, Stone, & Hufford, 2008). Finally, prior research specifically and exclusively examined frequencies of social and recreational activities. However, social interactions can occur across a wide range of contexts beyond these activities, including brief small-talk at a grocery store, or during professional interactions at work. As such, total social interactions cannot be captured by the prior approach, restricting the ability to make comprehensive claims about the totality of daily social behavior. Thus, the extant literature provides limited insight into the frequency, and no insight into the temporal patterning, of social behavior in adults with ASD in comparison to their neurotypical peers, which is crucial to evaluating the fundamental presumption that the quantity of social interaction is reduced in ASD.

Recent literature suggests that alexithymia may in fact account for some of the social deficits and impairment previously attributed to ASD (Bird & Cook, 2013). Alexithymia is an impairment in the ability to recognize emotion and is associated with interpersonal deficits and increased social rejection (Chester, Pond, & DeWall, 2015; Lane et al., 1996). Rates of alexithymia are significantly higher in adults with ASD than in their neurotypical peers (Hill, Berthoz, & Frith, 2004; Lombardo, Barnes, Wheelwright, & Baron-Cohen, 2007) and several recent studies have found evidence that alexithymia severity, and not ASD severity, predicts social deficits such as reduced emotion recognition, interoceptive accuracy, and the ability to copy another individual's physical motion (Brezis et al., 2017; Cook, Brewer, Shah, & Bird, 2013; Shah, Hall, Catmur, & Bird, 2016). Thus, it is important to consider alexithymia in addition to ASD in research on social functioning in this population.

Several demographic and clinical factors are also associated with the quantity of social interaction. In neurotypical adults, older age has been associated with reduced frequency of social contact (Lansford, Sherman, & Antonucci, 1998; Marcum, 2013), and females have been found to have longer and more frequent social interactions than males (Booth, 1972; Wheeler & Nezlek, 1977). In adults with ASD, older age and greater ASD symptom severity were associated with a lower likelihood of peer relationships, and lower functioning and independence were associated with fewer social activities (Orsmond et al., 2004, 2013).

EMA allows individuals to self-report their social interactions in-the-moment, providing a more accurate estimate of interpersonal behavior than retrospective recall (Shiffman et al., 2008). Ecologically valid, real-time data can be particularly valuable for understanding the daily lives of individuals with ASD, as their caregivers (and even the individuals themselves) may have limited insight upon reflection (Damiano, Mazefsky, White, & Dichter, 2014). Additionally, EMA can reveal temporal patterns that may have been obscured in previous research (Hamaker & Wichers, 2017; Harari et al., 2016). Finally, EMA can also be used by individuals with higher adaptive and cognitive functioning who likely require fewer supports in their daily lives, permitting a more direct comparison between neurotypical and ASD groups (Chen, Bundy, Cordier, & Einfeld, 2014; Khor, Gray, Reid, & Melvin, 2014; Kovac, Mosner, Miller, Hanna, & Dichter, 2016). To date, there has been limited work utilizing EMA to study social interaction in ASD. Only one study has addressed the social behavior of individuals with ASD using EMA data collection (Chen, Bundy, Cordier, Chien, & Einfeld, 2017), indicating low levels of social behavior relative to other activities, with males being significantly less likely to engage in social interaction. However, this study used beep-contingent, instead of event-contingent, recording (ECR; see Moskowitz & Sadikaj, 2012), limiting inferences about the quantity and temporal patterning of social interactions. Additionally, this study had no control group, prohibiting comparisons to neurotypical adults. Given the promise of EMA to investigate basic questions about quantities and patterns of social behavior, a crucial next step is to investigate social interactions of young and middle-age adults with ASD in comparison to their neurotypical peers utilizing an ECR approach.

Based on previous research, we hypothesized that 1) the quantity of social interactions would be negatively associated with age and male sex (Chen et al., 2017; Orsmond et al., 2004, 2013). Given the small literature suggesting a possible relationship between IQ and social functioning (Magiati, Tay, & Howlin, 2014), we also controlled for intellectual functioning (IQ). In addition, we hypothesized that, beyond the effects of demographic factors, 2a) adults with ASD would exhibit fewer social interactions than individuals without ASD, and that 2b) those with ASD would demonstrate a daily cycle of social interaction with lower amplitude than neurotypical adults. Finally, we hypothesized that, above and beyond the effects of ASD, individuals with higher levels of alexithymia would 3a) exhibit fewer social interactions, and 3b) display a daily cycle of social interaction characterized by attenuated amplitude compared to neurotypical adults.

1. Methods

1.1. Participants

Participants were adults with and without ASD drawn from a larger intervention study (see Participants in Supplement). Neurotypical adults were recruited into the study through the psychology department at a University in the mid-Atlantic region of the U.S. Adults with ASD

Table 1
Demographic and clinical characteristics of the sample.

	ASD (n = 23)	Neurotypical (n = 52)	*t* or χ^2 value
Sex (male), *n (%)*	18 (78%)	15 (29%)	15.803***
Age, *M (SD)*	25.16 (6.82)	20.8 (4.28)	2.827**
AQ Total Score, *M (SD)*	35.82 (6.15)	18.38 (5.07)	11.916***
ADOS-2 Severity Score, *M (SD)*	5.86 (2.86)	NA[a]	NA[a]
KBIT-2 Standard IQ Score, *M (SD)*	107.21 (15.48)	101.69 (12.79)	1.5001
TAS-20 Raw Score, *M (SD)*	54.17 (12.49)	43.71 (10.67)	3.4905**

Note. Welch's T-test or a Chi-square test was used for group comparisons.
AQ = Autism Quotient; ADOS-2 = Autism Diagnostic Observation Schedule, Second Edition; KBIT-2 = Kaufman Brief Intelligence Test, Second Edition; TAS-20 = Toronto Alexithymia Scale. [a]Neurotypical group did not receive an ADOS. $^{**}p < .01$. $^{***}p < .001$.

were recruited through the University, local providers, and ASD-related events, as well as general local community contacts. Participants received either course credit or financial compensation. All participants provided informed consent prior to beginning the study and were required to be at least 18 years of age at the time of consent.

Eligibility criteria for the study included a composite IQ score of 70 or above as measured by the Kaufman Brief Intelligence Test – Second Edition (KBIT-2 (Kaufman & Kaufman, 2004); and a functioning smartphone in order to ensure ability to complete the study procedures. In addition, neurotypical adults were required to have a below-cutoff score on the Adult Autism Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), whereas participants who scored above threshold were placed in the ASD group[1] (see measures for details). The sample consisted of seventy-five adults, ages 18–47 years (M = 22.15 years, SD = 5.53; 50% White, 8% Black, 24% Asian, 13% Hispanic, 4% Multiple races and 1% Declined to answer; see Table 1). Study procedures were approved by the Institutional Review Board of the identified University and were carried out in accordance with established ethical guidelines.

1.2. Procedure

Participants completed an online screener (AQ) and either two or three lab visits. Clinical assessment and questionnaire data were collected at the initial visit. At their first or second visit (depending on ASD group status), participants were trained in an EMA protocol in which they were asked to report their social interactions through a Google Form via their smartphone over one full week (i.e., seven days). As part of the larger intervention study, participants were randomly assigned to groups in which they were asked to log additional information about the person with whom they interacted; however, interaction logging instructions for social interactions pertinent to the present investigation were identical across conditions. Participants were taught to identify and log any social interaction (e.g., chatting with a friend, helping a customer, or talking on the phone) longer than 5 s that involved a back-and-forth between themselves and one or more individuals (Wheeler & Reis, 1991). Examples of social interactions that were provided to participants included chatting with a friend, helping a customer, and giving directions to a stranger. Participants learned that being in the presence of another person, such as sitting in class or watching a movie with someone, would not qualify unless there was a specific interaction. Research assistants confirmed participant understanding of the study definition of social interaction through a standardized training. Participants were required to complete at least three trials in which they were asked whether a specific type of interaction should be logged and subsequently correctly identify at least two of these consecutively.

