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# Ecological momentary assessment of symptom trajectories during sugar reduction: application of substance use disorder criteria

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ABSTRACT

Excessive sugar consumption and the difficulty faced in reducing intake have fuelled debate over whether sugar is addictive. This study aimed to identify the most prominent substance use disorder (SUD) symptoms experienced during sugar reduction and to determine whether distinct symptom burden trajectories emerged over time. Adults from New Zealand willing to quit free sugars (n = 203) participated in an ecological momentary assessment (EMA) study. A pre-EMA survey assessed food addiction symptoms, dietary intake, BMI, craving, self-efficacy, and psychological distress. Participants received five EMAs a day for two weeks to assess sugar consumption and DSM-5 SUD criteria reflecting impaired control, tolerance, withdrawal, social impairment and risky use. Nearly one-third of participants (31.0%) remained sugar-free throughout follow-up. Sugar consumption was reported in 9% of EMAs and peaked in the evening EMA (11.5%), primarily as snacks and desserts or baked goods. The most frequent symptoms were cravings, preoccupation and difficulty remaining abstinent. Common withdrawal symptoms were low energy, body aches and pains, and low mood. Group-based trajectory modelling identified a low (47%) and high (53%) symptom burden group. Pre-EMA assessment associated with high burden group membership included presence of food addiction as per Yale Food Addiction Scale, higher sugar consumption, BMI, craving, anxiety, and stress, as well as lower self-efficacy. The findings indicate that SUD-like symptoms occur during attempts to reduce or stop sugar intake. To determine whether these symptoms persist and are associated with significant impairment or distress future research should extend the EMA protocol to include a pre-quit assessment and longer-term monitoring.

## 1. Introduction

Excessive sugar consumption is a growing global public health concern, linked to increased risk of metabolic dysfunction, obesity, cardiovascular disease, and oral health issues (Huang et al., 2023). To help mitigate such risks, the World Health Organization recommends limiting free sugars, defined as all monosaccharides and disaccharides added to foods or beverages as well as those naturally present in honey, syrups, fruit juices, and fruit juice concentrates, to less than 10% of daily energy intake (DEI) (World Health Organization, 2015). Yet, many people struggle to reduce or eliminate sugar from their diets, even when actively trying to quit (Rodda et al., 2020). This has prompted debate that excessive sugar intake may be driven by mechanisms akin to addiction (Avena & Gold, 2011; Gearhardt & DiFeliceantonio, 2023; Monteiro & Cannon, 2023).

Pre-clinical and clinical studies show that patterns of sugar consumptions can lead to neurochemical and behavioural changes similar to those seen with other substances of addiction (Avena et al., 2008, 2009; DiNicolantonio et al., 2018; Freeman et al., 2018; Hoebel et al., 2009). Literature reviews illustrate that sugar, or foods high in sugar, activate the reward system and produce feelings of pleasure in rodents and humans, thereby reinforcing subsequent consumption (Freeman et al., 2018; Gearhardt & Schulte, 2021; Qin et al., 2025). Evidence from human studies, though limited, indicates that sugar consumption can manifest behaviours consistent with diagnostic criteria for substance use disorders (SUDs), including impaired control, social impairment, risky use, and tolerance (American Psychiatric Association, 2013; Gearhardt et al., 2009; Kampov-Polevoy et al., 2006; Parnarouskis & Gearhardt, 2022). Furthermore, people abstaining from sugar have reported increased cravings and signs of withdrawal, including headaches, difficulty concentrating, reduced motivation, lower contentment, mood changes, irritability, physical discomfort, and reduced overall wellbeing (Falbe et al., 2019; Rodda et al., 2020; Schiestl et al., 2022; Sylvetsky et al., 2020).

Current evidence remains insufficient to classify certain patterns of sugar-related behaviour as indicative of a mental health disorder. Many studies have either a narrow focus on specific dietary items, such as sugar-sweetened beverages or chocolate, or they examine ultra-processed foods which include but are not limited to foods high in sugar (Westwater et al., 2016). Progress in this area is further hampered

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by the predominance of cross-sectional designs, which are inappropriate to assess temporal patterns related to consumption and behaviour (Carlson & Morrison, 2009). These designs may also be unable to adequately capture the full symptom range characterising SUD, due to bias in recall and subjective interpretation of symptoms (Parnarouskis & Gearhardt, 2022; Shiffman et al., 2008).

While the literature provides support for the addictive potential of sugar (Avena et al., 2008; Avena & Gold, 2011; DiNicolantonio et al., 2018; Freeman et al., 2018; Gearhardt & Schulte, 2021; Hoebel et al., 2009; Qin et al., 2025), little is known about how symptoms vary over time or between people during intentional sugar reduction. Some people may experience few or no symptoms, while others may report more frequent, severe, or persistent symptoms as seen with other SUDs (American Psychiatric Association, 2013). Understanding these variations could help identify people that may be at risk of developing maladaptive patterns of behaviour that make it difficult to regulate consumption. To date, no studies have used methods of real-time monitoring to track SUD symptoms over time in people attempting to reduce free sugar consumption in a general population sample.

