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BRIEF REPORT

Opportunities for free play and young children's autonomic regulation

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Abstract

Aspects of the social environment have been linked to the physiological mechanisms underlying behavioral self-regulation. Play, a behavior connected to regulatory behaviors such as delay of gratification and regulation of emotions, might be an aspect of social environments that is supportive of healthy physiological adaptation. We examined whether opportunities for social free play with peers, as reported by mothers, would predict children's autonomic regulation (via respiratory sinus arrhythmia; RSA) in a sample of 78 five-year-old children. As a proxy for play experience generally, frequency of social free play in the past week predicted higher levels of RSA functioning across both baseline and stress conditions, but did not account for physiological rate of change between conditions. Thus, frequent social free play opportunities might be a general positive influence on children's autonomic regulation by supporting increased parasympathetic activation but not a significant influence on children's response to stress in the moment. Attention to the role of play in autonomic regulation is critical, as children's free play opportunities might be declining.

KEYWORDS

autonomic regulation, early childhood, free play, respiratory sinus arrhythmia, vagal tone

1 | INTRODUCTION

Healthy physiology is a critical component of children's behavioral self-regulation. In particular, individual differences in patterns of children's parasympathetic regulation have been linked with self-regulatory capacities, such as emotion regulation in social contexts (Miller et al., 2013 ; Quiñones-Camacho & Davis, 2019), externalizing problems (Zhang et al., 2020), and executive functioning tasks (Scrimin et al., 2019). While some of these studies (e.g., Quiñones-Camacho & Davis, 2019; Zhang et al., 2020) focus on parasympathetic regulation as a predictor of children's regulatory outcomes, understanding the aspects of the social environment that support the development of adaptive physiological systems in the first place is also a goal of research in this area (e.g., Hastings et al., 2008; Miller et al., 2013; West et al., 2020). In line with these latter studies, we investigated children's opportunities for social free play with peers as a predictor of the development of healthy physiological functioning.

Despite positive associations between play and specific self-regulatory skills, such as delay of gratification (Cemore & Herwig, 2005), emotion regulation (LaFreniere, 2011; Lindsey & Colwell, 2013), and executive functioning (Thibodeau et al., 2016), play has yet to be investigated as an influence on the development of the adaptive physiological functioning that might underlie these skills. The idea that play might relate to individual differences in children's physiological functioning is supported by work associating social play with positive regulation of neurobiological reactivity over time (Hatfield & Williford, 2017) and the fact that physiologically stressed children given occasions for free play subsequently demonstrate less anxiety than those denied play (Barnett & Storm, 1981). We hypothesized that higher frequency of social free play would positively relate to both higher vagal tone and vagal flexibility as measured by respiratory sinus arrhythmia (RSA).

RSA is a measure of the adaptive functioning of the vagus nerve (Cranial Nerve X; Beauchaine & Thayer, 2015), which is part of the

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parasympathetic nervous system that innervates the heart and inhibits sympathetic activity and threat-defensive behaviors such as fight, flight, and freeze responses (Petrocchi & Cheli, 2019). The vagus nerve also inhibits hypothalamic–pituitary–axis activity that is related to stress and promotes calming and restorative functions (Porges, 2011). Studies measuring individual differences in RSA have suggested that healthy vagal tone is associated with children's positive affect (West et al., 2020) and executive function skills (Obradović & Finch, 2017), two variables that are also associated with social forms of free play in early childhood (Howes, 2014; Thibodeau et al., 2016), although play's relation to RSA has not been investigated directly.

RSA is calculated by assessing heart rate variability as it covaries with respiration (Beauchaine et al., 2019). Because heart rate changes rapidly depending upon context and situation, two types of RSA have been investigated: tonic and phasic vagal tone (or vagal flexibility; Laborde et al., 2017). *Tonic* vagal tone refers to RSA during a nonstressful or baseline condition and is the assessment of RSA at a single time point. However, if multiple time points and conditions are included, RSA can be evaluated as it changes across conditions. This change, referred to as *phasic* vagal tone or *vagal flexibility*, is often calculated as an arithmetic change score between baseline and stress (e.g., Blair & Peters, 2003; Calkins et al., 2008; Hastings et al., 2008; Quiñones-Camacho & Davis, 2019; Zhang et al., 2020). This approach captures differences between conditions but does not capture the rate of change. Consequently, we used structural equation modeling to assess both tonic and phasic vagal tone, which enabled us to probe physiological functioning both at particular states (i.e., baseline and stress) and as it changes across conditions. Although the use of nonlinear, dynamic statistical techniques to examine RSA change over time is gaining in popularity (e.g., Miller et al., 2013; Miller et al., 2016; Obradović & Finch, 2017), such studies are still relatively few (West et al., 2020). This study thus contributes to the growing literature identifying and discriminating effects on both tonic and phasic vagal functioning.