Participants were then asked to store a link to the Google Form survey on their phone and use it to report qualifying social interactions immediately after they occur. Google Forms automatically time-stamps all responses. In addition, participants received 12 random-interval reminders each day via text message. The first and the last reminders were always delivered at 9 am and 9 pm, with the other 10 occurring between those times at semi-random intervals (i.e., intervals were constrained to be no less than 27 min long and no greater than 108 min long). The text of the random-interval reminder read, "Hello, have you been keeping up with [name of the study]? Click the link to tell us about your social interactions. Thanks!" and included the link to report an interaction. Consistent with other studies (e.g., Côté, Moskowitz, & Zuroff, 2012), this sampling method was chosen in order to maximize the number of social interactions participants report throughout the study. Data collection continued until a full seven days after the study began and thus extended into an eighth study day if a participant began the first day in the afternoon. At their final visit, participants completed a debriefing survey.

1.3. Measures

1.3.1. Adult Autism Spectrum Quotient (AQ)

All study participants completed the AQ online as a screener instrument (Baron-Cohen et al., 2001). The AQ is a 50 item self-report questionnaire that is intended to measure symptom severity of ASD-related traits in the general population. Each item is rated on a 4-point scale ranging from *definitely agree* to *definitely disagree*. An example of a question is "I am good at social chitchat." A raw total is calculated by summing the total items agreed with (i.e., either a 1 or 2). Higher total raw scores indicate greater levels of severity. A total score of 32 was used as the cutoff for individuals who did not identify as having a prior diagnosis of ASD (Baron-Cohen et al., 2001). For participants who identified as having a previous diagnosis of ASD, a cutoff score of 26 was utilized to maximize sensitivity of the ASD group (Woodbury-Smith, Robinson, Wheelwright, & Baron-Cohen, 2005). The AQ demonstrated high internal consistency (Cronbach's α = .91).

1.3.2. Autism Diagnostic Observation Schedule – Second Edition (ADOS-2)

The Autism Diagnostic Observation Schedule – Second Edition (ADOS-2) is a semi-structured interview designed to assess ASD symptom severity by eliciting social interactions (Lord et al., 2012). Based on the scoring of the ADOS-2, participants receive a classification of autism, autism spectrum disorder, or non-spectrum, as well as a standardized severity score. All participants assigned to the ASD group completed a Module 4 (fluent speech) ADOS-2, however, participants assigned to the neurotypical group did not complete the ADOS-2. The current study used the revised Module 4 algorithm (Hus & Lord, 2014), which has demonstrated utility in adults with ASD and without ID (Pugliese et al., 2015). All ADOS-2 examiners were certified research-reliable in administration and scoring.

1.3.3. Kaufman Brief Intelligence Test – Second Edition (KBIT-2)

The Kaufman Brief Intelligence Test – Second Edition (KBIT-2) is a

[1] One participant was placed in the ASD group despite a below cutoff score on the AQ due to prior clinical knowledge of the participant. Removing this participant from the analyses had no impact on the results.

brief measure of intelligence (Kaufman & Kaufman, 2004). It is intended for use with individuals aged 4–90. Standardized scores are calculated using age-specific norms. The IQ composite is composed of a verbal and nonverbal component. All participants completed the KBIT-2.

1.3.4. Social responsiveness scale – Second Edition (SRS-2)

The Social Responsiveness Scale – Second Edition (SRS-2) is a 65-item questionnaire measuring the severity of symptoms associated with ASD (Constantino & Gruber, 2012). This study only utilized the self-report version of the SRS-2, intended for individuals aged 19 years and older. Each item is rated on a 4-point Likert scale ranging from 1 (*Not True*) to 4 (*Almost Always True*). The SRS-2 consists of five subscales: Social Awareness, Social Cognition, Social Communication, Social Motivation, and Restricted Interests and Repetitive Behavior. Each of the five subscales, as well as the overall Total score, produces a standardized T-score, with higher scores suggesting greater impairment. The SRS-2 demonstrated high internal consistency (Cronbach's α = .96).

1.3.5. Toronto Alexithymia Scale (TAS-20)

The Toronto Alexithymia Scale (TAS-20) is a self-report measure of alexithymia symptoms (Bagby, Parker, & Taylor, 1994). Alexithymia is defined by challenges with emotional awareness, including difficulties recognizing and expressing emotions (Lane et al., 1996). The TAS-20 consists of 20 items such as, "it is difficult for me to find the right words for my feelings." Each item is rated on a 5-point scale ranging from strongly disagree to strongly agree. A raw total is calculated by summing the total ratings across items. Higher total raw scores suggest larger impairments in emotional awareness. The TAS-20 has been used extensively with adults with ASD (Cook et al., 2013; Shah et al., 2016), and has demonstrated good test-retest reliability and convergent validity in that population (Berthoz & Hill, 2005). All participants completed the TAS-20. Internal consistency of the TAS-20 was high (Cronbach's α = .88).

1.3.6. Developmental history form

All participants completed a developmental history form consisting of questions pertaining to demographic characteristics (e.g., education, residential status) and diagnostic history.

1.3.7. Debriefing survey

The debriefing survey was a brief four-item questionnaire. Participants were asked to report how often they logged social interactions with and without the reminder on a 0–100 scale using a slider (e.g., "How frequently did you complete your social logging with the text reminder?"). Additionally, participants were asked what they liked and did not like about the study. All participants completed this form.

1.3.8. Ecological momentary assessment of social interaction

Participants were asked to report each social interaction separately using a brief one-item online form. The text of the item read: "Have you had a social interaction in the last 30 min?" and participants were given the option to respond either "yes" or "no". Only social interactions reported between 9 AM and 9 PM were included in analyses. Based on prior research (Brown & Moskowitz, 1998; Granholm, Ben-Zeev, Fulford, & Swendsen, 2013), social interaction totals were binned and summed into morning (9 AM–12 PM), afternoon (12:01 PM–3 PM), late afternoon (3:01 PM–6 PM), and evening (6:01 PM–9 PM) time periods for each day. To ensure all participants reported on equivalent and complete days, only data from days 2 through 7 were included in the analyses. Therefore, the final analyses include the sums of social interactions in each of the 24 possible time bins across 6 days.

Given the importance of differentiating true missing values from bins with no reported social interactions in them (i.e., meaningful zero values), two indices were used to indicate missing data at the day level. First, the participant must not have reported any social interactions during that particular day of study. Second, the participant could not have provided any responses to text reminders for that day, regardless of whether the response indicated a social interaction. In total, 16 participants (23.2%) were missing at least one day (range 1–4), while a total of 28 (6.8%) total days were missing. However, consistent with prior work (Sandstrom & Dunn, 2014), if a participant reported a non-zero number of social interactions in a given day or responded to a reminder at any point throughout the day, all timepoints within that day that were blank were considered as representing meaningful zero values and treated as if the participant had zero interactions during that timepoint. In total, there were 153 (10%) bins across participants with meaningful zero values indicated by responses of "no social interaction" to a reminder prompt, and 363 (23%) bins with meaningful zero values indicated by non-response to prompts during non-missing days. In sum, at least one bin was coded as a meaningful zero value for each participant (range 1–15), with an average of 5.25 meaningful zero values/participant (22%).

On average, participants self-reported 74% compliance with the reminder on the debriefing form, with the majority (64%) reporting a response rate > 80%. Self-reported response rates were not significantly related to age, sex, ASD status, IQ, or alexithymia severity (all *r*s < .256, all *p*s > .124). Participants were considered to have low compliance if they fell in the lowest quartile for self-reported response rate both with (< 60%) and without (< 30%) the reminder prompt. Consistent with previous work (Moran, Culbreth, & Barch, 2018), participants (2 ASD, 4 neurotypical) who self-reported low compliance (with and without the text reminders) were removed from further analyses.