Ecological momentary assessment (EMA) is a promising method for capturing symptoms in real-world conditions. EMA collects in-the-moment data through repeated mobile prompts, allowing for the detection of context-sensitive symptoms such as cravings, withdrawal, and impaired control (Shiffman, 2009; Shiffman et al., 2008). The DSM-5 notes that SUD symptoms may persist beyond detoxification and include relapse and strong urges, which may be observable only in people actively attempting to reduce their use (American Psychiatric Association, 2013). EMA is also well suited to assessing pharmacological features such as tolerance and withdrawal, which have been documented in cross-sectional studies (Parnarouskis & Gearhardt, 2022) but rarely measured in real time. While symptoms like social impairment and risky use are not momentary states, they can be captured using a coverage strategy, where participants report on their experiences across the full day at regular intervals (Shiffman, 2009; Shiffman et al., 2008).

The current study used EMA to examine whether reducing free sugar consumption elicits addiction-like responses in adults in New Zealand, where sugar is widely available and average intake exceeds twice the recommended daily limit (Kibblewhite et al., 2017; World Health Organization, 2015). The primary aim was to identify the most prominent SUD symptoms experienced during the reduction period and assess their salience and frequency over time. A secondary aim was to determine whether distinct symptom burden trajectories emerged over the 14-day monitoring period.

## 2. Methods

### 2.1. Design

This was an intensive longitudinal study delivered by smartphone. Participants completed a pre-EMA survey, agreed to quit sugar and followed a 14-day EMA protocol with a post-EMA satisfaction survey and personalised report. EMA items operationalised the SUD criteria following multiple rounds of end-user testing and refinement. The study received ethics approval from the AUT research ethics committee. Reporting of the study is consistent with the Checklist for Reporting EMA Studies (CREMAS) (Liao et al., 2016).

### 2.2. Participants and recruitment

Participants were aged 16 and older at the time of enrolment and residing in New Zealand. Inclusion criteria were (i) consuming free sugar on a daily basis (ii) be willing to quit for 14 days (iii) able to download the Habit Hacker Monitor app and receive smartphone notifications. Participants with Type I or Type II Diabetes were excluded. Recruitment was in January – February 2024 and occurred through Facebook and Instagram paid advertising targeting people in New Zealand who had an interest in finding out whether sugar was addictive. The pre-EMA survey was completed by 254 participants of whom 51 were excluded because of residence outside of New Zealand (n = 31), incomplete onboarding process (n = 19), or having quit sugar prior to pre-EMA survey (n = 1). All remaining 203 participants who started monitoring were included for analysis, regardless of EMA completion rate.

### 2.3. Measures and procedure

Only procedures and measures relevant to the current analyses are reported. A baseline survey collected demographic information and self-reported height and weight. Pre-EMA sugar consumption was estimated using an adapted version of the validated online Food Frequency Questionnaire (FFQ) (Brittain et al., 2021; Forster et al., 2014) with items grouped for ease of completion into breakfast, drinks, snacks, desserts, and baked goods. These responses were used to estimate daily free sugar intake in grams. Additional measures included the Yale Food Addiction Scale (YFAS) 2.0 (Gearhardt et al., 2016), the 15-item Food Craving Questionnaire-Trait-reduced version (FCQ-T-r) (Meule et al., 2014), the 8-item Weight Efficacy Lifestyle Questionnaire Short-Form (WEL-SF)(Ames et al., 2015), and the 21-item Depression, Anxiety and Stress Scale (DASS-21)(Henry & Crawford, 2005).

After screening in Qualtrics, eligible participants completed the baseline survey and provided contact details. Participants then received study information and a link to download the Habit Hacker Monitor via the SEMA3 (O'Brien et al., 2024) mobile app on Android or iOS. They received a brief EMA training online or by phone which also confirmed the sugar quit date. Training included provision of a FAQ sheet which defined free sugars. Text reminders were sent to prompt quitting and survey completion, with follow-ups at days 7 and 10 and additional prompts if five or more EMAs were missed. Participants received a shopping voucher of up to $100 NZD, based on $1 NZD per completed EMA and a bonus for completing over 80% of EMAs. A personalised report was also provided, showing trends in sugar intake and associations with variables such as cravings.

### 2.4. EMA protocol

Habit Hacker Monitor delivered five signal-contingent EMAs that were sent semi-randomly throughout the day, totalling a maximum of 70 EMAs per participant across the 14 days. Push notifications were sent within fixed 1.5-h intervals that were personalised to participants' waking hours. For example, for a person waking up at 7.00 a.m., intervals were between 7.00 and 9.30 a.m., 10.00 a.m.-12.30 p.m., 13.00-15.30pm, 16.00-18.30pm, and 19.00-21.30pm. Each EMA could be completed up to 60 min after the first notification. Reminder notifications were sent 30 min and 2 min before expiry of the EMA. The order of the EMA items was randomised to increase participant attention while still assuring that items reflecting in-the-moment feelings (withdrawal, craving) preceded items on sugar consumption to prevent priming thoughts about sugar which may prompt craving or influence mood.