Higher tonic vagal tone at baseline corresponds with more positive outcomes, such as better cognitive performance and prefrontal neural functioning (Thayer et al., 2009). In contrast, vagal flexibility, assessing if the vagal response is adaptive or supportive of well-being behaviors, is dependent upon the context and situation (Porges, 2007). For example, a decrease in vagal tone may facilitate physical and mental responses to stress, but if the stimuli or context requires more executive effortful control, and hence, more vagal activity, too large a decrease in vagal tone could be characterized as maladaptive. In our assessment of vagal flexibility, we included a "stress" condition that required parent–child dyads to work together on a difficult puzzle. We expected this context to prompt a decrease in children's vagal tone. Likewise, for the shift from stress to recovery, an increase was considered adaptive as it would suggest an appropriate alleviation of the stress response with the removal of the stressor (Porges, 2011).

If social free play supports physiological processes related to self-regulation, we hypothesized that frequent opportunities for play with peers might promote healthy physiological functioning through vagal tone, as measured by RSA. Specifically, we expected a positive relation between children's social free play opportunities and tonic vagal tone at baseline and in the stress condition. We also expected greater opportunities for social free play to correspond with greater vagal flexibility, as characterized by slower rates of change (gradual slope) between baseline and stress and faster rates of change (steeper slope) between stress and recovery.

2 | METHOD

2.1 | Participants

Data were taken from a larger longitudinal study of children's early life experience with survey assessments prenatally and at 3 months, and surveys/laboratory observations at 8 months, 12 months, 4 years ($M_{age} = 4.40$ years, range = 3.25–5.09 years) and 5 years ($M_{age} = 5.63$ years, range = 4.92–6.33 years). Play data were collected at the last two time points, and RSA only at the age of 5 years because elements of our protocol (e.g., sitting still, cognitive stress task) are difficult for younger children. At the 5-year assessment, the sample included 78 mothers ($M_{age} = 36.75$ years; range = 25–49 years) and children (44 girls, 34 boys). Although 96 families participated, one child refused to participate in the RSA data collection and the remainder were dropped owing to technical problems with the equipment, an unexpected power outage, and issues common in RSA data collection with young children, such as children touching the electrodes, movement, and electrodes falling off (Quiñones-Camacho & Davis,). Children mostly came from households with other children: no other children (11.5%), 1 (37.2%), 2 (26.9%), 3 (12.8%), 4 (9%), 5 (2.6%), and half of the children spent at least 20 h per week in school/daycare: ≤ 5h (7.7%), 6–10 h (11.5%), 11–20 h (20.5%), 20–30 h (9%), ≥30 h (41%).

Mothers' education levels ranged from some high school (8.2%), high school diploma/ GED (11.2%), some college (19.5%), Associate's or Technical degree (8.7%), Bachelor's degree (23.8%), Master's degree (12.6%), to Doctorate/professional degree (5.6%). Annual household income ranged from under $50,000 (59.8%), $50,000–$75,000 (15.2%), $75,000-$100,000 (9.5%), to over $100,000 (6.9%). Participants received a gift card to thank them for participating.

2.2 | Measures

2.2.1 | Social free play opportunities

Opportunities for social free play were measured at the 4-year and 5-year assessments through two items on the Evolved Developmental Niche Provision Report (Narvaez et al., 2019), a checklist about the child's experience in the past week (6-point Likert scale; 1 = never; 6 = several times a day) that provides a snapshot of a child's routine experiences. The play score was the mean of two questions: "How much did the child play actively and freely with other children outside (play organized by the children; not organized activities)?" and "How much did the child play actively and freely with other children inside (play organized by the children, not organized activities and not passive watching)?" We correlated the mean scores from the two time points to test for consistency in the child's experience. Owing to the significant developmental and environmental changes that might occur in the interval (e.g., onset of formal schooling), we expected a moderate positive correlation to indicate consistency in frequency of opportunities for play. Only data from the 5-year assessment was used in the models predicting RSA.

