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doi:10.1017/S0954422421000123

# A scoping review of chronotype and temporal patterns of eating of adults: tools used, findings, and future directions

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## Abstract

Circadian rhythms, metabolic processes and dietary intake are inextricably linked. Timing of food intake is a modifiable temporal cue for the circadian system and may be influenced by numerous factors, including individual chronotype – an indicator of an individual's circadian rhythm in relation to the light–dark cycle. This scoping review examines temporal patterns of eating across chronotypes and assesses tools that have been used to collect data on temporal patterns of eating and chronotype. A systematic search identified thirty-six studies in which aspects of temporal patterns of eating, including meal timings; meal skipping; energy distribution across the day; meal frequency; time interval between meals, or meals and wake/sleep times; midpoint of food/energy intake; meal regularity; and duration of eating window, were presented in relation to chronotype. Findings indicate that, compared with morning chronotypes, evening chronotypes tend to skip meals more frequently, have later mealtimes, and distribute greater energy intake towards later times of the day. More studies should explore the difference in meal regularity and duration of eating window amongst chronotypes. Currently, tools used in collecting data on chronotype and temporal patterns of eating are varied, limiting the direct comparison of findings between studies. Development of a standardised assessment tool will allow future studies to confidently compare findings to inform the development and assessment of guidelines that provide recommendations on temporal patterns of eating for optimal health.

**Keywords: Chrononutrition: Chronotype: Temporal meal patterns: Meal timing: Meal regularity**

*(Received 11 December 2020; revised 30 April 2021; accepted 6 May 2021)*

## Introduction

The times at which we eat can impact on our health, with a comprehensive review by the American Heart Association revealing that eating later in the day increases risk of developing type 2 diabetes and obesity(1). This is due to disruptions to the circadian system, which is coordinated by a 'central clock', found in the suprachiasmatic nucleus of the anterior hypothalamus of the brain, which receives signals of light and dark over 24 h(2). The 'central clock' synchronises 'peripheral clocks' located in multiple sites such as the liver, pancreas and adipose tissue through hormonal, humoral and neuronal signals(2). The synchrony between the external environment of light and dark with our internal central and peripheral clocks regulates behavioural cycles such that humans sleep at night, and wake and feed in the day. To match this behaviour, key metabolic processes also follow a circadian rhythm, which explains why glucose tolerance, insulin sensitivity and thermic effects of food are highest in the morning, and decrease as the day progresses into night(3). Hence, a consequence of eating later into the night is poorer glycaemic control and a relative insulin resistance(4,5). Additionally, whilst light is the primary cue or *zeitgeber* for the central clock, peripheral clocks may be entrained by other *zeitgebers* such as body temperature and behavioural factors such as timing of food intake(2). Thus, when feed–fast cycles are altered in relation to the light–dark cycle, peripheral clocks misalign in relation to the central clock, leading to circadian rhythm misalignment(6). This misalignment has been shown to raise glucose and insulin levels, blood pressure, and inflammatory markers in healthy adults(7,8). Studies have also suggested that other temporal aspects of food intake, separate to meal timing, may impact on risk factors for chronic disease, including meal frequency (number of eating occasions in a day)(1,9) and regularity (the consistency of frequency and spacing of eating occasions across the day)(10). Together, these studies fall within the emerging area of chrononutrition, which focuses on the effects of the timing, frequency and regularity of eating behaviour(11) on health outcomes through circadian clock regulation of metabolism.

One factor that influences eating behaviour is an individual's chronotype. Chronotype is an indicator of the phase, or timing, of one's circadian rhythm in relation to the light–dark cycle(12).

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Chronotype markers include rhythms of physiological processes regulated by the central clock, such as core body temperature, plasma cortisol and melatonin(13). For instance, melatonin levels are low in the day and rise at night, with production inhibited by bright light(14). The rhythm of melatonin secretion under dim light conditions, or dim light melatonin onset (DLMO), is the most reliable marker of circadian phase(15). However, DLMO collection can be expensive and burdensome. As such, questionnaires have been developed to identify actual or preferred times for daily activities, such as eating and sleeping, as behavioural indicators of chronotype(16). For example, sleep and wake times relate to the period (cycle length) of the internal circadian clock(17). It is not surprising, therefore, that a typical population consists of a range of morning to evening chronotypes; the former population tends to wake and sleep early, while the latter group wakes and sleeps late(18). Evening chronotypes commonly experience circadian misalignment because of their propensity toward nocturnal behaviours, which are out of synchrony with the light–dark cycle. These behaviours are associated with higher odds of hypertension(19), diabetes and metabolic syndrome compared with morning types after adjustment for confounding variables(20). Therefore, identifying the chronotype of an individual has relevance in understanding their health outcomes.

A recent scoping review reported that evening chronotypes across Europe, Asia, and North and South America have poorer diet quality, including lower vegetable intake and greater intake of sweet food/beverages and alcohol(21,22), increasing cardiometabolic disease risk(23). With a chrononutrition lens, we argue that it is pertinent to investigate whether not only diet quality but also food timing may contribute to increased health risk for those with later chronotype. To do so, it is important to first identify all time-related factors of eating, hereon referred to as *temporal patterns of eating*, in a range of chronotypes, and compare trends between chronotypes. Two recent reviews have considered chronotype in relation to diet (Mazri and colleagues(21) and Almoosawi *et al.*(11)). While both reviews discussed some evidence of the relationship between late chronotype and meal timing (e.g. delayed meals, breakfast skipping), the main focus was on the relationship between chronotype and food/nutrient intake, and cardiometabolic health, respectively. As such, it was not within the scope of these reviews to cover all temporal patterns of eating or discuss in detail the methodology of collecting data on chronotype and food timing. This highlights the need for further studies and, in particular, a systematic approach to establishing consistent and valid methods to capture chronotype and food timing.