Habit Hacker Monitor delivered EMA items designed to assess the presence of SUD symptoms related to sugar and potential time-dependent correlates (Table 1). Items were sourced from previous studies on EMA and SUD symptoms (Dunbar et al., 2010; Mitchell et al., 2014; Piasecki et al., 2011; Serre et al., 2018; Shiffman et al., 2020; Spillane & Soyster, 2023), co-design (Soyster & Fisher, 2019), and the Yale Food Addiction Scale (Schiestl et al., 2022), and collated in a spreadsheet alongside details on EMA frequency, response options, number of items, and study duration. The item that best reflected each DSM-5 substance use disorder criterion was selected through investigator consensus and refined through multiple rounds of testing to ensure clarity and ease of response. To minimise participant burden, we varied EMA scheduling whereby items reflecting occurrences that likely happened less frequently appeared once a day at the end of day. Items

**Table 1**
EMA items assessing SUD symptoms.

| Criterion | EMA item | Response options | Timing | Endorsement |
|---|---|---|---|---|
| Larger amounts | When I had sugar, I had more than planned | SLIDER (0-4): Strongly disagree – strongly agree. | If item *sugar consumption* endorsed | Likert score 3-4 |
| Sugar consumption | Since the last check-in, have you had any of the following foods or drinks that contain sugar? Tick all that apply | CHECKLIST: (1) Breakfast foods like cereal, pancakes, spreads, sweetened yoghurt, liquid breakfast (2) Drinks like soft drinks, juices, energy drinks, flavoured milk or milkshakes (3) Snacks like chocolate, lollies, biscuits, bars (4) Desserts and baked goods like cakes, ice cream or frozen yoghurt, custards, sweet pastries or slices (5) A spoonful of sugar you or another person added to your food or drink (999) No | Five times daily | checked |
| Unsuccessful efforts | Endorsed if any sugar consumption reported as per EMA item *sugar consumption* | See item *sugar consumption.* | | |
| Great deal of time | Over the last 24 h, I spent a lot of time thinking about and making, baking, or getting foods with sugar | SLIDER (0-4): Strongly disagree – strongly agree. | End of day only | Likert score 3-4 |
| Craving | Right now, I am craving sugar | SLIDER (0-4): Strongly disagree – strongly agree. | Five times daily | Likert score 3-4 |
| Activities given up | Over the last 24 h, I have avoided social activities, work or school because I thought I would consume sugar there | SLIDER (0-4): Strongly disagree – strongly agree. | End of day only | Likert score 3-4 |
| Use despite knowledge of problem | Over the last 24 h, I have thought about the physical or emotional problems sugar can cause | SLIDER (0-4): Strongly disagree – strongly agree. | End of day only | Likert score 3-4 if item *sugar consumption* endorsed that day |
| Tolerance | After I had sugar, I felt satisfied | SLIDER (0-4): Strongly disagree – strongly agree. | If item *sugar consumption* endorsed | Likert score 3-4 |
| Withdrawal checklist | Right now, what are you feeling in your body? Feel free to tick multiple boxes. | CHECKLIST: (1) Nausea (2) Restlessness (3) Headache (4) Difficulty paying attention (5) Irritability (6) Body aches and pains (999) None of these | Five times daily | checked |
| Withdrawal Arousal | Right now, how is your energy level? | SLIDER (0-4): very low – very high | Five times daily | Likert score 0-1 |
| Withdrawal Valence | Right now, how are you feeling overall? | SLIDER (0-4): very bad – very good | Five times daily | Likert score 0-1 |
| Withdrawal | Endorsed if at least 4 out of 8 reported as per checklist and individual items. | See items *witdrawal checklist, withdrawal arousal, withdrawal valence* | | |

for larger amounts and tolerance were only measured in EMAs where sugar consumption was reported. EMA items were phrased as statements or questions and measured on a Likert scale (0-4), as multiple choice, as a checklist, or numerical.

### *2.5. Statistical analysis*

Data were managed and analysed using STATA version 18.5 (StataCorp, College Station, TX). Descriptive statistics are reported as counts and percentages or medians with interquartile ranges (IQR), as appropriate. Frequencies of SUD symptoms were calculated based on the proportion of participants endorsing each EMA item (Table 1). Daily symptom burden was computed by summing symptoms endorsed at least once per day or in the end-of-day EMA.

Symptom burden trajectories over the 14-day monitoring period were modelled using group-based trajectory modelling (GBTM) with the Stata plugin 'traj', which applies finite mixture models to identify clusters of people following similar symptom patterns over time (Jones & Nagin, 2013). A zero-inflated Poisson distribution was specified due to the large number of days with zero symptoms. A linear function was applied to the zero-inflation component, under the assumption that endorsement of sugar consumption predicted non-zero symptom reporting since consuming sugar was required to meet certain symptoms, such as tolerance. Models with increasing numbers of trajectory groups and polynomial terms (linear, quadratic, cubic) were tested sequentially. Model selection was guided by the Akaike Information Criterion (AIC), with final selection based on recommended adequacy criteria for GBTM: close agreement between estimated and actual group membership proportions, average posterior probability of membership >0.7, odds of correct classification >5, narrow confidence intervals, and sufficient group sizes to allow further analysis (Burnham & Anderson, 2004). Results for all tested models are detailed in Appendix A.

Lower symptom burden may reflect missed EMAs, particularly when in-the-moment symptoms (e.g., craving, withdrawal) resolved before the next prompt, or when end-of-day EMAs capturing symptoms such as time spent, avoidance, and continued use were skipped. To evaluate this, compliance across trajectory groups was assessed using visual inspection of missing data plots by 1) EMA initiation, 2) completion of at least one EMA daily, and 3) completion of the final EMA.