1.4. Data analytic plan

Given the hierarchical structure of the data, we utilized a multilevel modeling (MLM) framework, which can account for the inherent dependency of observations within persons, when testing models of person level differences (Singer & Willett, 2003). Models were created using an additive hierarchical multiple regression framework. Nested models with additional parameters were subsequently compared to the previous model using log likelihood ratio tests, which follow a χ^2 distribution. A Maximum Likelihood (ML) estimation procedure was used for all analyses to facilitate model comparisons. Continuous, between-person predictor variables were centered around their grand mean, while categorical variables and outcome variables were not centered (Enders & Tofighi, 2007). R version 3.4.4 (R Core Team, 2018) and the lme4 package (Bates, Mächler, Bolker, & Walker, 2015) were used for primary analyses, and the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2017) was used to calculate *p* values for fixed effects. Effect sizes of fixed effects were calculated using the package r2glmm to compute partial r^2 values with the Nakagawa and Schielzeth approach (for details see Edwards, Muller, Wolfinger, Qaqish, & Schabenberger, 2008; Jaeger, Edwards, Das, & Sen, 2017; Nakagawa, Johnson, & Schielzeth, 2017). Additional sensitivity analyses were run using Mplus 8.1 (Muthén & Muthén, 1998–2017; see Appendix).

First, descriptive statistics were calculated to examine the frequency of survey responses and social interactions across persons. Next, differences between the ASD and neurotypical groups on demographic and clinical variables were examined using Welch's *t*-test and χ^2 tests.

Before examining hypotheses, we used two procedures to determine the correct number of levels for the MLM. First, empty means models with random intercepts were used to partition the variability in the quantity of social interactions. Consistent with prior work (Fjermestad et al., 2016; Kahn & Schneider, 2013), we used ICC thresholds of 8% to ascertain if sufficient variance was evident at Level 2 in a two-level (observations within persons) model, or Level 3 in a three-level (observations within days within persons) model. We also used log likelihood ratio tests to compare the non-nested, two-level, and three-level

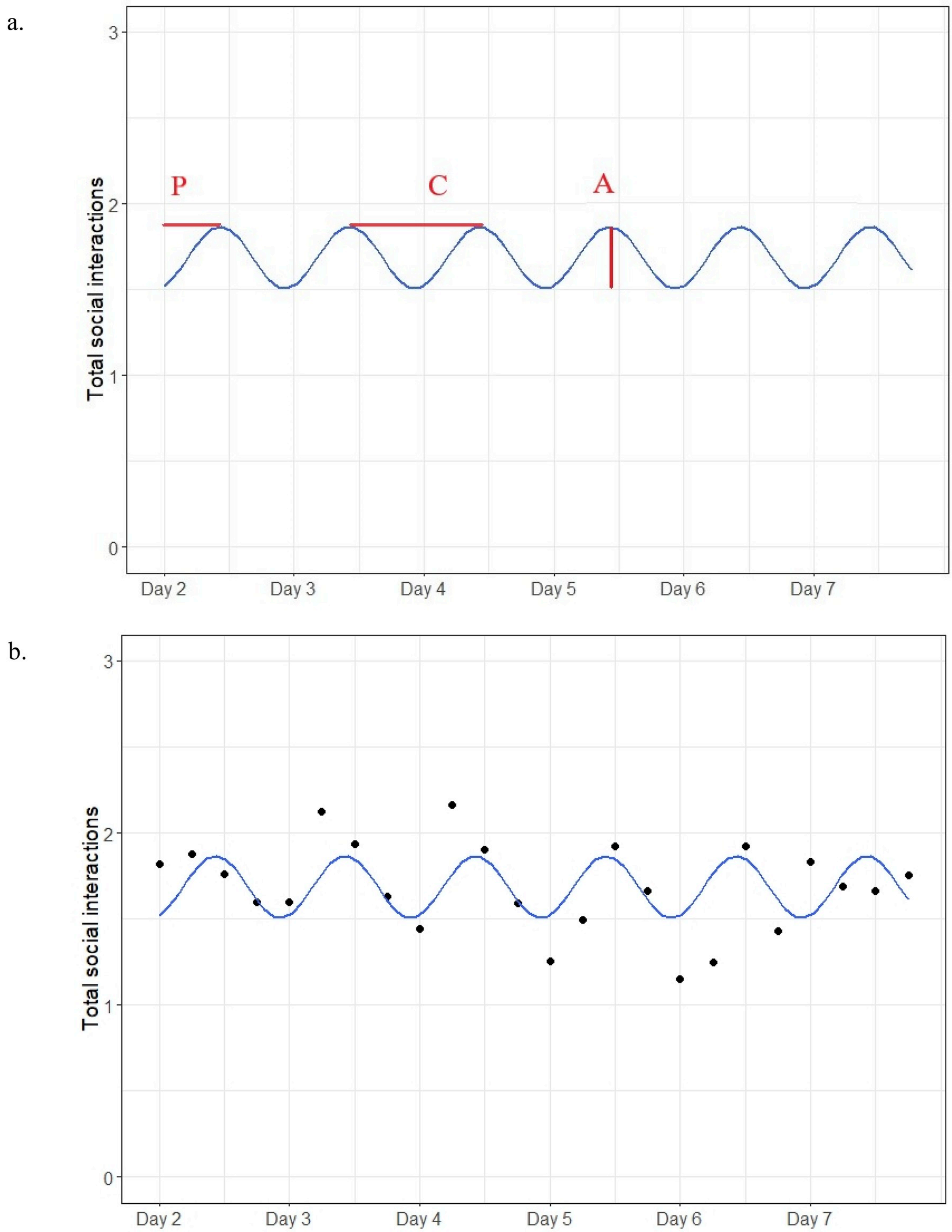


Fig. 1. a. Graph of an example sine and cosine function. Note: P = phase; C = cycle; A = amplitude. 1b. Time series graph of mean daily social interactions across days 2 through 7 of the study for all participants, with sine and cosine function overlaid.

models. Finally, we used a conjoint two-step approach to adjudicate initial model selection.

Next, we examined within-person (level 1) mean-level patterns in a two-level model. First, we included a linear parameter representing change across day of study. Consistent with prior work on patterns of social interaction (Warner, 1988), we then compared a cyclical model with 1-day cycle length (4 bins) to a simple linear trend model. Cyclical models are well-suited for modeling non-linear patterns of change often found in longitudinal behavioral data (Huh, Kaysen, & Atkins, 2015). The rising and falling of the cycle is represented as a sinusoidal function with a sine function corresponding to the phase (location) of the cycle and the cosine function representing its amplitude (height). If a cyclical trend was present (see Fig. 1), we conducted sensitivity analyses where we modeled a within-person pattern as a day-level polynomial trend in a three-level model (see Appendix). In addition, if we found a significant within-person cyclical trend, we tested the significance of within-person random slopes. Finally, to examine the impact of day of the week, a dichotomous variable representing weekend days compared to weekdays was added to the model.

To investigate our first hypothesis, that social interactions would be positively related to IQ and negatively related to age and male sex, these variables were added to the model as between-person fixed effects. In addition, to control for intervention effects (which were not a focus of the present study), dichotomous treatment status was added to the model.

To investigate hypothesis 2a, that individuals with ASD would have fewer social interactions than individuals without ASD, dichotomous ASD group status was added to the model. In order to test hypothesis 2b, that individuals with ASD would exhibit cycles of social interaction with lower amplitude than neurotypical individuals, the interaction between dichotomous ASD group status and the sine (reflecting the phase) and cosine (reflecting the amplitude) functions were added to the model (see Huh et al., 2015). In addition, we conducted supplementary analyses to investigate whether substituting continuous SRS-2 scores for the binary ASD status variable changed the pattern of results.

To assess our hypothesis 3a, that higher levels of alexithymia would be related to fewer social interactions, TAS-20 total score was added to the model. In addition, to examine whether alexithymia symptoms were associated with cycles of lower amplitude (hypothesis 3b), the interaction between TAS severity and the sine and cosine functions were added to the model.

Equation (1) illustrates the final cyclical multi-level regression model.