Further, a recent position statement from the American Heart Association highlighted the translational importance of research in this area. This expert opinion statement, for the first time, made recommendations regarding the importance of taking into consideration temporal aspects of eating on cardiometabolic health, and recommended that being mindful of the timing and frequency of food intake may alleviate cardiometabolic health risks(1). To assist with the translation of this advice into practice, this review will focus on understanding the temporal patterns of eating of different chronotypes, as well as identifying and assessing the tools used by studies in collecting data on temporal patterns of eating and chronotype, to enable identification of strengths, weaknesses and gaps. Recommendations on ways to improve data collection of chronotype and temporal patterns of eating will be made based on findings from this review. This will pave the way for improved collection of data on temporal patterns of eating and chronotype and a greater understanding of how chronotype may influence temporal patterns of eating and, possibly, health outcomes.

## Methods

This scoping review was conducted according to the standard process outlined in Arksey *et al.*(24). According to Arksey and colleagues, the aim of a scoping review is not to synthesise evidence like a systematic review; rather, scoping reviews have an analytical structure, whereby themes are identified, creating a narrative of the existing literature. The strength of a scoping review lies in its rigor and transparency in mapping the area of research in question.

A systematic literature search was conducted via the electronic databases Medline, Embase, Emcare, PsycInfo, Cochrane Library, Web of Science and Scopus for articles published from earliest to 23 June 2020. MeSH headings and keywords were initially identified in Medline, and re-run on the other databases with modifications to accommodate to each database where necessary. Extra headings identified on other databases were included across all databases and searches rerun for consistency (Supplementary material: Search terms). In Covidence(25), two independent reviewers screened identified articles. Initial screening based on title and abstracts was conducted by Y.Y. and A.C./M.H./M.B., with disagreements resolved by J.D., and subsequent screening based on full-text assessment was conducted by Y.Y. and M.H., with disagreements resolved by J.D./A.C./M.B. The reference lists of reviews and full-text articles were searched for relevant publications, which equally underwent title, abstract and full-text screening of eligibility. Articles were excluded if they were non-human studies, were reviews, or were not in English.

The inclusion criteria were developed from the Joanna Brigg's Institute Reviewer's Manual for Scoping Reviews(26).

- Participants: adults ≥18 years
- Concept: chronotype; and dietary behaviours related to timing of food and energy intake, including studies on meal skipping, meal frequency, meal regularity, duration of eating window, and duration between meals, or meals and wake/sleep times
- Context: nil.
- Types of evidence sources: randomised controlled trials, non-randomised controlled trials, before and after studies, prospective and retrospective cohort studies, cross-sectional studies, and case–control studies

## Results

Fig. 1 represents a PRISMA extension for scoping reviews (PRISMA-ScR) flow diagram of study selection. From an initial

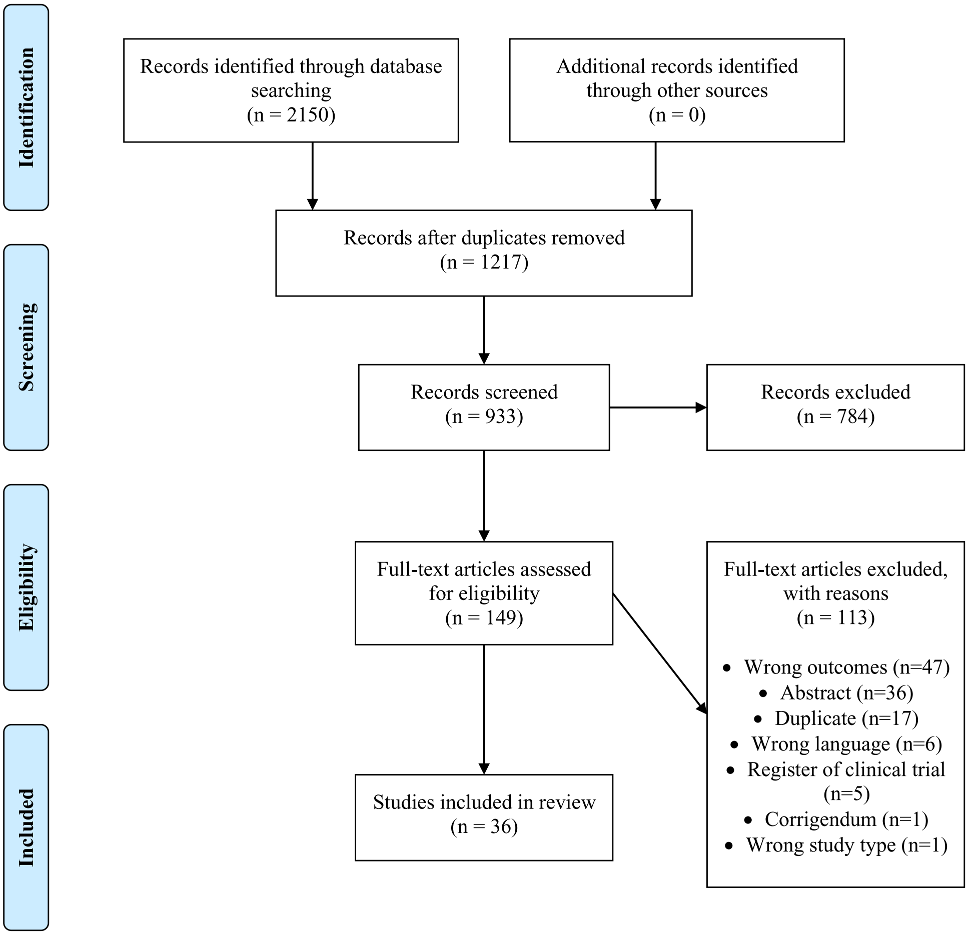


**Fig. 1.** PRISMA flow chart of the review progress. Thirty-six papers were identified as having met the study criteria.

search where 2150 articles were retrieved, screening yielded 36 studies to include in this review (Table 1).