2.2.2 | Respiratory sinus arrhythmia

Children's RSA functioning was evaluated using electrocardiogram (ECG) and respiration rate and volume. Together, ECG and respiration comprise an index of vagal tone functioning: the amplitude of heart rate rhythm associated with frequency of spontaneous breathing (Porges & Byrne, 1992). Both mother and child were monitored but only child data are reported here. In order to monitor ECG and respiration, three disposable Ag–AgCl electrodes were placed on the participant's chest in a lead II configuration (two under the clavicle and 1 on the lower left rib), connected to an ECG amplifier, and output to a Vagal Tone Monitor-II (Biopac Nomadix, Inc.).

2.2.3 | Biological data qualification

Bionomadix Wireless Respiration and ECG module pair (matched transmitter and receiver) detected the peak of the R-wave with 1-ms accuracy, timed sequential heart periods to the nearest millisecond (Riniolo & Porges, 1997) and stored the heart periods in files for off-line analyses of RSA and heart period. The data files of sequential heart periods (i.e., R–R intervals in ms) were input into CardioEdit software (Brain–Body Center, University of Illinois at Chicago, 2007) in order to edit outlier data produced by movement and digitizing error. Editing consisted of integer addition or division of sequential values.

Heart period data were visually inspected and edited off-line using CardioEdit software. Editing consisted of integer arithmetic (i.e., dividing intervals when detections were missed or and adding intervals when spuriously invalid detections occurred). RSA was derived from the edited heart period via CardioBatch Plus Synchrony v1 (Brain–Body Center for Psychophysiology and Bioengineering, University of North Carolina, Chapel Hill, 2018), which employs the Porges (1985) method. The Porges method applies a time-frequency algorithm to quantify the amplitude of RSA with age-specific parameters, sensitive to the maturational shifts in the frequency of spontaneous breathing. CardioBatch Plus Synchrony additionally uses the same resampling rate (step b below), according to the fastest respiration rate for either member of the dyad. For the current study, steps included: (a) R–R intervals were timed to the nearest millisecond to produce a time series of sequential heart periods; (b) sequential heart periods were resampled into 250-ms intervals to produce time-based data; (c) the time-based series was detrended by a cubic moving polynomial filter MPF (41-point for adult and 21-point for child) (Porges & Bohrer, 1990) that was stepped through the data to create a smoothed template and the template was subtracted from the original time-based series to generate a detrended residual series; (d) the detrended time series was bandpassed to restrict the variance in the heart period pattern associated with spontaneous breathing (i.e., child: 0.24–1.04 Hz) specific to each member of the dyad; and (e) the resulting bandpassed time series was divided into epochs (30 s, in this case), the natural logarithm of the variance of each epoch was calculated as the measure of the amplitude of RSA (Riniolo & Porges, 1997), and the epochs were averaged within each condition.

2.3 | Procedures

In order to investigate both tonic and phasic vagal tone, participants underwent a standard RSA data collection procedure across three time points (Laborde et al., 2017) while under observation at a university center. A trained experimenter assessed vagal tone functioning of the child under three different conditions: baseline, stress, and recovery. Prior to gathering children's RSA baseline, the dyad participated in a series of sedentary activities (e.g., reading a book). RSA data collection started with a baseline period of two minutes where dyads viewed a nonarousing, relaxing video (butterflies with soothing instrumental music). Next, they were asked to complete a challenging three-dimensional puzzle together in five minutes (stress period). In the recovery phase, dyads viewed a second nonarousing, relaxing video (babies with soothing piano music) for 2 min. Participants were instructed not to talk during the conditions in order to prevent respiration changes and consequent RSA alterations. The child was allowed to move his/her hands in order to manipulate the puzzle pieces but remained seated throughout the procedure.

Instruments included BioPac hardware and AcqKnowledge software. Editing of data for outliers and artifacts was done offline according to Porges Laboratory method using CardioEdit. Editors received RSA editing reliability testing through The Brain-Body Center for Psychophysiology and Bioengineering laboratory.