Symptom profiles were compared across groups to determine whether higher burden reflected more frequent endorsement or specific symptoms dependent on sugar consumption. Signs of potential withdrawal were analysed similarly. A false discovery rate (FDR) correction using the Benjamini-Hochberg procedure was applied to account for multiple comparisons across symptoms, days, and groups. In addition, gender-based differences in symptom profile and withdrawal signs were examined using the same FDR-corrected approach.

Two sensitivity analyses were conducted to assess the robustness of trajectory groupings to variations in the symptom burden composite. The first excluded post-consumption items (larger amounts and tolerance) to remove dependency on sugar intake, and the zero-inflation model was adjusted accordingly. The second included only in-the-moment symptoms (larger amounts, failed efforts, craving, tolerance, and withdrawal). Groupings from both analyses were compared to the primary model using Cohen's kappa.

Predictors of group membership were examined using logistic regression with trajectory group as the dependent variable. Baseline presence of addiction according to YFAS, daily sugar consumption, BMI, craving, self-efficacy, and the DASS subscales were each modelled separately and adjusted for the *a priori* specified covariates age, gender, and education. Regression models were not stratified by gender given the limited number of male participants. Instead, descriptive statistics were examined by group and gender.

## 3. Results

### 3.1. Participant characteristics and compliance

As shown in Appendix B, most participants were women (85%) and exceeded recommended daily sugar intake (65%), with a median age of 38 years (IQR 15) and median BMI of 27 kg/m$^2$ (IQR 9). Among 203 participants, 194 completed the 14-day monitoring period. Five completed less than 50% of EMAs. Of 14,210 scheduled EMAs, 14,009 were received, with minor discrepancies due to discontinuation or technical issues. A total of 12,006 were initiated and 11,726 completed. Median initiation time was 6 min (IQR = 22), with a median of 61 EMAs completed per participant (IQR = 12). Response rates remained high (>82%), declining slightly from 84 to 86% in week 1 to 81–84% in week 2.

### 3.2. Sugar consumption patterns

Nearly one-third of participants (31.0%) remained sugar-free throughout the 14-day period. The median number of days with reported sugar consumption was 2 (IQR = 0–7). Sugar was reported in 9% of EMAs, most commonly as snacks (3.1%), desserts/baked goods (2.3%), and drinks (2.1%). Consumption peaked in evening EMAs (11.5%), primarily as snacks (4.0%) and desserts/baked goods (3.7%) (Fig. 1).

### 3.3. Symptom burden and frequency

Median daily symptom burden was 1 (IQR = 2). One-third of participants (n = 67) reported no symptoms on over half of their monitoring days. High symptom burden was rare, with only 19 participants reporting five or more symptoms on at least two days. Craving (21%) and great deal of time (20%) were consistently the most prevalent symptoms across the criteria assessed at least once a day, while larger amounts (31%) and tolerance (29%) were commonly endorsed in those who consumed sugar. The most frequently reported signs of withdrawal included low energy (28%), body aches and pains (15%), and low mood (12%) (Table 2).

### 3.4. Symptom trajectories over time

After comparing GBTM results and fit indices, we selected a model which showed two distinct trajectories of symptom burden after quitting sugar consumption. Trajectories were relatively stable and interpreted as low and high symptom burden, where estimated probability of group membership were 47 and 53%, respectively (Fig. 2). In the low symptom group, almost half of participants (49%) abstained from sugar throughout monitoring, whereas abstinence from sugar was substantially less common in the high symptom group (14%). Plotting individual trajectories revealed variable symptom burden over time within each group (Appendix C). Compliance plots showed no evidence of bias from missing data (Appendix D).

**Table 2**
Endorsement frequency of EMA items assessing SUD symptoms.

| Criterion | Times assessed, N | Times endorsed n (%) |
|---|---|---|
| Larger amounts | 1059 | 326 (30.8%) |
| Sugar consumption | 11752 | (1) Breakfast foods: 133 (1.1%)<br>(2) Drinks: 243 (2.1%)<br>(3) Snacks 363 (3.1%)<br>(4) Desserts and baked goods: 274 (2.3%)<br>(5) A spoonful of sugar: 138 (1.2%)<br>(999) No: 10,690 (91.0%) |
| Unsuccessful efforts | 11752 | 1062 (9.0%) |
| Great deal of time | 2351 | 464 (19.7%) |
| Craving | 11764 | 2448 (20.8%) |
| Activities given up | 2350 | 99 (4.2%) |
| Use despite knowledge of problem | 2350 | 186 (7.9%) |
| Tolerance | 1060 | 306 (28.9%) |
| Withdrawal checklist | 11794 | (1) Nausea: 310 (2.6%)<br>(2) Restlessness: 739 (6.3%)<br>(3) Headache: 1371 (11.6%)<br>(4) Difficulty paying attention: 1085 (9.2%)<br>(5) Irritability: 1237 (10.5%)<br>(6) Body aches and pains: 1796 (15.2%)<br>(999) None of these: 7546 (64.0%) |
| Withdrawal Arousal | 11793 | 3318 (28.1%) |
| Withdrawal Valence | 11771 | 1430 (12.1%) |
| Withdrawal[a] | 11806 | 697 (5.9%) |

[a] At least 4 items endorsed out of the checklist and single withdrawal items.