## *Demographics*

Study dates ranged from 1973 to 2020, with 89% published after 2010. Studies were mainly conducted in Europe ($n = 13$)(28,29,31,33,36–39,42,44,48,56,62), followed by Asia ($n = 11$)(30,34,40,41,50,51,53,58–61), North America ($n = 7$)(22,27,35,43,46,47,57) and South America ($n = 6$)(32,52,54,55,62,63). Most were cross-sectional ($n = 31$)(22,27–30,32,34,36,38–44,46,47,50–63), with two randomised trials(33,35), two prospective studies(37,48) and a single pre/post study(31). A majority of the studies included tertiary students ($n = 17$)(29,30,33,34,38,40,42,44,50,52–55,58,59,62,63), followed by community-dwelling adults ($n = 7$)(27,28,36,37,43,57,60), and workplace employees, which included non-shift workers ($n = 2$)(39,51) and shift workers ($n = 1$)(61). The remaining studies included individuals with medical conditions or requirements, such as people with type 2 diabetes ($n = 3$)(22,41,46), people impacted by overweight and obesity ($n = 3$)(31,35,56), pregnant women ($n = 1$)(32), bariatric surgery patients ($n = 1$)(48) and individuals with bipolar disorder ($n = 1$)(47). Across all studies, there were 27 685 participants, ranging in age from 18 to 85 years. Seven studies included only female participants(32,40,50,58,60,61,63), with the rest including a mix of genders.

## *Assessment of chronotype*

Details of the questionnaires used to capture chronotype in the studies are presented in Table 2. These instruments record behavioural indicators of chronotype through preferred or actual timing of daily activities such as sleep and wake. In addition to the variety of methods used to chronotype, studies also used different cut-off points to differentiate between chronotypes (Table 3).

Twenty-three studies estimated chronotype by ‘morningness-eveningness preference’, using the Morningness Eveningness Questionnaire (MEQ)(16) ($n = 14$)(28,30,31,34,35,38,39,48,54–56,59–61), study-specific questionnaires and interviews containing MEQ components ($n = 3$)(40,42,47), the Composite Scale of Morningness (CSM)(70) ($n = 3$)(33,41,44), the shortened six-item MEQ ($n = 2$)(36,37) and the Diurnal Type Scale (DTS) ($n = 1$)(53) (Table 3).

Other quantitative instruments included those based on ‘mid-point of sleep’ or inactivity to estimate melatonin onset as an indicator of circadian timing(71). The Munich Chronotype Questionnaire (MCTQ) estimates chronotype using the midpoint between sleep and wake time on free days, corrected for sleep debt over the work week ($\mathrm{MSF_{SC}}$)(72). The resulting time estimate can be categorised as representing morning, intermediate or evening chronotype based on cut-off values(69). $\mathrm{MSF_{SC}}$ has shown to

**Table 1.** Summary of study characteristics

| Author & Year, Country, Study type | Population | Outcome measures | Measurement tools | Results |
|---|---|---|---|---|
| **Baron *et al.*, 2011**(52)<br>United States<br>Cross-sectional study | Adults from the community (non-shift workers)<br>Female: n=25<br>Male: n=27<br>Average sleep times: n=28<br>Late sleep times: n=23<br>Age: 31 years±12 years | **Chronotype**<br>• Midpoint of sleep (average over 7 days)<br>• Average sleep times: between 01:00-05:29 h<br>• Late sleep times: after 05:30 h<br>**Temporal patterns of eating**<br>• Meal frequency/day<br>• Breakfast skippers (consuming breakfast ≤2/week)<br>• Time of breakfast, lunch, dinner, and last meal<br>• Duration between meals and snacks<br>• Calorie intake at breakfast, lunch, dinner, after dinner, and after 20:00 h<br>• Cumulative calorie intake across the day | **Chronotype**<br>• 7-day sleep logs and actigraphy<br>**Temporal patterns of eating**<br>• 7-day food logs | • Compared to average sleepers, late sleepers had significantly:<br>○ later breakfast, lunch, dinner, and last mealtimes.<br>○ shorter duration between breakfast and lunch, and longer duration between last meal and sleep onset.<br>○ higher caloric intake at dinner and after 20:00 h.<br>○ fewer calories early in the day between 09:00-12:00 h.<br>○ no difference in meal frequency, frequency of breakfast skipping, and average % of calories consumed after evening meals.<br>• Later sleep timing was positively associated with higher consumption of calories after 20:00 h (r=0.56, p<0.001), and later timing of last meal/snack (r=0.52, p<0.001). |
| **Costa *et al.*, 1987**(38)<br>Italy<br>Cross-sectional study | Students, housewives, clerks, artisans, tradesmen, and industrial workers<br>Female: n=266<br>Male: n=404<br>Age: 32.6±10.1 years | **Chronotype**<br>• Morningness-Eveningness preference<br>**Temporal patterns of eating**<br>• Breakfast, lunch, and dinner time | **Chronotype**<br>• Italian version of the MEQ<br>**Temporal patterns of eating**<br>• Questionnaire including questions on usual mealtimes | • Times of breakfast, lunch, and dinner are advanced in M-types compared to E-types (no statistics run).<br>• Inverse relationship between morningness score and breakfast time during work (r=-0.24) and free days (r=-0.39), (p<0.01). |
| **Friborg *et al.*, 2014**(39)<br>Norway<br>Cross-sectional study | University students<br>***Female:***<br>n=124<br>Age: 23.4±5 years<br>***Male:***<br>n=38<br>Age: 24.3±5.4 years | **Chronotype**<br>• MSF$_{SC}$<br>**Temporal patterns of eating**<br>• Eating habit score | **Chronotype**<br>• 7-day sleep diary<br>**Temporal patterns of eating**<br>• Eating habit score: Four questions on days/week breakfast, lunch, dinner, and supper were eaten and one on number of meals a day | • Inverse relationship between chronotype score and eating habits score (r=-0.14, p<0.001). |
| **Gangwar *et al.*, 2018**(49)<br>India<br>Cross-sectional study | First-year medical undergraduates<br>***E-type***<br>n=73<br>Age: 18.21±0.67 years<br>Male: n=47<br>***I-type***<br>n=87<br>Age: 18.9±0.69 years<br>Male: n=57<br>***M-type***<br>n=43<br>Age: 18.05±0.65 years<br>Male: n=27 | **Chronotype**<br>• Morningness-Eveningness preference<br>• Group 1: Definite evening chronotype<br>• Group 2: Intermediate chronotype<br>• Group 3: Definite morning chronotype<br>No detail on cut-off score used<br>**Temporal patterns of eating**<br>• Dinner time (<21:00 h or ≥21:00 h) | **Chronotype**<br>• MEQ<br>**Temporal patterns of eating**<br>• Preformed proforma including dinner time | • More E-types had dinner ≥21:00 h than I-types, and more I-types had dinner ≥21:00 h than M-types (p<0.001). |
| **Garaulet *et al.*, 2013**(36)<br>Spain | Overweight and obese patients<br>n=420<br>Age and gender of larger | **Chronotype**<br>• Morningness-Eveningness preference<br>• M-type: >64 points | **Chronotype**<br>• MEQ<br>**Temporal patterns of eating** | • Late lunch eaters (after 1500h) had lower MEQ scores (more eveningness) compared to early eaters (before 1500h) (p=0.032). |