3 | RESULTS

We began our analyses by examining the play measures from the two time points. The means were similar (4 years: $M = 4.47$; SD = 1.00; 5 years: $M = 4.77$; SD = 0.95). Given that these data were gathered approximately 1.5 years apart across a transitional developmental period, the positive correlation that emerged suggested that this measure captured consistent individual variation in children's opportunities for play: $r(73) = .39$, $p = .001$.

Next, we examined the RSA data and as expected, values across the three conditions were nonlinear (see Table 1 for descriptive statistics and correlations). Due to the varying nature of RSA fluctuations, the dip in the stress condition relative to baseline and recovery was expected. Lower vagal tone values indicate less parasympathetic activation, which indicates a rise in heart rate variability, which was expected as participants completed the puzzle task.

TABLE 1 Descriptive statistics for study variables

Variable	Min	Max	Mean (SD)	Skewness (SD)	Kurtosis	1	2	3
1. Play	1.00	6.00	4.77 (0.95)	−1.07 (.27)	2.51	–		
2. RSA baseline	1.83	7.82	6.12 (1.10)	−1.13 (.27)	2.69	.32**	–	
3. RSA stress	2.30	7.25	5.51 (1.00)	−.72 (.27)	.43	.30**	.76**	–
4. RSA recovery	2.15	8.25	6.14 (0.94)	−1.11 (.27)	3.47	.25*	.84**	.82**

Note: $N = 78$.
*$p < .05$.
**$p < .01$.

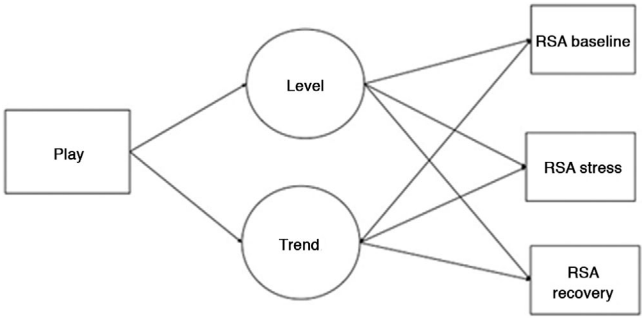

FIGURE 1 Latent basis coefficient model for children's RSA as predicted by social free play

We used a latent basis coefficient model to accurately account for nonlinear fluctuations in vagal tone functioning. This type of latent growth curve model takes into account nonlinear change patterns across time because the basis coefficient at some time points is freely estimated (Grimm et al., 2011; McArdle & Epstein, 1987), and it has been used in previous RSA research with data from children this age (Miller et al., 2013). The models were conducted using Mplus (Muthén & Muthén, 2019). Goodness of fit was assessed using standardized root mean square residual (SRMR) values below 0.08, comparative fit index (CFI) values greater than or equal to .95 and chi-square with *p* values greater than .05 (Hu & Bentler, 1999).

Our model included two latent variables (see Figure 1). The latent variable *level* indicated children's latent RSA values at specific time points; factor loadings of this variable were all fixed to be 1. The second latent variable, *trend*, modeled vagal flexibility through latent RSA change (slope) between time points. We created two models to capture level and trend across the three conditions. In Model 1, the factor loadings of *trend* were 0 and 1 fixed for baseline and stress respectively, with the factor loading for recovery allowed to be freely estimated. In this case, *level* indicated children's latent RSA value at baseline and *trend* indicated the latent change in RSA between baseline and stress. In Model 2, the factor loadings for *trend* included 0 and 1 for stress and recovery, respectively, with baseline being allowed to freely vary. In this case, *level* indicated children's latent RSA value at the stress condition and *trend* indicated the latent change in RSA between stress and recovery.

Modeling the child's RSA values across all three conditions with reports of the child's play experience as an exogenous factor demonstrated two good fitting models for baseline to stress, $\chi^2 = 5.70$, $p = .34$, CFI = .99, SRMR = .042; and stress to recovery, $\chi^2 = 5.42$, $p = .37$, CFI = .99, SRMR = .061. Previous work (Miller et al., 2013) investigating dynamic RSA change using latent basis coefficient modeling in this age group found gender differences; in our sample, gender and RSA during stress ($r = .27$, $p = .02$) and recovery ($r = .25$, $p = .03$) were also significantly correlated. Consequently, we used gender as a control variable.