### 3.5. Symptom profiles by trajectory group

Table 3 shows the symptoms contributing to symptom burden over time per group. Participants in the high symptom group showed higher

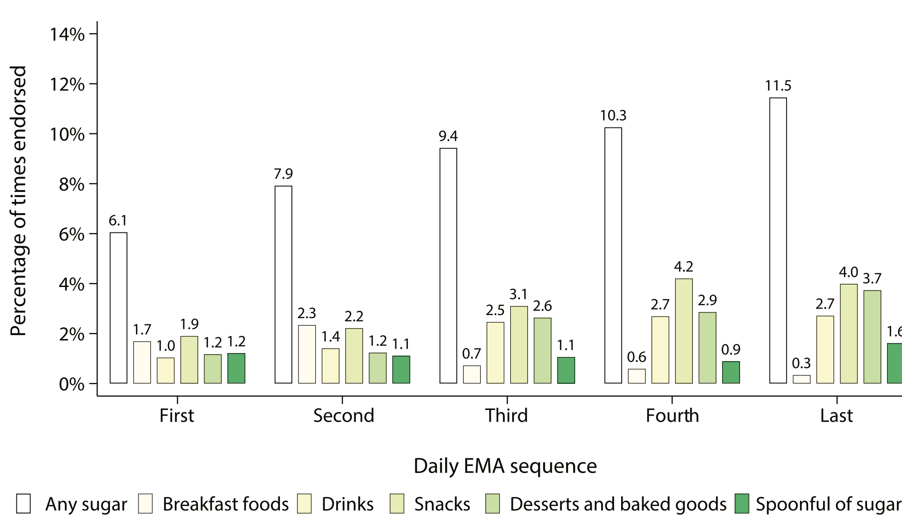


**Fig. 1.** Sugar consumption over the course of day by type of dietary item.

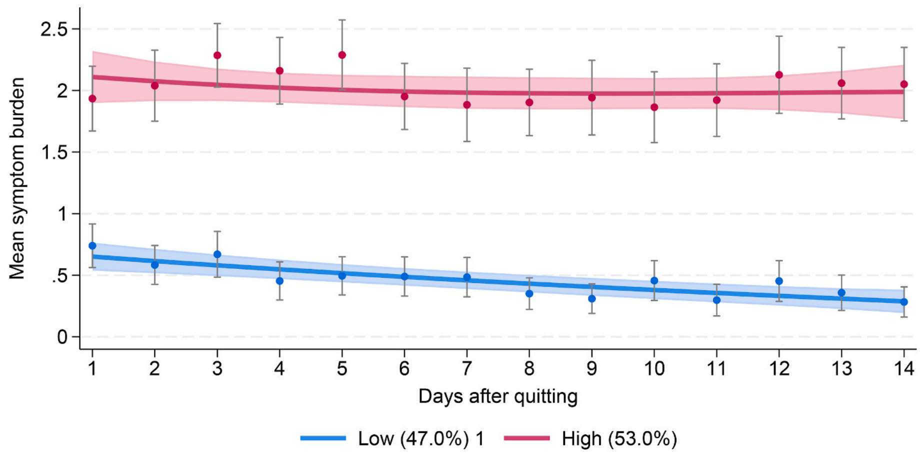


**Fig. 2.** Group-based trajectory modelling results of symptom burden. Solid lines reflect estimated trajectories with 95%CI of estimated means, dot symbols reflect observed group means at each day since quitting with 95% CI of observed means, legend shows estimated group percentages.