**Table 1.** *(Continued)*

| Author & Year, Country, Study type | Population | Outcome measures | Measurement tools | Results |
|---|---|---|---|---|
| Pre-post study: 20-week weight loss | population (n=510) from which this sample was obtained:<br>Age: 42±11 years<br>Female: 49.5%<br>Male: 50.5% | • I-type: 53-64 points<br>• E-type: <53 points<br>**Temporal patterns of eating**<br>• Early or late eaters of lunch (using median values of the population as cut-off points) | • Random 1-week weighed 7-day dietary record to represent intake over the weight loss period | |
| **Gontijo *et al.*, 2018**(60)<br>Brazil<br>Cross-sectional study | Healthy pregnant women in the first trimester of pregnancy<br>n=100 | **Chronotype**<br>• $MSF_{SC}$<br>**Temporal patterns of eating**<br>• Nightly fasting<br>• Eating duration (length of time between first and last caloric event)<br>• Time of first/last meal<br>• Meal frequency | **Chronotype**<br>• Survey of usual sleep habits on weekdays and weekends during pregnancy<br>**Temporal patterns of eating**<br>• 3 24-h dietary recalls on non-consecutive days, including 1 weekend | • No association between chronotype and nightly fasting, eating duration, time of the first meal, time of the last meal, and meal frequency. |
| **Halsey *et al.*, 2011**(35)<br>United Kingdom<br>Randomised crossover trial | University students and individuals living in the London area<br>Female: n=26<br>Male: n=23<br>Age: 22.6±3.9 years | **Chronotype**<br>• Morningness-Eveningness preference<br>**Temporal patterns of eating**<br>• Frequency of breakfast in a week | **Chronotype**<br>• CSM<br>**Temporal patterns of eating**<br>• Self-completed questionnaire about breakfast frequency over a week | • Positive correlation between morningness and frequency of breakfast consumption (r=0.41, p=0.005). |
| **Ishihara, Miyasita, and Inugami, 1985**(44)<br>Japan<br>Cross-sectional study | University students<br>M-type: n=110<br>E-type: n=339<br>Age: 19.5 years (mean)<br>*Data on gender not reported | **Chronotype**<br>• Morningness-Eveningness preference<br>• M-type: 59-86 points<br>• E-type: 16-41 points<br>*intermediate types not included<br>**Temporal patterns of eating**<br>• Breakfast, lunch, and dinner time<br>• Breakfast consumption | Chronotype<br>• Validated Japanese version of the MEQ<br>Temporal patterns of eating<br>• Life Habits Inventory including mealtimes, meal frequency | • E-types had a trend of later breakfast, lunch, and dinner times (p>0.05).<br>• More E-types did not eat breakfast than M-types (34.8% vs. 5.5%). |
| **Lucassen *et al.*, 2013**(55)<br>United States<br>Randomised controlled trial | Obese men and premenopausal women with <6.5 h sleep per night<br>***M-type***<br>n=80<br>Age: 41.7±5.9 years<br>Female: n=61<br>Male: n=19<br>***E-type***<br>n=39<br>Age: 38.6±7.8 years<br>Female: n=31<br>Male: n=8 | **Chronotype**<br>• Morningness-Eveningness preference<br>• M-type: 50-86 points<br>• E-type: 16-49 points<br>**Temporal patterns of eating**<br>• Number of eating occasions a day<br>• Time of first eating occasion<br>• Calorie intake and % of total calorie intake after 20:00 h | **Chronotype**<br>• MEQ<br>**Temporal patterns of eating**<br>• 3-day food record (preferably 2 weekdays and 1 weekend) | • Individuals with greater eveningness had fewer eating occasions ($r^2$=0.048, p=0.044). and greater % of total calorie intake after 20:00 h ($r^2$=0.129, p<0.001).<br>• After correction for BMI, chronotype score is inversely related to the first eating occasion (coefficient = −0.059), caloric intake after 20:00 (coefficient = −10.687), percent caloric intake after 20:00 (coefficient = −0.445), (p= 0.001). |
| **Maukonen *et al.*, 2017**(29)<br>Finland<br>Cross-sectional study | Adults from the community<br>***M-type***<br>n= 904<br>Male: 50.1%<br>Age: 53.4 (0.4) years<br>***I-type***<br>n= 726<br>Male: 43.3% | **Chronotype**<br>• Morningness-Eveningness preference<br>• M-type: 6-12 points<br>• I-type: 13-18 points<br>• E-type: 19-27 points<br>**Temporal patterns of eating**<br>Average week (excluding Fridays) and weekends, separately: | **Chronotype**<br>• Shortened 6-item MEQ<br>**Temporal patterns of eating**<br>• 48-h dietary recall of 2 previous consecutive days<br>• 3-day food records for completion at home following the 48-h dietary recall | ***Across the week (except Fridays):***<br>• M- and E-types both had four energy intake peaks a day; with that of E-types ˜1 hour later than M-types.<br>• E-types had lower cumulative energy intake compared to M-types from the beginning of the day until 22:00 h.<br>***On weekends:***<br>• E-types had 6 peaks of energy intake while morning types had 3; For E-types, the highest energy intake |