Level 1:

$$\# \text{ of interactions} = (\beta)_0 + \text{Dayofstudy}*(\beta)_1 + \sin(2\pi/4)\text{Time}_{ti}*(\beta)_2 + \cos(2\pi/4)\text{Time}_{ti}*(\beta)_3 + e$$

Level 2:

$$(\beta)_0 = (\beta)_{00} + \text{Intervention}*(\beta)_{01} + \text{IQ}*(\beta)_{02} + \text{Age}*(\beta)_{03} + \text{Sex}*(\beta)_{04} + \text{ASD}*(\beta)_{05} + \text{Alexithymia}*(\beta)_{06} + r_0$$

$$(\beta)_1 = (\beta)_{10} + r_1$$

$$(\beta)_2 = (\beta)_{20} + \text{ASD}*(\beta)_{21} + \text{Alexithymia}*(\beta)_{22} + r_2$$

$$(\beta)_3 = (\beta)_{30} + \text{ASD}*(\beta)_{31} + \text{Alexithymia}*(\beta)_{32} + r_3$$

2. Results

Participants completed a total of 4524 responses with an average of 60.32 responses per person (SD = 35.88). Additionally, participants reported engaging in 3545 total social interactions with an average of 47.27 interactions per person (SD = 30.01). Participants in the ASD group were significantly older than the neurotypical group and more likely to be male (see Table 1). In addition, the ASD group rated themselves significantly higher on ASD and alexithymia symptom severity. The two groups did not significantly differ on IQ.

Preliminary data analysis indicated that 20% of the variance in interaction quantity was due to differences between people ($ICC_{L2} = .20$). Likelihood ratio tests indicated that the two-level model (with observations nested within persons) was a significant improvement over a baseline model with no random intercept for individual participants, $-2\Delta LL(1) = 74.30, p < .001$. Thus, at least two levels were required for subsequent models. In the three-level model (with observations nested within days and days nested within persons), of the 80% of the variance captured by intraindividual variability, 79% was due to within day differences (Level 1), while only 1% was due to differences across days (Level 2). However, likelihood ratio tests indicated that a three-level model was a significant improvement over a two-level model, $-2\Delta LL(1) = 137.19$, $p < .001$ (see Appendix). Therefore, the two-step adjudication approach was equivocal on whether the two- or three-level model was superior. Due to the very small absolute amount of variance explained by Level 2 in the three-level model, and the requirements of modeling a continuous cyclical function over time, the two-level model was selected as the primary model sequence. Regardless, when the three-level model sequence was examined using appropriate within-day polynomial functions (see Appendix), the pattern of effects reported below did not change.

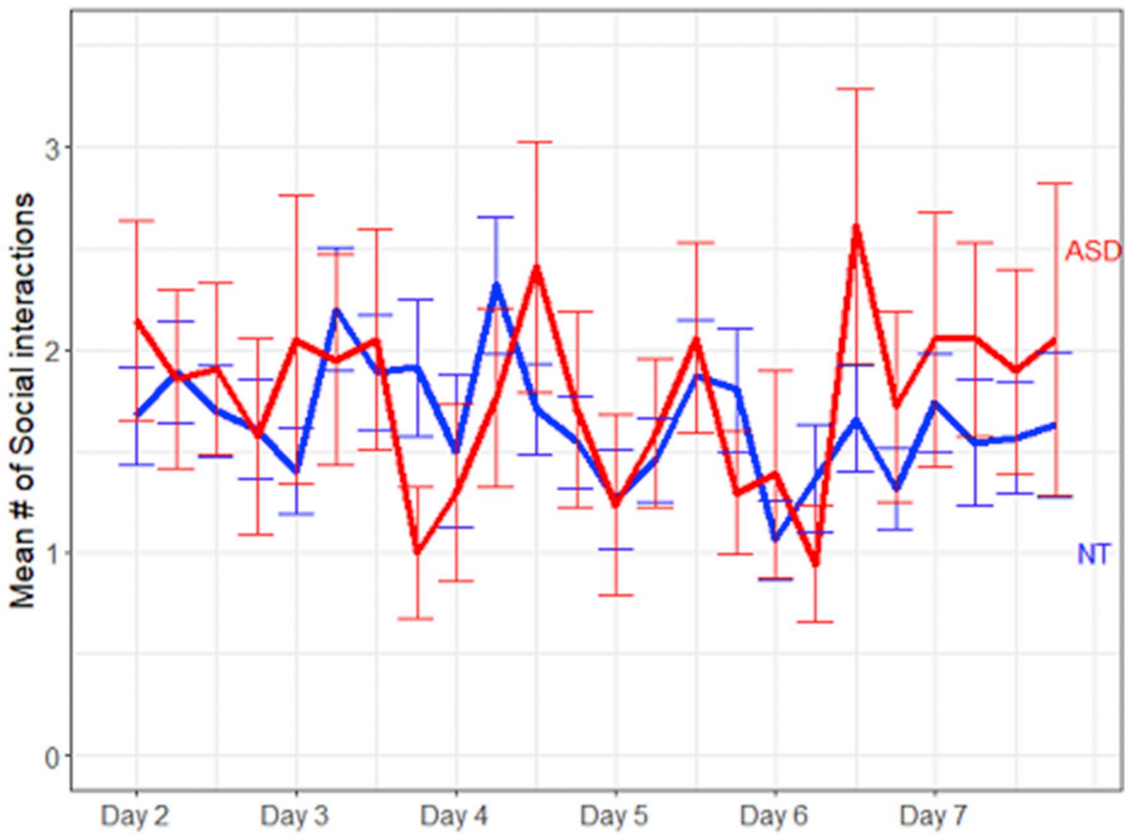
Model 1, which reflected a within-person linear trend of day of study, represented a significantly improved fit compared to a random intercept model, $-2\Delta LL(1) = 4.07$, $p = .043$ (see Table 2). There was a significant negative within-person linear trend of day of study, $b = -.05$ (.03), $p = .043$, which suggests that participants reported fewer interactions over the course of the study. In addition, Model 2, which also included a cyclical within-person pattern, was a significant improvement over Model 1, $-2\Delta LL(2) = 8.44$, $p = .015$. There was a significant effect of the sine function (phase), $b = -.16$ (.06), $p = .008$ (see Fig. 1b).

Table 2
Fixed effects estimates (Top) and variance-covariance estimates (Bottom) for models of the predictors of social interactions.

Parameter	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	1.90 (0.16)	1.89 (0.16)	1.62 (0.24)	1.66 (0.25)	1.61 (0.23)
Level 1 (timepoint)					
Day of study	−0.05* (0.03)	−0.05* (0.03)	−0.05* (0.03)	−0.05* (0.03)	−0.05⁺ (0.03)
Amplitude (cosine)		−0.08 (0.06)	−0.08 (0.06)	−0.08 (0.07)	−0.08 (0.08)
Phase (sine)		−0.16** (0.06)	−0.16** (0.06)	−0.15* (0.07)	−0.13 (0.08)
Level 2 (person)					
Control Group			0.31 (0.24)	0.30 (0.24)	0.23 (0.22)
Male			0.15 (0.23)	0.22 (0.25)	0.18 (0.23)
Age			0.02 (0.02)	0.03 (0.02)	0.03⁺ (0.02)
IQ			0.01 (0.01)	0.01 (0.01)	0.01 (0.01)
ASD				−0.21 (0.28)	0.16 (0.28)
ASD × amplitude				0.00 (0.14)	0.01 (0.15)
ASD × phase				0.06 (0.14)	0.13 (0.15)
Alexithymia Severity					−0.03** (0.01)
Alexithymia Severity × amplitude					−0.00 (0.01)
Alexithymia Severity × phase					0.01 (0.01)
	Random parameters				
Level 2					
Intercept/intercept (σ^2)	0.75*** (0.18)	0.75*** (0.17)	0.69*** (0.17)	0.68*** (0.17)	0.57*** (0.16)
Level 1					
Intercept/intercept (w_0)	3.02*** (0.06)	3.00*** (0.06)	3.00*** (0.06)	3.00*** (0.06)	3.00*** (0.06)
−2*log likelihood	6216.9	6208.5	6203.1	6202.4	6191.1

Note. ASD = ASD group status. Standard errors are in parentheses. $^+p < .10$. $^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.

a.



b.