Our hypothesis was that social free play opportunities would positively predict RSA mean levels and the rate of change across conditions. For both models, this hypothesis was supported for level of RSA ($\beta_{\text{baseline}} = .44$, $p = .002$; $\beta_{\text{stress}} = .36$, $p = .002$) but not for rate of change across conditions ($\beta_{\text{baseline-to-stress}} = -.11$, $p = .20$; $\beta_{\text{stress-to-recovery}} = .02$, $p = .56$).

4 | DISCUSSION

The aim of this study was to examine young children's opportunities for social free play as a possible predictor of physiological regulation as measured by vagal tone. We chose play as a predictor because of the plethora of research relating it to self-regulatory behaviors (e.g., Bodrova et al., 2013; Pellegrini, 1992; Uren & Stagnitti, 2009) and because it has been linked longitudinally to improved neurophysiological functioning as measured by cortisol (Hatfield & Williford, 2017). However, this study is the first to connect opportunities for social free play to vagal functioning—a physiological mechanism underlying self-regulation.

Our measures of RSA at baseline and during a challenging cognitive task indicated lower levels of stress (higher tonic vagal tone) among those children with reports of greater opportunities for social free play in the past week, although play did not relate to vagal flexibility (phasic vagal tone). These results suggest a general role for social free play experience in the development of autonomic regulation, but not necessarily a specific influence of peer play opportunities on children's responses to an immediate stressor. Overall, the findings are consistent with work linking experiences in the social environment to RSA and with research connecting play and self-regulation.

Caregiving aspects of the social environment, such as the quality of the mother–child relationship (Calkins et al., 2008), parental socialization (Hastings et al., 2008), and family cohesion (West et al., 2020), have been associated with individual differences in young children's RSA. Our findings extend this research by suggesting that play with other children might be a social environment that relates to vagal functioning along with caregiving contexts. Certainly, children benefit from coregulation of vagal functioning with caregivers in early childhood (Calkins et al., 2008) as they do in infancy, and parenting contexts are connected to both tonic and phasic vagal tone (Diamond et al., 2012). Our findings suggest that this peer context contributes specifically to tonic vagal tone. What exactly about peer play contexts links them to baseline regulation is unclear, but future work might usefully explore those factors that make social free play different from caregiving contexts, such as the fact that play is typically child directed, involves physical activity, and affords affiliative social connections associated with well-being (Burdette & Whitaker, 2005). Both high quality coregulation and social contexts without adult participation might thus foster healthy autonomic regulation.

The idea that social free play might be a context relevant specifically to baseline physiological self-regulation, as suggested by our findings, is consistent with research relating opportunities for play with well-being and lower stress. Play is generally associated with increased positive mood and decreased allostatic load (Burdette & Whitaker, 2005). Frequent opportunities for social free play might thus contribute some of the experience needed for children to develop and maintain neurobiological homeostasis (Graziano & Derefinko, 2013). Although research with humans and animals alike demonstrates organisms are unlikely to play when under threat (Siviy, 2010), the increase in stress caused by normative events in early childhood (e.g., the first day of school) is relieved by play (Barnett, 1984). As such, one interpretation of our findings is that opportunities for social free play afford settings in which children are able to relieve and manage stress (Barnett & Storm, 1981). If play is frequent, these opportunities for reducing allostatic load might result in higher baseline RSA.

Opportunities for social free play did not predict vagal flexibility, meaning that children whose mothers reported more play did not seem to have regulatory advantages in vagal flexibility; that is, they showed no evidence of a buffering effect of general play experience in the speed of their autonomic response to the stress of a cognitive task. Although these results seem inconsistent with the fact that play has been identified as a mechanism for coping with stress (Siviy, 2010; Yogman et al., 2018), research on play and stress has emphasized the benefits of playing while enduring cognitive, social, or emotional challenges, or play's effectiveness in lowering children's anxiety while experiencing stressful situations (Barnett & Storm, 1981). General play experience prior to stressful challenges thus might alter children's static regulation, but detecting the effects of play on physiology in response to stress might require measurements of RSA that are concurrent both with the advent of a stressor and with children's engagement in play.