**Table 1.** *(Continued)*

| Author & Year, Country, Study type | Population | Outcome measures | Measurement tools | Results |
|---|---|---|---|---|
| | Age: 48.4 (0.5) years<br>***E-type***<br>n= 224<br>Male: 37.5%<br>Age: 43.9 (0.9) years | • Cumulative energy intake across the day<br>• Energy intake (kJ, % of total daily energy) in the morning (03:00 h to 09:59 h) and in the evening (20:00 h to 02:59 h) | | peak was at 19:00 h, while for M-types, the 3 peaks at 08:00 h, 00:00 h, and 17:00 h were similar.<br>• E-types had lower cumulative energy intake compared to M-types from the beginning of the day until 01:00 h.<br>***Across all days of the week (except Fridays)***<br>• In the morning, E-types had significantly lower total and % of total energy intake than M-types.<br>• In the evening, E-types had significantly greater total and % of total energy intake than M-types. |
| **Maukonen *et al.*, 2019**(30)<br>Finland<br>Prospective study | Adults from the community<br>***M-type***<br>n=552<br>Male: 46.9%<br>Age: 55.7 (0.5) years<br>***I-type***<br>n=433<br>Male: 41.3%<br>Age: 51 (0.6) years<br>***E-type***<br>n=112<br>Male: 35.7%<br>Age: 47.3 (1.2) years | **Chronotype**<br>• Morningness-Eveningness preference<br>• M-type: 6-12 points<br>• I-type: 13-18 points<br>• E-type: 19-27 points<br>**Temporal patterns of eating**<br>• Energy intake (% of total daily energy) in the morning (03:00 h to 09:59 h) and in the evening (20:00 h to 02:59 h) | **Chronotype**<br>• Shortened 6-item MEQ<br>**Temporal patterns of eating**<br>• 48-h dietary recall of 2 previous consecutive days | • E-types had significantly lower % energy intake in the morning and higher % energy intake in the evening than M-types. |
| **Meule *et al.*, 2012**(28)<br>Germany<br>Cross-sectional study | University students from a sample of 471 pre-screened to be of definite M-types and E-types.<br>Female: n=56<br>Male: n=10<br>Age=23.08±2.68 years | **Chronotype**<br>• Morningness-Eveningness preference<br>• M-type: ≥55 points<br>• E-type: ≤44 points<br>**Temporal patterns of eating**<br>• Breakfast consumption (yes/no)<br>• Number of hours since last meal | The questionnaires below were conducted in the morning (n=25) and the evening (n=31):<br>**Chronotype**<br>• MEQ<br>**Temporal patterns of eating**<br>• Questionnaire, including number of hours since last meal and breakfast consumption | Significantly:<br>• More M-types had breakfast than E-types.<br>• More hours since last meal amongst E-types than M-types in the morning.<br>• More hours since last meal amongst E-types in the morning than evening. |
| **Munoz *et al.*, 2017**(32)<br>Spain<br>Cross-sectional study | University staff<br>***M-type***<br>n=80<br>Age: 41±11 years<br>***E-type***<br>n=91<br>Age: 43±15 years<br>*Data on gender not reported | **Chronotype**<br>• Morningness-Eveningness preference<br>• M-type: >51 points<br>• E-type: ≤51 points<br>**Temporal patterns of eating**<br>• % of total calorie intake at breakfast, mid-morning snack, lunch, mid-afternoon snack, and dinner | **Chronotype**<br>• MEQ<br>**Temporal patterns of eating**<br>• 24-h dietary recall | **Normal weight subjects (BMI=18.5-24.9kg/$m^2$)**<br>• M-types had higher % total calorie intake at lunch (p=0.008) than E-types.<br>• E-types had higher % total calorie intake at mid-afternoon snack (p=0.041) than M-types.<br>**Overweight subjects (BMI≥25kg/$m^2$)**<br>• M-types had significantly higher % total calorie intake at breakfast and lunch than E-types.<br>• E-types had higher % total calorie intake at mid-morning snack (p=0.021) than M-types. |
| **Nakade *et al.*, 2009**(43)<br>Japan<br>Cross-sectional study | Female tertiary students<br>n=800<br>Age: 18-29 years | **Chronotype**<br>• Morningness-Eveningness preference<br>**Temporal patterns of eating**<br>• Breakfast time and frequency. | **Chronotype & Temporal patterns of eating**<br>Integrated questionnaire of habits in the previous month, including<br>• Japanese version of the MEQ<br>• An excerpt from Examination of Eating | • Less frequent breakfast consumers had lower ME scores than more frequent breakfast consumers (p<0.001).<br>• Late breakfast consumers had lower ME scores than early breakfast consumers (p<0.001). |