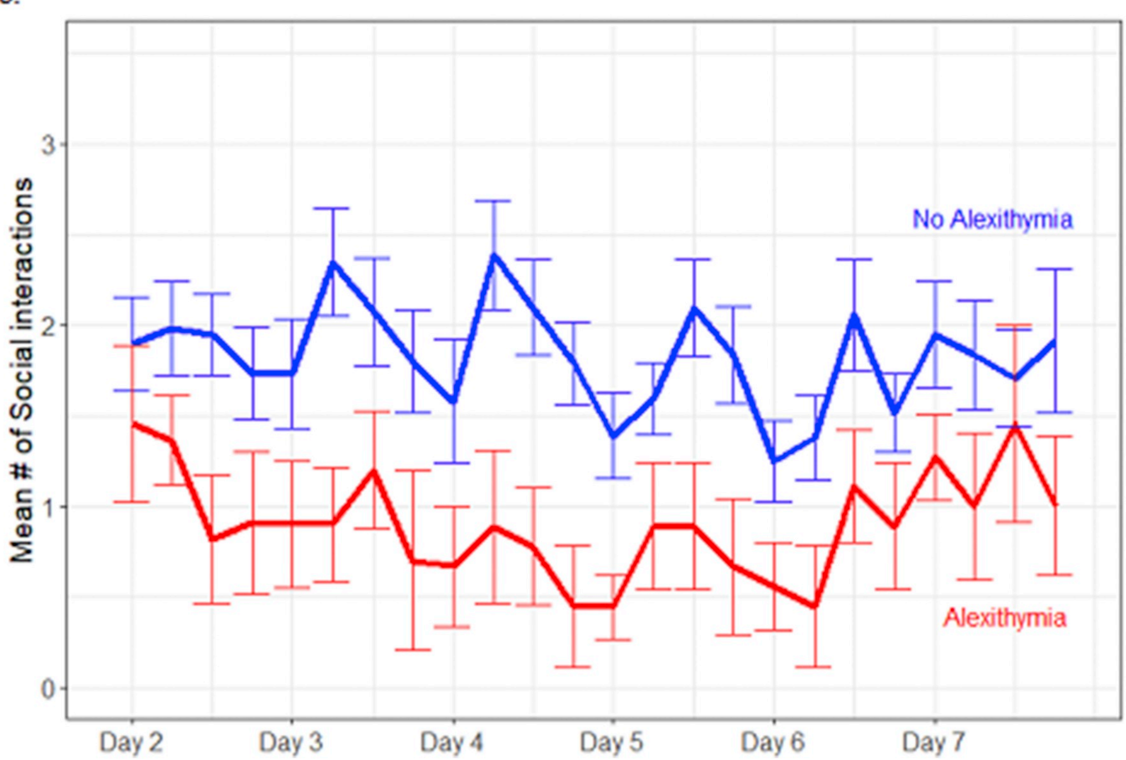


Fig. 2. Time series plots of mean social interactions with standard error bars across the course of the study for a. individuals with and without ASD and b. individuals with and without Alexithymia as measured by the TAS. Note: NT = Neurotypical

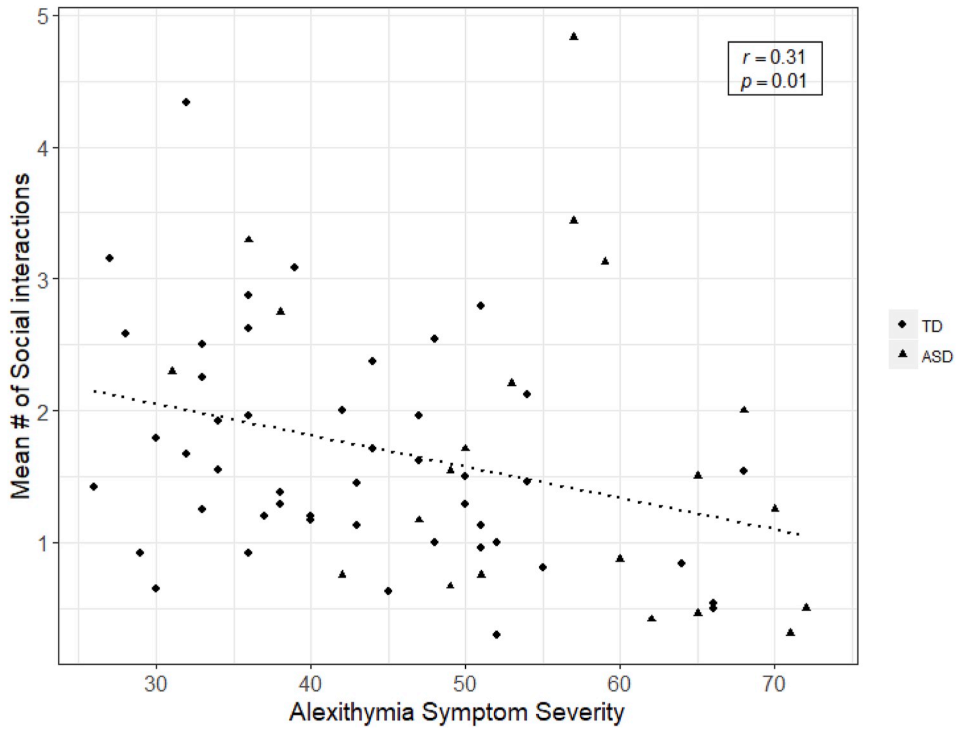


Fig. 3. Scatterplot of the association between alexithymia symptoms severity (as measured by the TAS-20) and person-level mean social interactions across time period (e.g. morning, early afternoon, late afternoon, evening).

There was no significant effect of within-person random slopes or the dichotomous variable representing weekend days compared to weekdays and neither were included in subsequent models.

To test hypothesis 1, person-level demographic factors (i.e., age, IQ score, and sex) were added to the model as level 2 fixed effects. In addition, a dichotomous variable representing treatment status was added to the model to control for intervention effects (Model 3; see Table 2). Results indicated that this model did not significantly improve fit, -2ΔLL(4) = 5.36, p = .252. Additionally, none of the person-level predictors were significant.

The addition of dichotomous ASD group status and its interactions with the sine and cosine functions did not significantly improve model fit over Model 3, -2ΔLL(3) = 0.77, p = .858 (Model 4; see Table 2). In addition, ASD group status and its interactions were not significant (see Fig. 2a). These results remained unchanged when using a continuous measure of ASD symptom severity (i.e., SRS-2; all $ps > .139$).

Finally, alexithymia symptom severity and its interactions with the sine and cosine functions were added to the model (Model 5; see Table 2). This model was a significant improvement over Model 4 -2ΔLL (3) = 11.29, p = .010. Above and beyond the effects of ASD, alexithymia symptom severity had a significant, negative association with number of social interactions (see Fig. 3) and accounted for about 16% of the total between-person variance, b = -.03 (0.01) p = .001, R^2 = .031. The interactions between alexithymia and the sine function, as well as the cosine function, were not significant (see Fig. 2b). We conducted additional exploratory analyses examining interactions between demographic factors, ASD status, and Alexithymia severity, but none of these interactions were significant (see Appendix).

3. Discussion

The goal of the present study was to directly examine the frequency and temporal patterning of in-person social interaction in adults with and without ASD. Based on previous work, we hypothesized that number of social interactions would be predicted by participant age, sex, IQ, ASD status, and alexithymia symptoms. We also expected social interactions to follow a cyclical pattern within and across days. Consistent with this, our results did support the presence of cyclical patterning and the hypothesis that alexithymia symptoms were negatively related to total social interactions (regardless of ASD status). Contrary to our hypotheses, number of social interactions did not vary as a function of participant age, sex, IQ, or ASD status. This stands in contrast to prior work suggesting that adults with ASD have fewer social interactions than neurotypical peers.