**Table 3**
SUD symptoms over time, by trajectory group.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low (n = 97) | | | | | | | | | | | | | | |
| Larger amounts[a] | 3.1 | **0.0**[b] | **1.0**[b] | **1.0**[b] | **1.0**[b] | **2.1**[b] | 1.0 | **1.0**[b] | **1.0**[b] | **2.2**[b] | **0.0**[b] | **2.1**[b] | 1.1 | **0.0**[b] |
| Unsuccessful efforts | 16.7 | **8.3**[b] | **14.4**[b] | **9.3**[b] | **8.2**[b] | **10.4**[b] | **10.3**[b] | **5.2**[b] | **7.2**[b] | **7.6**[b] | **8.5**[b] | **12.6**[b] | **7.4**[b] | **7.6**[b] |
| Great deal of time | **8.5**[b] | **7.1**[b] | **12.9**[b] | **7.1**[b] | **8.3**[b] | **7.2**[b] | **7.2**[b] | **3.7**[b] | **1.2**[b] | **3.8**[b] | **3.8**[b] | **1.3**[b] | **6.0**[b] | **3.9**[b] |
| Craving | **33.3**[b] | **29.2**[b] | **26.8**[b] | **21.6**[b] | **21.6**[b] | **17.7**[b] | **17.5**[b] | **17.5**[b] | **12.4**[b] | **20.7**[b] | **10.6**[b] | **14.7**[b] | **14.7**[b] | **8.7**[b] |
| Activities given up | 2.4 | 4.8 | 1.2 | 1.2 | 3.6 | 0.0 | 1.2 | 0.0 | 1.2 | 2.5 | 1.3 | 1.3 | 3.6 | 0.0 |
| Knowledge of problems | 2.4 | 1.2 | 3.5 | **0.0**[b] | **1.2**[b] | 0.0 | 1.2 | **0.0**[b] | 1.2 | 1.3 | 1.3 | 5.1 | **0.0**[b] | **0.0**[b] |
| Tolerance[a] | 5.2 | 3.1 | 6.2 | **1.0**[b] | **2.1**[b] | 4.2 | 5.2 | 3.1 | 2.1 | 3.3 | 4.3 | **5.3**[b] | 2.1 | 4.3 |
| Withdrawal | **4.2**[b] | **6.3**[b] | **3.1**[b] | 5.2 | **5.2**[b] | 8.3 | 6.2 | **5.2**[b] | **5.2**[b] | **5.4**[b] | **1.1**[b] | **4.2**[b] | **2.1**[b] | 4.3 |
| **High (n=106)** | | | | | | | | | | | | | | |
| Larger amounts[a] | 11.3 | **13.6**[b] | **18.1**[b] | **20.8**[b] | **19.2**[b] | **19.4**[b] | 10.7 | **17.5**[b] | **16.5**[b] | **20.4**[b] | **16.7**[b] | **20.6**[b] | 11.9 | **18.4**[b] |
| Unsuccessful efforts | 35.8 | **35.0**[b] | **41.9**[b] | **43.4**[b] | **46.2**[b] | **35.9**[b] | **38.8**[b] | **38.8**[b] | **38.8**[b] | **37.9**[b] | **42.2**[b] | **44.1**[b] | **47.5**[b] | **48.0**[b] |
| Great deal of time | **34.1**[b] | **34.8**[b] | **42.7**[b] | **33.3**[b] | **41.1**[b] | **33.0**[b] | **33.7**[b] | **28.6**[b] | **26.3**[b] | **28.6**[b] | **26.5**[b] | **34.9**[b] | **32.6**[b] | **29.1**[b] |
| Craving | **68.9**[b] | **66.0**[b] | **73.3**[b] | **68.9**[b] | **70.2**[b] | **64.1**[b] | **60.2**[b] | **60.2**[b] | **61.2**[b] | **57.3**[b] | **59.8**[b] | **60.8**[b] | **63.4**[b] | **55.1**[b] |
| Activities given up | 4.5 | 6.7 | 10.1 | 6.7 | 5.6 | 6.8 | 6.0 | 6.0 | 8.8 | 3.6 | 4.8 | 4.8 | 9.3 | 8.1 |
| Knowledge of problems | 12.5 | 11.2 | 14.6 | **15.7**[b] | **15.6**[b] | 8.0 | 13.3 | **13.1**[b] | 15.0 | 11.9 | 13.3 | 16.9 | **16.3**[b] | **22.1**[b] |
| Tolerance[a] | 10.4 | 13.6 | 12.4 | **17.9**[b] | **15.4**[b] | 13.6 | 13.6 | 8.7 | 12.6 | 12.6 | 13.7 | **21.6**[b] | 11.9 | 17.3 |
| Withdrawal | **24.5**[b] | **30.1**[b] | **25.7**[b] | 17.9 | **24.0**[b] | 21.4 | 22.3 | **26.2**[b] | **26.2**[b] | **22.3**[b] | **23.5**[b] | **19.6**[b] | **21.8**[b] | 14.3 |

Values indicate percentages; [a] Based on those who consumed sugar (i.e., unsuccessful effort); [b] bold font denotes significant differences after Benjamini-Hochberg FDR correction ($p < 0.05$).

endorsement rates for nearly all criteria, with significant differences observed on the majority of monitoring days for craving, great deal of time, unsuccessful efforts, larger amounts, and withdrawal. Total number of craving episodes throughout the monitoring period was significantly greater in the high burden group (median 42 versus 20, $p < 0.001$). Withdrawal signs of low energy, body aches and pains, irritability, difficulty paying attention, headache, restlessness, and low mood were generally more prevalent in the high burden group, though after adjustment, significant differences were observed only on select days (Appendix E).

Sensitivity analyses confirmed that the character of the items underlying the symptom burden composite did not account for the differences in trajectories. Sensitivity analysis 1, which excluded post-consumption items, demonstrated strong agreement (Cohen's $\kappa = 0.811$, $p < 0.001$) with the main model. Sensitivity analysis 2, which included in-the-moment items only, yielded similar results (Cohen's $\kappa = 0.831$, $p < 0.001$).

### *3.6. Gender-based differences before and during monitoring*

Demographic characteristics were generally similar across genders (Appendix E). Pre-EMA craving scores were significantly higher in women compared to men (median 54 versus 49, $p = 0.026$). A greater proportion of women reported any sugar consumption during monitoring (71% versus 60%, $p = 0.267$) and were classified in the high burden group (54% versus 40%, $p = 0.207$), although there was no evidence of a statistical difference. Symptom profiles or withdrawal signs did not differ notably by gender (Appendix F and G). However, craving episodes were more frequent in women than men (median 28 versus 17, $p < 0.001$).