**Table 1.** *(Continued)*

| Author & Year, Country, Study type | Population | Outcome measures | Measurement tools | Results |
|---|---|---|---|---|
| | | | Habits of Japan's National Health and Nutrition Examination Survey | |
| **Nimitphong *et al.*, 2018**[48]<br>Thailand<br>Cross-sectional study | Individuals with type 2 diabetes<br>Female: n=126<br>Male: n=84<br>Age: 58.6±11 years | **Chronotype**<br>- Morningness-Eveningness preference<br>- E-type: CSM score <45<br>- M-type CSM score ≥45<br>**Temporal patterns of eating**<br>- Breakfast, lunch, dinner, and last mealtime<br>- % of daily calories consumed at breakfast, lunch, dinner, and snacks<br>- Frequency of food intake | **Chronotype**<br>- Validated Thai version of the CSM<br>**Temporal patterns of eating**<br>- 24-h dietary recall | - Morning chronotypes had significantly earlier breakfast, lunch, dinner, and last mealtimes.<br>- Between chronotypes, no difference in calorie distribution among main meals and snacks or frequency of food intake.<br>- Morning chronotypes associated with earlier breakfast times (coefficient =-0.614, p<0.001). |
| **Östberg, 1973**[33]<br>Sweden<br>Cross-sectional study | Psychology students<br>Female: n=17<br>Male: n=4<br>M-type: n=14<br>E-type: n=7<br>Age: 19-26 years | **Chronotype**<br>- Morningness-Eveningness preference<br>**Temporal patterns of eating**<br>- Normalised calorie distribution in half-hour steps | **Chronotype**<br>- Questionnaire concerning personal preference and habits, to discriminate between extreme morning and evening types<br>**Temporal patterns of eating**<br>- 4-day food record | M-types led in circadian food intake by 1.75 h. |
| **Quante *et al.*, 2019**[56]<br>United States<br>Cross-sectional study | Adults<br>n=126<br>Male: 37%<br>Age: 35.4±11 years | **Chronotype**<br>- L5 midpoint (time of peak inactivity, average over 7 days)<br>**Temporal patterns of eating**<br>- Time of first and last eating episode | **Chronotype**<br>- Actigraphy<br>**Temporal patterns of eating**<br>- Questionnaire on app of timing of first and last eating episode over 7 days. | - Time of first eating episode is correlated with L5 midpoint (r=0.4, p<0.001)<br>- Time of last eating episode is correlated with L5 midpoint (r=0.57, p<0.001)<br>- Later timing of first eating episode (after 07:45-09:45 h versus 05:00-07:45 h) was associated with L5 midpoint (β=1.2 [95% CI:0.73-1.66])<br>- Later timing of last eating episode (after 20:00-21:00 h versus 17:00-20:00 h) was associated with L5 midpoint (β=0.64 [95% CI:0.19-1.1])<br>- First eating episode was associated with L5 midpoint among non-M-types (β=1.18 [95% CI:0.58-1.77]) but not M-types. |
| **Randler and Jankowski, 2014**[31]<br>Poland and Germany<br>Cross-sectional study | University students of social sciences<br>n=570<br>***Poland:***<br>Female: 83%<br>Age: 20.81±1.73 years<br>***Germany:***<br>Female: 78%<br>Age: 21.73±2.01 years | **Chronotype**<br>- Morningness-Eveningness preference<br>**Temporal patterns of eating**<br>- Breakfast, lunch, and dinner time (averaged over a 7-day week) | **Chronotype**<br>- CSM<br>**Temporal patterns of eating**<br>- Self-report timetable questionnaire, with questions taken from the Social Rhythm Metric[103], including times of breakfast, lunch, and dinner over a 7-day week. | - In both the Polish and German populations, CSM was inversely correlated with time of breakfast, i.e., E-types had later breakfast (r=-0.425, r=-0.408) and dinner (r=-0.298, r=-0.234) times (p<0.001)<br>- CSM was inversely correlated with time of lunch in the Polish (r=-0.238, p<0.001) but not German population. |
| **Reutrakul *et al.*, 2013**[22]<br>United States<br>Cross-sectional study | Adults with type 2 diabetes aged 18-85 years<br>Female: n=135<br>Male: n=59 | **Chronotype**<br>- $MSF_{SC}$<br>- Q1: 01:30±0:46 h<br>- Q2: 02:48±0:20 h<br>- Q3: 03.54±0:17 h<br>- Q4: 05:50±1:30 h<br>**Temporal patterns of eating**<br>- % of daily calories consumed at | **Chronotype**<br>- Pittsburgh Sleep Quality Index of sleep patterns in the previous month<br>**Temporal patterns of eating**<br>- 24-h dietary recall | - Later $MSF_{SC}$ consumed greater % of daily calories at dinner and had later breakfast and dinner times (p<0.05).<br>- $MSF_{SC}$ associated with % of daily calories consumed at dinner (β =0.024, p=0.006). |