We conceptualized our measure of play opportunities in the past week as a proxy for individual differences in children's play experience generally given its consistency with reports over a year earlier. However, even if children's vagal tone at baseline and under stress is a function of recent, rather than habitual, peer play experience, our findings align with research demonstrating proximal associations between opportunities for play and subsequent reduction of anxiety in young children (Barnett, 1984; Burdette & Whitaker, 2005). They also resemble to animal models linking even short periods of play with measurable differences in neuronal processes supporting social activity and behavioral flexibility (Yogman et al., 2018). Longitudinal work will be needed to determine if variations in RSA emerge from recent or habitual social free play opportunities.

4.1 | Future directions

Useful elucidation of the relation between play and RSA might come from investigations of the specific behaviors in play that link to RSA. Studying the type and quality of children's play could illuminate the emotional and contextual aspects relevant to both baseline and potentially phasic RSA. Specifically, both pretend and physical play are typically characterized by changing states of arousal, including heightened emotions and the need to conform to behavioral constraints that govern the play (Bretherton, 1989; Pellegrini & Smith, 1998). Simulation of emotion within the safety of a play context might facilitate development of strategies for managing and regulating the physiology specifically associated with changes in arousal more so—or in addition to—affecting base rates of arousal. Likewise, the constraints of pretend and physical play contexts demand regulation of behavior in the moment if the play is to continue, so participation in these forms of play might mean more rehearsal for changes in self-regulatory demands. For example, rough-and-tumble play includes patterns of rising and falling arousal and requires learning to send and receive signals for when to aggress or disengage (Bodrova et al., 2013; Pellegrini & Smith, 1998). Theoretically, regular embodiment of these challenges might link to vagal flexibility, perhaps even more so than to baseline levels of RSA.

4.2 | Limitations

This study relied on parent reports of peer play opportunities in the past week as a proxy for children's play experience generally. Despite the consistency across time points, observation of play over a time span greater than a week would provide important corroboration. Our data also cannot rule out the possibility that children who play frequently are those who live in households with lower stress that otherwise foster high baseline RSA.

5 | CONCLUSIONS

Typically, play is discussed in terms of its facilitation of self-regulation generally or within the emotional domain (e.g., Hoffmann & Russ, 2012; Singer et al., 2006), but the study presented here suggests that social free play might be relevant to autonomic regulation—to vagal tone in particular. This connection is critical for two reasons. First, vagal tone has been identified as a neurobiological component of a wide array of social and moral capacities. For example, vagal tone functioning in infancy/early childhood predicts development of adaptive skills related to morality in middle childhood, including sympathy, emotional regulation, attention, behavior problems, and self-control (Feldman, 2009). Vagal tone has also been identified as a neural pathway to compassion (Porges, 2017; Stellar et al., 2015) and cooperative behavior (Beffara et al., 2016), including prosociality (Kogan et al., 2014). It is considered an online biomarker for emotion regulation and psychopathology (Beauchaine, 2015), sociality (Carter & Porges, 2013), feelings of safety (Porges, 2017), and prosocial behaviors, such as empathy and compassion (Diamond et al., 2012). Social free play, through autonomic regulation, thus might be an important component of these capacities—an idea that is consistent with research connecting play with prosocial behavior and lower aggression (Howes & Matheson, 1992).

The second reason that understanding the relation between play and vagal tone is critical is owing to the fact that children's engagement in play might be declining (Singer et al., 2009). If so, and if play has implications for the development of healthy parasympathetic activity, then children's optimal physiological development might be undermined by decreasing opportunities for play. Gray (2011) has suggested that a documented decline in free play in recent decades corresponds with a rise in psychopathology among children and adolescents. Although the work presented here does not speak directly to this hypothesis, the data lend support to the idea that opportunities for social free play might influence healthy neuropsychological development.

AUTHOR CONTRIBUTIONS

All authors contributed to the conception and design of the study. Data acquisition was conducted by M. T. and A. K. Analysis and interpretation was done by T. G., M. T., and D. K. Drafting of the manuscript was completed by T. G. and M. K. with edits and revisions from the other authors.

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DATA AVAILABILITY STATEMENT

Data are available from the last author.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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