This is the first study to map the quantities and patterns of in-vivo social interactions among adults with ASD in comparison to their neurotypical peers. Findings suggest that retrospective bias may partially account for prior reports indicating that adults with ASD have a lower quantity of social interactions. Indeed, our results are consistent with prior work indicating that ASD symptom severity is not related to relationship status or social network size in cognitively-able adults (Geurts, Stek, & Comijs, 2016; Strunz et al., 2017). However, while adults with ASD may not differ in the total quantity of interactions, it is likely that the quality of their social interactions are poorer (Baron-Cohen & Wheelwright, 2003). For example, one study utilizing a daily diary method found that adults with ASD did not spend less time alone than matched controls; however, they differed in the individuals with whom they spent their time (Hintzen, Delespaul, van Os, & Myin-Germeys, 2010). Future research should include items about the type and quality of social interaction to explore whether there are important differences in the quality, context, and experience of social interactions for adults with ASD. These findings have important implications for treatment, which is often focused on increasing the quantity of social interactions for individuals with ASD. Our results suggest that it may more valuable for individuals with ASD to focus on enriching the interactions they already have, rather than attempt to engage in more frequent interactions.

While alexithymia has previously been associated with a broad range of psychopathology (Grabe, Spitzer, & Freyberger, 2004), this is the first study to directly link alexithymia severity to reduced social interactions. These results held with and without controlling for ASD status and demographic factors (see Appendix). Our findings extend a growing body of literature indicating that symptoms of alexithymia, not ASD symptom severity, may drive social isolation for individuals with ASD (Bird & Cook, 2013; Cook et al., 2013; Shah et al., 2016). Given the vast phenotypic heterogeneity seen among adults with ASD, alexithymia severity may be an important factor in identifying those who are most likely to show difficulties in their social interactions. While the mechanisms connecting alexithymia with social deficits are still unclear, evidence to date suggests alexithymia may interfere with how physiological arousal impacts the experience of emotions in adults with ASD (Gaigg, Cornell, & Bird, 2018). Future research should seek to determine if this link may help explain the decrease in social interactions seen here among individuals with higher levels of alexithymia, particularly among those with ASD.

3.1. Strengths and limitations

A major strength of this study was utilizing modern data collection methods to reduce reporting error and bias (Shiffman et al., 2008) as well as advanced data analytic techniques to allow for an analysis of how processes unfold over time (Hamaker & Wichers, 2017; Harari et al., 2016). In addition, this is the first study examining quantities of social behavior of adults with ASD to include a neurotypical comparison group, allowing for the first time to identify whether, and to what degree, individuals with ASD are engaging in atypical amounts of social interaction. Finally, daily quantities of social interactions reported and response rates to the EMA protocol in this study are consistent with previously reported daily quantities (Brown & Moskowitz, 1998; Moskowitz, 1994; Wheeler & Nezlek, 1977) and response rates reported in the larger literature (Liao, Skelton, Dunton, & Bruening, 2016; Wen, Schneider, Stone, & Spruijt-Metz, 2017), increasing confidence that these findings may be generalizable to other ASD samples.

One limitation of our data is that we only collected data for one week and did not ask participants to report interactions during late night through early morning hours. Thus, we could not examine whether participants demonstrated weekly fluctuations or whether the sinusoidal patterns we found extend throughout a 24-h period. In addition, participants were asked to report interactions within 30 min of their occurrence and given random interval reminders to report missed interactions that varied in interval distance up to 108 min. The data was binned into 3-h time bins to account for a lack of time-specificity (consistent with prior work); however, this prevented a more fine-grained, hourly analysis of the data. Although there were significant differences in the makeup of the ASD and neurotypical samples such that the ASD sample was older and more likely to be male, these variables were controlled for in the models, and did not significantly impact the results. Given potential lifestyle differences between students and adults from the community, we also ran supplemental analysis looking at the effect of recruitment source and found that it did not significantly impact the results (see Appendix). In addition, the frequency of social interaction in both samples was largely consistent with prior reports using diverse methodologies (Brown & Moskowitz, 1998; Moskowitz, 1994; Wheeler & Nezlek, 1977), increasing confidence in the generalizability of the sample. Relatedly, while the sample size of participants with ASD is relatively small, the novelty of the study design (which precluded derivation of meaningful power estimates), large amount of within-person data, and robustness of the identified pattern of interaction somewhat allays this concern. Additionally, we utilized a more inclusive method of defining ASD status by requiring that participants meet threshold on only the AQ. This limitation is mitigated by sensitivity analyses indicating that, when ASD group status is replaced with the SRS-2 in models, results are similar to those found in the main analyses. Finally, we recognize that alexithymia and autism are highly related (Poquérusse, Pastore, Dellantonio, & Esposito, 2018) and it is difficult to disentangle their individual effects, particularly with a comparison sample not selected for elevated alexithymia. Future research should examine the unique impact of alexithymia symptoms compared to ASD symptoms in an alexithymia-enriched non-ASD sample to more rigorously rule out the impact of ASD.

3.2. Summary of findings

This is the first study to map patterns of in-vivo social interactions of adults with ASD in comparison to neurotypical adults. This study reveals, for the first time, a cyclical pattern of social behavior in adults, and that this pattern is robust to the presence of ASD and alexithymia symptoms. In addition, in contrast to prior retrospective reports, our data indicate that alexithymia, not ASD symptom severity, may drive reductions in quantity of social interactions. These findings call attention to the need to reevaluate previously accepted notions regarding differences in social behavior utilizing modern methods such as in-vivo reporting. They also highlight the importance of using such tools to better and more precisely understand how the rhythms of social behavior unfold across time in both clinical and non-clinical populations as an index of the quality of fundamental aspects of human social behavior.

Declarations of interest

None.

Acknowledgements

This project was supported by the Alan Alda Fund for Communication. We would like to thank all the participants who provided not only their time but their information and without whom this study would not have been possible. Finally, we would like to thank the research assistants who tirelessly collected and entered data for this project.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.brat.2019.103477.

References

Bagby, R. M., Parker, J. D., & Taylor, G. J. (1994). The twenty-item Toronto Alexithymia Scale–I. Item selection and cross-validation of the factor structure. *Journal of Psychosomatic Research, 38*(1), 23–32.

Baron-Cohen, S., & Wheelwright, S. (2003). The friendship questionnaire: An investigation of adults with asperger syndrome or high-functioning autism, and normal sex differences. *Journal of Autism and Developmental Disorders, 33*(5), 509–517.

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (AQ): Evidence from asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders, 31*(1), 5–17.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *67*(1), 48. https://doi.org/10.18637/jss.v067.i01.

Berthoz, S., & Hill, E. L. (2005). The validity of using self-reports to assess emotion regulation abilities in adults with autism spectrum disorder. *European Psychiatry, 20*(3), 291–298. https://doi.org/10.1016/j.eurpsy.2004.06.013.

Bird, G., & Cook, R. (2013). Mixed emotions: The contribution of alexithymia to the emotional symptoms of autism. *Translational Psychiatry, 3*, e285. https://doi.org/10.1038/tp.2013.61.

Bishop-Fitzpatrick, L., DaWalt, L. S., Greenberg, J. S., & Mailick, M. R. (2017). Participation in recreational activities buffers the impact of perceived stress on quality of life in adults with autism spectrum disorder. *Autism Research, 10*(5), 973–982. https://doi.org/10.1002/aur.1753.

Bodenmann, G., Atkins, D. C., Schar, M., & Poffet, V. (2010). The association between daily stress and sexual activity. *Journal of Family Psychology, 24*(3), 271–279. https://doi.org/10.1037/a0019365.

Booth, A. (1972). Sex and social participation. *American Sociological Review, 37*(2), 183–193. https://doi.org/10.2307/2094026.

Brezis, R.-S., Noy, L., Alony, T., Gotlieb, R., Cohen, R., Golland, Y., et al. (2017). Patterns of joint improvisation in adults with autism spectrum disorder. *Frontiers in Psychology, 8*. https://doi.org/10.3389/fpsyg.2017.01790 1790.