**Table 1.** *(Continued)*

| Author & Year, Country, Study type | Population | Outcome measures | Measurement tools | Results |
|---|---|---|---|---|
| | | breakfast and dinner<br>• Breakfast and dinner time | | |
| **Reutrakul *et al.*, 2014**(51)<br>United States<br>Cross-sectional study | Adults with type 2 diabetes aged 18-85 years<br>Female: n=135<br>Male: n=59 | **Chronotype**<br>• MSF$_{SC}$<br>**Temporal patterns of eating**<br>• Breakfast skipping | **Chronotype**<br>• Self-reported usual bedtime, wake-up time, and sleep onset latency on weekdays and weekends in the previous month.<br>**Temporal patterns of eating**<br>• 24-h dietary recall | • Breakfast skippers had later MSF$_{SC}$ (p=0.002)<br>• Breakfast skipping was associated with later MSF$_{SC}$ ($\beta$ =0.98, p=0.014) |
| **Romo-nava *et al.*, 2020**(54)<br>Mayo Clinic Bipolar Biobank (United States)<br>Cross-sectional study | Bipolar disorder patients<br>***E-type***<br>n=208<br>Female n=123<br>Age: 35.7±13.4 years<br>***Non-E-type***<br>n=575<br>Female: n=374<br>Age: 40.8±14.8 years | **Chronotype**<br>• Morningness-Eveningness preference<br>• Non-E-type: “Definitely a morning type”, “More a morning than an evening type”, “More an evening than a morning type”, “Neither describes me”<br>• E-type: “Definitely an evening type”<br>**Temporal patterns of eating**<br>• Breakfast skipping | **Chronotype & Temporal patterns of eating**<br>• BiB-PQ including a single self-report item on chronotype preference<br>• REAP-S, a self-report measure of dietary quality, including a question on breakfast skipping | E-types skipped breakfast more frequently (p<0.01). |
| **Ruiz-Lozano *et al.*, 2016**(34)<br>Spain<br>Prospective study | Patients who underwent bariatric surgery<br>n=252<br>Female: 79%<br>Age: 52±11 years | **Chronotype**<br>• Morningness-Eveningness preference<br>• M-type: >57 points (n=124)<br>• E-type: ≤57 points (n=128)<br>**Temporal patterns of eating**<br>• Breakfast, lunch, and dinner time | **Chronotype**<br>• MEQ<br>**Temporal patterns of eating**<br>• Validated questionnaire to assess meal patterns(98) | E-types had significantly later breakfast, lunch, and dinner times (p<0.001) than M-types. |
| **Sato-mito *et al.*, 2011**(40)<br>Japan<br>Cross-sectional study | Female dietetic students<br>n=3304<br>Age: 18-20 years | **Chronotype**<br>• Midpoint of sleep on weekdays split into quintiles<br>**Temporal patterns of eating**<br>• Breakfast, lunch, dinner time<br>• # of skipped breakfast, lunch, or dinner over a week | **Chronotype & Temporal patterns of eating**<br>12-page lifestyle questionnaire of habits in the previous month, including:<br>• Usual wake and sleep times on weekdays<br>• Times of breakfast, lunch, and dinner<br>• # of skipped breakfast, lunch, and dinner over a week | Later quintiles of midpoint of sleep are significantly associated with later breakfast, lunch, and dinner times, and more times a week of breakfast, lunch, or dinner skipping. |
| **Shimura *et al.*, 2020**(41)<br>Japan<br>Cross-sectional study | Employees of 29 companies across a range of fields<br>Female: n=2171<br>Male: n=3461<br>Other: n=8<br>Age: 36.9±10.2 years (range: 18-79) | **Chronotype**<br>• MSF$_{SC}$<br>• E-type: late third of the distribution of MSF$_{SC}$<br>**Temporal patterns of eating**<br>• Regularity of mealtimes<br>• Frequency of morning breakfast intake<br>• Time between dinner and bedtime | **Chronotype**<br>• Japanese version of the PSQI for sleep schedule on work and free days<br>**Temporal patterns of eating**<br>• Questionnaire on lifestyle habits, including mealtime regularity, breakfast frequency, and time between dinner and bedtime. | • Regularity of mealtimes (F-value=123.456), frequency of morning breakfast intake (F-value=189.007), and time between dinner and bedtime (F-value=15.792) are significantly associated with chronotype.<br>• Irregular mealtimes (aOR: 1.513-2.369), lack of morning breakfast (aOR: 1.735-2.946), and having dinner >2 hours before bedtime (aOR: 0.488-0.638) are significantly associated with E-type. |
| **Silva *et al.*, 2016**(57)<br>Brazil<br>Cross-sectional study | University students<br>Female: n=112<br>Male: n= 92<br>Age: 18-39 years | **Chronotype**<br>• MSF$_{SC}$<br>**Temporal patterns of eating**<br>• Skipped breakfast<br>• Breakfast, lunch, and dinner time | **Chronotype & Temporal patterns of eating**<br>Structured questionnaire of habits in the last two weeks, including:<br>• Usual wake and sleep times on weekdays and weekends<br>• Eating or skipping of breakfast<br>• Times of breakfast, lunch, and dinner | • Breakfast skippers had higher MSF$_{SC}$ than breakfast eaters (p=0.02).<br>• Significantly positive correlation between chronotype and breakfast time (r=0.24) and lunch time (r=0.19). |