### *3.7. Predictors of symptom burden trajectories*

Table 4 shows the results of the logistic regression. Compared to the low burden group, the high burden group was characterized by a greater proportion of participants identifying as woman (87% versus 82%) and younger median age (36 IQR 16 versus 40 IQR 16). Apart from the DASS depression scale, all baseline predictors were significantly associated with symptom burden group in models adjusted for gender, age, and education. Those classified as having addiction according to the YFAS were more likely to be in the high burden group than those who did not meet YFAS addiction criteria (OR 3.09, 95%CI 1.57-6.07, $p = 0.001$). Higher daily sugar consumption (per 10 g: OR 1.06, 95%CI 1.01-1.12, $p = 0.022$), BMI (per kg/m$^2$: OR 1.06, 95%CI 1.01-1.11, $p = 0.011$), craving (per 10 points: OR 1.58, 95%CI 1.21-2.07, $p = 0.001$), anxiety (per 10 points: OR 1.92, 95%CI 1.17-3.17, $p = 0.010$), stress (per 10

**Table 4**
Logistic regression results on baseline predictors of symptom burden group.

| | Low burden (reference) | High burden | RRR | 95%CI | p |
|---|---|---|---|---|---|
| | Median (IQR) | Median (IQR) | | | |
| Addiction according to YFAS | 97 (17.5)[a] | 43 (40.6)[a] | **3.09** | **1.57–6.07** | **0.001** |
| Daily sugar consumption (per 10 g) | 5.5 (4.2) | 6.9 (7.5) | **1.06** | **1.01–1.12** | **0.022** |
| BMI per kg/m$^2$ | 26.0 (7.9) | 27.8 (8.3) | **1.06** | **1.01–1.11** | **0.011** |
| Cravings score (per 10 point) | 4.9 (1.6) | 5.5 (1.3) | **1.58** | **1.21–2.07** | **0.001** |
| Self-efficacy score (per 10-points) | 4.4 (2.3) | 3.8 (1.7) | **0.75** | **0.61–0.91** | **0.005** |
| Depression score (per 10-points) | 0.8 (1.0) | 1.0 (1.0) | 1.31 | 0.87-1.99 | 0.201 |
| Anxiety score (per 10-points) | 0.4 (0.6) | 0.8 (0.8) | **1.92** | **1.17–3.17** | **0.010** |
| Stress score (per 10-points) | 1.2 (1.0) | 1.6 (1.0) | **1.84** | **1.23–2.74** | **0.003** |

[a] values represent number and percentage classified as having addiction on YFAS; range FCQ-T-r = 15-90; range WEL-SF = 0-80; range DASS-21 = 0-42, scores were multiplied by 2 to scale to norm version.

points: OR 1.84, 95%CI 1.23-2.74, p = 0.003), and lower self-efficacy (per 10 points: OR 0.75, 95%CI 0.61-0.91, p = 0.005) were associated with a higher likelihood of being in the high burden group.

## 4. Discussion

This study is the first to systematically assess the presence and temporal trends of DSM-5 SUD-related symptoms that might make it difficult to regulate sugar consumption. Two distinct symptom burden trajectories were identified, with the high burden group displaying persistent and elevated symptom reporting across the 14-day period. This group showed greater endorsement of hallmark SUD symptoms, including craving, unsuccessful efforts to cut down, and withdrawal-like experiences, and limited symptom reduction over time. These patterns resemble the chronic and relapsing course observed in SUD and suggest that, for some people, reducing sugar may elicit clinically relevant symptoms (American Psychiatric Association, 2013).

Craving, great deal of time, unsuccessful attempts, and withdrawal were among the most commonly endorsed symptoms on a daily base, corroborating research suggesting that sugar consumption may be maintained by reward-driven processes and appetitive urges similar to those implicated in substance use disorders (Ahmed et al., 2013; Falbe et al., 2019). In de high-burden group, the majority of participants reported cravings throughout follow-up. Even among participants in the low symptom burden group, nearly one-third reported cravings on several days, despite high abstinence rates. This pattern is consistent with addiction frameworks that conceptualise craving as a persistent feature during abstinence which contributes to relapse risk (American Psychiatric Association, 2013). Notably, cravings were more pronounced in female participants, both before and during monitoring, suggesting this symptom may be particularly salient in women. Withdrawal symptoms such as low energy, body aches and pains, irritability, headache, and difficulty paying attention were particularly prominent among participants in the high burden group, consistent with prior research documenting affective and somatic disturbances during sugar reduction attempts (Falbe et al., 2019; Schiestl et al., 2022). Symptoms reflecting risky use and social impairment were endorsed primarily by those in the high symptom burden group, offering further support for sugar potentially prompting maladaptive patterns of behaviour.

Participants classified as having addiction according to the YFAS adapted to sugar were three times more likely to belong to the high symptom burden group. This aligns with a recent EMA study showing that higher YFAS scores correspond to greater real-time experience of food addiction symptoms (Varnado et al., 2024). Importantly, our findings reflect a two-week quitting period in which participants quit sugar, highlighting that YFAS-defined addiction is predictive of symptom burden during active behaviour change. These results suggest that the YFAS could serve as a useful tool to identify individuals at risk for high symptom burden. Future studies could employ YFAS screening when exploring sugar-related symptoms of SUD in larger samples of people with elevated addiction symptoms.