Brown, K. W., & Moskowitz, D. S. (1998). Dynamic stability of behavior: The rhythms of our interpersonal lives. *J Pers, 66*(1), 105–134.

Chen, Y. W., Bundy, A. C., Cordier, R., Chien, Y. L., & Einfeld, S. L. (2017). A cross-

cultural exploration of the everyday social participation of individuals with autism spectrum disorders in Australia and Taiwan: An experience sampling study. *Autism, 21*(2), 231–241. https://doi.org/10.1177/1362361316636756.
Chen, Y. W., Bundy, A., Cordier, R., & Einfeld, S. (2014). Feasibility and usability of experience sampling methodology for capturing everyday experiences of individuals with autism spectrum disorders. *Disabil Health J, 7*(3), 361–366. https://doi.org/10.1016/j.dhjo.2014.04.004.
Chester, D. S., Pond, R. S., Jr., & DeWall, C. N. (2015). Alexithymia is associated with blunted anterior cingulate response to social rejection: Implications for daily rejection. *Social Cognitive and Affective Neuroscience, 10*(4), 517–522. https://doi.org/10.1093/scan/nsu082.
Coan, J. A., & Sbarra, D. A. (2015). Social baseline theory: The social regulation of risk and effort. *Curr Opin Psychol, 1*, 87–91. https://doi.org/10.1016/j.copsyc.2014.12.021.
Constantino, J. N., & Gruber, C. P. (2012). *Social responsiveness scale* (2nd ed.). Torrance, CA: Western Psychological Services SRS-2.
Cook, R., Brewer, R., Shah, P., & Bird, G. (2013). Alexithymia, not autism, predicts poor recognition of emotional facial expressions. *Psychological Science, 24*(5), 723–732. https://doi.org/10.1177/0956797612463582.
Côté, S., Moskowitz, D. S., & Zuroff, D. C. (2012). Social relationships and intraindividual variability in interpersonal behavior: Correlates of interpersonal spin. *J Pers Soc Psychol, 102*(3), 646–659. https://doi.org/10.1037/a0025313.
Damiano, C. R., Mazefsky, C. A., White, S. W., & Dichter, G. S. (2014). Future directions for research in autism spectrum disorders. *Journal of Clinical Child and Adolescent Psychology, 43*(5), 828–843. https://doi.org/10.1080/15374416.2014.945214.
Edwards, L. J., Muller, K. E., Wolfinger, R. D., Qaqish, B. F., & Schabenberger, O. (2008). An R2 statistic for fixed effects in the linear mixed model. *Statistics in Medicine, 27*(29), 6137–6157. https://doi.org/10.1002/sim.3429.
Enders, C. K., & Tofighi, D. (2007). Centering predictor variables in cross-sectional multilevel models: A new look at an old issue. *Psychological Methods, 12*(2), 121–138. https://doi.org/10.1037/1082-989x.12.2.121.
Fjermestad, K. W., Lerner, M. D., McLeod, B. D., Wergeland, G. J., Heiervang, E. R., Silverman, W. K., ... Haugland, B. S. (2016). Therapist-youth agreement on alliance change predicts long-term outcome in CBT for anxiety disorders. *Journal of Child Psychology and Psychiatry, 57*(5), 625–632. https://doi.org/10.1111/jcpp.12485.
Gaigg, S. B., Cornell, A. S., & Bird, G. (2018). The psychophysiological mechanisms of alexithymia in autism spectrum disorder. *Autism, 22*(2), 227–231. https://doi.org/10.1177/1362361316667062.
Geurts, H. M., Stek, M., & Comijs, H. (2016). Autism characteristics in older adults with depressive disorders. *American Journal of Geriatric Psychiatry, 24*(2), 161–169. https://doi.org/10.1016/j.jagp.2015.08.003.
Girard, J. M., Wright, A. G. C., Beeney, J. E., Lazarus, S. A., Scott, L. N., Stepp, S. D., et al. (2017). Interpersonal problems across levels of the psychopathology hierarchy. *Comprehensive Psychiatry, 79*, 53–69. https://doi.org/10.1016/j.comppsych.2017.06.014.
Golder, S. A., Wilkinson, D. M., & Huberman, B. A. (2007). *Rhythms of social interaction.* London: Messaging Within a Massive Online Network.
Grabe, H. J., Spitzer, C., & Freyberger, H. J. (2004). Alexithymia and personality in relation to dimensions of psychopathology. *American Journal of Psychiatry, 161*(7), 1299–1301. https://doi.org/10.1176/appi.ajp.161.7.1299.
Granholm, E., Ben-Zeev, D., Fulford, D., & Swendsen, J. (2013). Ecological momentary assessment of social functioning in schizophrenia: Impact of performance appraisals and affect on social interactions. *Schizophrenia Research, 145*(1–3), 120–124. https://doi.org/10.1016/j.schres.2013.01.005.
Hamaker, E. L., & Wichers, M. (2017). No time like the present:discovering the hidden dynamics in intensive longitudinal data. *Current Directions in Psychological Science, 26*(1), 10–15. https://doi.org/10.1177/0963721416666518.
Harari, G. M., Lane, N. D., Wang, R., Crosier, B. S., Campbell, A. T., & Gosling, S. D. (2016). Using smartphones to collect behavioral data in psychological science:opportunities, practical considerations, and challenges. *Perspectives on Psychological Science, 11*(6), 838–854. https://doi.org/10.1177/1745691616650285.
Hill, E., Berthoz, S., & Frith, U. (2004). Brief report: Cognitive processing of own emotions in individuals with autistic spectrum disorder and in their relatives. *Journal of Autism and Developmental Disorders, 34*(2), 229–235. https://doi.org/10.1023/b:Jadd.0000022613.41399.14.
Hintzen, A., Delespaul, P., van Os, J., & Myin-Germeys, I. (2010). Social needs in daily life in adults with pervasive developmental disorders. *Psychiatry Research, 179*(1), 75–80. https://doi.org/10.1016/j.psychres.2010.06.014.
Horowitz, L. M., & Strack, S. (Eds.). (2010). *Handbook of interpersonal psychology: Theory, research, assessment, and therapeutic interventions*. Hoboken, NJ, US: John Wiley & Sons Inc.
Huh, D., Kaysen, D. L., & Atkins, D. C. (2015). Modeling cyclical patterns in daily college drinking data with many zeroes. *Multivariate Behavioral Research, 50*(2), 184–196. https://doi.org/10.1080/00273171.2014.977433.
Hus, V., & Lord, C. (2014). The autism diagnostic observation Schedule, Module 4: Revised algorithm and standardized severity scores. *Journal of Autism and Developmental Disorders, 44*(8), 1996–2012. https://doi.org/10.1007/s10803-014-2080-3.
Jaeger, B. C., Edwards, L. J., Das, K., & Sen, P. K. (2017). An R2 statistic for fixed effects in the generalized linear mixed model. *Journal of Applied Statistics, 44*(6), 1086–1105. https://doi.org/10.1080/02664763.2016.1193725.
Kahn, J. H., & Schneider, W. J. (2013). It's the destination and it's the journey: Using multilevel modeling to assess patterns of change in psychotherapy. *Journal of Clinical Psychology, 69*(6), 543–570. https://doi.org/10.1002/jclp.21964.
Kaufman, A. S., & Kaufman, N. L. (2004). *Kaufman brief intelligence test* (2nd ed.). Circle Pines, MN: AGS Publishing.
Khor, A. S., Gray, K. M., Reid, S. C., & Melvin, G. A. (2014). Feasibility and validity of ecological momentary assessment in adolescents with high-functioning autism and Asperger's disorder. *Journal of Adolescence, 37*(1), 37–46. https://doi.org/10.1016/j.adolescence.2013.10.005.
Kovac, M., Mosner, M., Miller, S., Hanna, E. K., & Dichter, G. S. (2016). Experience sampling of positive affect in adolescents with autism: Feasibility and preliminary findings. *Res Autism Spectr Disord, 29–30*, 57–65. https://doi.org/10.1016/j.rasd.2016.06.003.
Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: Tests in linear mixed. *Effects Models, 82*(13), 26. https://doi.org/10.18637/jss.v082.i13 2017.
Lane, R. D., Sechrest, L., Reidel, R., Weldon, V., Kaszniak, A., & Schwartz, G. E. (1996). Impaired verbal and nonverbal emotion recognition in alexithymia. *Psychosomatic Medicine, 58*(3), 203–210.
Lansford, J. E., Sherman, A. M., & Antonucci, T. C. (1998). Satisfaction with social networks: An examination of socioemotional selectivity theory across cohorts. *Psychology and Aging, 13*(4), 544–552.
Leary, M. R., & Hoyle, R. H. (Eds.). (2009). *Handbook of individual differences in social behavior*. New York, NY, US: Guilford Press.
Liao, Y., Skelton, K., Dunton, G., & Bruening, M. (2016). A systematic review of methods and procedures used in ecological momentary assessments of diet and physical activity research in youth: An adapted STROBE checklist for reporting EMA studies (CREMAS). *Journal of Medical Internet Research, 18*(6), e151. https://doi.org/10.2196/jmir.4954.
Lombardo, M. V., Barnes, J. L., Wheelwright, S. J., & Baron-Cohen, S. (2007). Self-referential cognition and empathy in autism. *PLoS One, 2*(9), e883. https://doi.org/10.1371/journal.pone.0000883.
Lord, C., Elsabbagh, M., Baird, G., & Veenstra-Vanderweele, J. (2018). Autism spectrum disorder. *The Lancet, 392*(10146), 508–520. https://doi.org/10.1016/S0140-6736(18)31129-2.
Lord, C., Rutter, M., DiLavore, P. C., Risi, S., Gotham, K., & Bishop, S. (2012). *Autism diagnostic observation Schedule* (2nd ed.). Manual. Los Angeles, CA: Western Psychological Services.
Magiati, I., Tay, X. W., & Howlin, P. (2014). Cognitive, language, social and behavioural outcomes in adults with autism spectrum disorders: A systematic review of longitudinal follow-up studies in adulthood. *Clinical Psychology Review, 34*(1), 73–86. https://doi.org/10.1016/j.cpr.2013.11.002.
Marcum, C. S. (2013). Age differences in daily social activities. *Research on Aging, 35*(5), 612–640. https://doi.org/10.1177/0164027512453468.
Moran, E. K., Culbreth, A. J., & Barch, D. M. (2018). Emotion regulation predicts everyday emotion experience and social function in schizophrenia. *Clinical Psychological Science, 6*(2), 271–279. https://doi.org/10.1177/2167702617738827.
Moskowitz, D. S. (1994). Cross-situational generality and the interpersonal circumplex. *J Pers Soc Psychol, 5*, 921 Retrieved from http://proxy.library.stonybrook.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=edsgao&AN=edsgcl.15503391&site=eds-live&scope=site.
Moskowitz, D. S., & Sadikaj, G. (2012). Event-contingent recording. *Handbook of research methods for studying daily life* (pp. 160–175). New York, NY, US: Guilford Press.
Muthén, L. K., & Muthén, B. O. (1998-2017). *Mplus user's guide* (8th ed.). Los Angeles, CA: Muthén & Muthén.
Nakagawa, S., Johnson, P. C. D., & Schielzeth, H. (2017). The coefficient of determination R(2) and intra-class correlation coefficient from generalized linear mixed-effects models revisited and expanded. *Journal of The Royal Society Interface, 14*(134), 20170213. https://doi.org/10.1098/rsif.2017.0213.
Orsmond, G. I., Krauss, M. W., & Seltzer, M. M. (2004). Peer relationships and social and recreational activities among adolescents and adults with autism. *Journal of Autism and Developmental Disorders, 34*(3), 245–256.
Orsmond, G. I., Shattuck, P. T., Cooper, B. P., Sterzing, P. R., & Anderson, K. A. (2013). Social participation among young adults with an autism spectrum disorder. *Journal of Autism and Developmental Disorders, 43*(11), 2710–2719. https://doi.org/10.1007/s10803-013-1833-8.
Poquérusse, J., Pastore, L., Dellantonio, S., & Esposito, G. (2018). Alexithymia and autism spectrum disorder: A complex relationship. *Frontiers in Psychology, 9*. https://doi.org/10.3389/fpsyg.2018.01196 1196-1196.
Pugliese, C. E., Kenworthy, L., Bal, V. H., Wallace, G. L., Yerys, B. E., Maddox, B. B., et al. (2015). Replication and comparison of the newly proposed ADOS-2, Module 4 algorithm in ASD without ID: A multi-site study. *Journal of Autism and Developmental Disorders, 45*(12), 3919–3931. https://doi.org/10.1007/s10803-015-2586-3.
R Core Team (2018). *R: A language and environment for statistical computing.* Vienna, Austria: R Foundation for Statistical Computing.
Sandstrom, G. M., & Dunn, E. W. (2014). Social interactions and well-being:the surprising power of weak ties. *Personality and Social Psychology Bulletin, 40*(7), 910–922. https://doi.org/10.1177/0146167214529799.
Shah, P., Hall, R., Catmur, C., & Bird, G. (2016). Alexithymia, not autism, is associated with impaired interoception. *Cortex, 81*, 215–220. https://doi.org/10.1016/j.cortex.2016.03.021.
Shiffman, S., Stone, A. A., & Hufford, M. R. (2008). Ecological momentary assessment. *Annual Review of Clinical Psychology, 4*, 1–32.
Singer, J. D., & Willett, J. B. (2003). *Applied longitudinal data analysis: Modeling change and event occurrence.* New York, NY: Oxford University Press.
Stone, A. A., & Shiffman, S. (1994). Ecological momentary assessment (ema) in behavioral medicine. *Annals of Behavioral Medicine, 16*(3), 199–202. https://doi.org/10.1093/abm/16.3.199.
Strunz, S., Schermuck, C., Ballerstein, S., Ahlers, C. J., Dziobek, I., & Roepke, S. (2017). Romantic relationships and relationship satisfaction among adults with asperger syndrome and high-functioning autism. *Journal of Clinical Psychology, 73*(1),

113–125. https://doi.org/10.1002/jclp.22319.
Tomasello, M. (1999). *The cultural origins of human cognition.* Cambridge, MA, US: Harvard University Press.
Volkmar, F. R., Lord, C., Bailey, A., Schultz, R. T., & Klin, A. (2004). Autism and pervasive developmental disorders. *Journal of Child Psychology and Psychiatry, 45*(1), 135–170. https://doi.org/10.1046/j.0021-9630.2003.00317.x.
Warner, R. (1988). Rhythm in social interaction. *The social psychology of time: New perspectives* (pp. 63–88). Thousand Oaks, CA, US: Sage Publications, Inc.
Wen, C. K. F., Schneider, S., Stone, A. A., & Spruijt-Metz, D. (2017). Compliance with mobile ecological momentary assessment protocols in children and adolescents: A systematic review and meta-analysis. *Journal of Medical Internet Research, 19*(4), e132. https://doi.org/10.2196/jmir.6641.
Wheeler, L., & Nezlek, J. (1977). Sex differences in social participation. *J Pers Soc Psychol, 35*(10), 742–754. https://doi.org/10.1037/0022-3514.35.10.742.
Wheeler, L., & Reis, H. T. (1991). Self-recording of everyday life events: Origins, types, and uses. *Journal of Personality, 59*(3), 339–354. https://doi.org/10.1111/j.1467-6494.1991.tb00252.x.
Woodbury-Smith, M. R., Robinson, J., Wheelwright, S., & Baron-Cohen, S. (2005). Screening adults for asperger syndrome using the AQ: A preliminary study of its diagnostic validity in clinical practice. *Journal of Autism and Developmental Disorders, 35*(3), 331–335.