Our findings highlight parallels between psychological factors previously linked to SUD outcomes and those associated with high symptom burden during sugar reduction. For example, meta-analytic evidence indicates strong associations between anxiety and mood disorder with alcohol and illicit drug use disorders (Sinha, 2024). Furthermore, literature demonstrates relationships between stress with craving, impaired control and risk of relapse (Lai et al., 2015). Our findings reinforce associations between psychological distress and SUD, with higher anxiety and stress scores nearly doubling the risk of being in the high burden group. The study also observed higher depression scores in those with a high symptom burden, although there was no evidence of a significant difference. Self-efficacy can predict treatment outcomes, as evidenced by research showing that higher levels of self-efficacy are associated with reductions in both frequency and quantity of alcohol and other drug use (Kadden & Litt, 2011). In line with this, baseline self-efficacy in our study was associated with a high symptom burden trajectory. These findings underscore the need for interventions to address psychological factors when supporting individuals to reduce sugar intake.

This study was tightly focused on exploring the relevance of SUD symptoms and whether they appear in a sugar reduction attempt. Because our work focused narrowly on these parameters it did not take into account possible other explanations for similar symptoms. For example, hormones, BMI, emotional regulation, appetite and response to sweet taste can contribute to pre-occupation, tolerance, overconsumption and cravings (Miller, 2019). Future studies might consider a broader range of factors when exploring why some people experience difficulty in regulating their sugar consumption.

Several methodological factors influence interpretation of these findings. This was the first study to systematically examine whether SUD symptoms apply in real time to sugar reduction but for sugar to be considered addictive more work is needed. For example, it is currently unclear whether sugar over-consumption causes significant impairment of distress over a specified period. We demonstrated the SUD symptoms were relevant and should be further explored through extending our study protocol by including a pre-quit monitoring period which provides more accurate comparisons than retrospective recall (Schuler et al., 2021). Additionally, longitudinal designs are needed that extend beyond 14 days after quitting and incorporate both subjective reports and objective measures of sugar consumption. This would allow better assessment of symptom persistence, remission and relapse, functional impairment, and the emergence of maladaptive patterns of sugar consumption.

The study design required participants to attempt sugar abstinence during a 14-day study period to maximise detection of withdrawal-like symptoms. While this enhances symptom capture, it limits generalisability to habitual consumption and raises the possibility that some experiences reflect temporary responses to disrupted routines rather than addiction per se.

Measures included adapted DSM-5 symptom criteria delivered through EMA. Items were drawn from established tools and refined through pilot testing for clarity, ease of response, and fit with real-time assessment. This process likely improved detection of in-the-moment symptoms such as cravings or failed efforts to abstain, but may have underestimated symptoms requiring cumulative assessment, such as tolerance or continued use despite problems. The item assessing great deal of time included thinking about sugar, which deviates from the DSM-5 criterion and may have led to overestimation of this symptom. Differences in symptom prevalence compared to other studies may also reflect the operationalisation of symptoms within a momentary abstinence framework, which prioritises specificity over general consumption indicators. Based on retention in our current study, extension of our EMA protocol could include refining criteria to ensure fit with the assessment format and comparability with DSM-based frameworks.

Given the online components of the study, there is a theoretical risk of automated bot responses. However, all participants completed a brief EMA training session with the research team, and EMA completion via SEMA3 required individualized logins and repeated engagement over two weeks, making automated participation unlikely (Donkin et al., 2025). In addition, examination of the EMA data did not reveal indications of suspicious or non-human response patterns.

Procedural elements, including frequent EMAs, personalised feedback, financial incentives, and follow-up reminders yielded exceptionally high compliance compared with typical EMA studies (Jones et al., 2019), supporting strong data quality and reliable capture of symptom trajectories. However, such elements may also have introduced bias due to heightened self-monitoring or social desirability. The EMA protocol itself, while improving ecological validity, may have deterred participation from people with less structured routines. Furthermore, the self-selected sample was predominantly female and middle-aged. As recruitment mentioned interest in sugar addictiveness, this may have introduced expectation bias in symptom reporting. These factors limit generalisability to broader populations.

## 5. Conclusion

This study provides novel evidence that reducing free sugar intake can elicit a range of symptoms resembling those observed in SUDs, with distinct trajectories of symptom burden emerging over time. Craving, impaired control, and withdrawal-like experiences were particularly prominent among a subgroup of participants, suggesting that for some people, attempts to reduce sugar may elicit responses resembling patterns observed in addiction models. Future research should extend the current EMA protocol to include a pre-quit baseline period, longitudinal tracking of symptoms and assessment of impairment over a 12-month period.

## CRediT authorship contribution statement

**Rimke Bijker:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Investigation, Formal analysis, Data curation. **Nathan I.N. Henry:** Writing – review & editing, Formal analysis. **Simone N. Rodda:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Funding acquisition, Conceptualization.

## Ethical statement

This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by the Auckland University of Technology Ethics Committee (AUTEC Reference number 23/234). Written informed consent to participate in the study was obtained from all participants before the commencement of data collection.

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## Declaration of competing interest

The authors declare that they have no competing interests in relation to this manuscript.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.appet.2026.108549.

## Data availability

Data will be made available upon reasonable request.

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