**Table 1.** *(Continued)*

| Author & Year, Country, Study type | Population | Outcome measures | Measurement tools | Results |
|---|---|---|---|---|
| **Takeuchi *et al.*, 2015**[47]<br>Japan<br>Cross-sectional study | University and medical training schools (for physiotherapists and medical nurses) students<br>Female: n=2045<br>Male: n=1880<br>Age: 18-40 years | **Chronotype**<br>• Morningness-Eveningness preference<br>• M-type: 17-28 points<br>• I-type: 13-16 points<br>• E-type: 7-12 points<br>**Temporal patterns of eating**<br>• Frequency of having nutritionally rich (including carbohydrates, protein, vitamins, and minerals) meals in a week | **Chronotype**<br>Japanese version of the DTS produced for students<br>**Temporal patterns of eating**<br>Not stated | M-types had a nutritionally rich breakfast, lunch, and dinner significantly more frequently than I-types and E-types. |
| **Teixeira, Mota, and Crispim, 2018**[58]<br>Brazil<br>Cross-sectional study | Undergraduate students<br>Female: n=488<br>Male: n=233<br>E-type: 21±3 years<br>I-type: 20.4±3 years<br>M-type: 20.4±2.9 years | **Chronotype**<br>• Morningness-Eveningness preference<br>• M-type: 59-86 points<br>• I-type: 42-58 points<br>• E-type: 16-41 points<br>**Temporal patterns of eating**<br>• Breakfast, lunch, and dinner time<br>• Breakfast skippers (consuming breakfast ≤2/week) | **Chronotype**<br>• MEQ (Brazil validated)<br>**Temporal patterns of eating**<br>24-h dietary recall<br>Question on the number of times/week breakfast is consumed | • E-types and I-types had breakfast, lunch, and dinner significantly later than M-types.<br>Prevalence of skipping breakfast significantly higher among E-types (p=0.02) compared to M-types and I-types; E-types have 1.7 times higher odds (CI 95%: 1.1-2.9) of skipping breakfast than M-types and I-types.<br>Significantly negative association between diurnal preference and breakfast time (r=-0.18), and lunch time (r=-0.11). |
| **Teixeira *et al.*, 2019**[59]<br>Brazil<br>Cross-sectional study | Undergraduate students<br>Female: n=485<br>Male: n=233<br>Age: 20.5±2.9 years | **Chronotype**<br>• Morningness-Eveningness preference<br>• M-type: 59-86 points<br>• I-type: 42-58 points<br>• E-type: 16-41 points<br>**Temporal patterns of eating**<br>• Caloric midpoint<br>• Early eaters: caloric midpoint before 15:00 h<br>• Late eaters: caloric midpoint after 15:00 h | **Chronotype**<br>• MEQ (Brazil validated)<br>**Temporal patterns of eating**<br>• 24-h dietary recall | • Late eaters had significantly lower ME score and higher frequency of eveningness.<br>• ME score is negatively correlated with caloric midpoint (r=-0.15, p<0.001). |
| **Vera *et al.*, 2018**[27]<br>Spain<br>Cross-sectional study | Overweight and obese subjects from the Obesity, Nutrigenetics, Timing, and Mediterranean study aged 40 ±13 years<br>n=2126<br>***M-type***<br>Female: n=902<br>Age: 42.97±12.67 years<br>***E-type***<br>Female: n=820<br>Age: 36.17±12.68 years | **Chronotype**<br>• Morningness-Eveningness preference<br>• E-type: ME score <53<br>• M-type: ME score ≥53<br>**Temporal patterns of eating**<br>• Breakfast, lunch, and dinner time<br>• Midpoint of intake (time between first and last eating episodes) | **Chronotype**<br>• MEQ<br>**Temporal patterns of eating**<br>• 24-h dietary recall | • Evening chronotypes had later breakfast (p<0.001), lunch (p=0.184), and dinner times (p=0.001), and midpoint of intake (p<0.001). |
| **Xiao, Garaulet, and Scheer, 2019**[53]<br>United States<br>Cross-sectional study | Middle-to-older-aged adults in the community<br>**BMI < 25 kg/m$^2$**<br>n=232<br>Female: 65.5%<br>Age: 63.2±6.2years | **Chronotype**<br>• MSF$_{SC}$<br>• M-type: <03:04 h<br>• E-type: >03:04 h<br>**Temporal patterns of eating**<br>• Breakfast, lunch, and dinner time | **Chronotype**<br>• Self-reported rise and bedtimes over 7 days.<br>**Temporal patterns of eating**<br>• ASA24 | • E-types had significantly later breakfast, lunch, and dinner times.<br>• E-types had significantly less time between wake up and breakfast and more time between dinner and bedtime. |

**Table 1.** *(Continued)*

| Author & Year, Country, Study type | Population | Outcome measures | Measurement tools | Results |
|---|---|---|---|---|
| | **BMI 25–<30 kg/m$^2$**<br>n=367<br>Female: 40.1%<br>Age: 63.5±5.7 years<br>**BMI ≥ 30 kg/m$^2$**<br>n=273<br>Female: 52.8%<br>Age: 62.4±5.9 years | • Time between wakeup and breakfast<br>• Time between dinner and bedtime | | |
| **Yadav and Singh, 2013**(50)<br>India<br>Cross-sectional study | Healthy female undergraduate students<br>n=40<br>Age: 19.6 (19-21.5) years | **Chronotype**<br>• Morningness-Eveningness preference<br>• Participants to self-rate among 7 chronotype classes from "extremely early" to "extremely late", with intermediate type in between.<br>**Temporal patterns of eating**<br>On college days and vacation days separately:<br>• Feeding frequency between 06:00 h to 23:00 h | **Chronotype**<br>• Hindi and English version of the MCTQ<br>**Temporal patterns of eating**<br>• Daily feeding logs for 3 weeks (that includes college days and vacation days) on an hourly basis from 06:00 h to 23:00 h. | • During college days, M-types had 3 clear peaks in eating frequency at 08:00-09:00 h, 14:00-15:00 h, and 21:00-22:00 h, which was the same in I-types, except the second peak occurred at 13:00-14:00 h instead of 14:00-15:00 h.<br>• During vacation days, there were also 3 peaks in both M-types and I-types. M-types had an earlier 2nd peak at 12:00-13:00 h while I-types had a later 1st peak at 21:00-22:00 h.<br>• E-type data was not presented as there were no clear feeding patterns during both college and vacation days. |
| **Yasuda *et al.*, 2018**(46)<br>Japan<br>Cross-sectional study | College and graduate school students<br>***Female***<br>n=118<br>Breakfast 0-3x/week:<br>Age: 22.2±3.4 years<br>Breakfast 4-6x/week:<br>Age: 21±1.8 years<br>Breakfast 7x/week: Age: 21.2 ±2.4 years<br>***Male***<br>n=152<br>Breakfast 0-3x/week:<br>Age: 22.2±2.3 years<br>Breakfast 4-6x/week:<br>Age: 21.5±2.3 years<br>Breakfast 7x/week: Age: 20.5 ±2.0 years | **Chronotype**<br>• Morningness-Eveningness preference<br>**Temporal patterns of eating**<br>• Frequency of breakfast in a week | **Chronotype**<br>• MEQ<br>**Temporal patterns of eating**<br>• Self-report questionnaire including question on frequency of breakfast intake per week in the previous month | Among men and women, MEQ scores were the lowest in individuals who had breakfast 0-3 times a week, compared to 4-7, or 7 times a week (p<0.001). |
| **Yazdinezhad *et al.*, 2019**(45)<br>Iran<br>Cross-sectional study | 96 housewives<br>***Normal weight***<br>M-types:<br>n=25<br>Age: 30.6±10.6 years<br>E-types:<br>n=16<br>Age: 31.7±8.2 years<br>***Overweight/obese***<br>M-types: | **Chronotype**<br>• Morningness-Eveningness preference<br>• M-type: 52-86 points<br>• E-type: 16-51 points<br>**Temporal patterns of eating**<br>• Breakfast, mid-morning snack, lunch, mid-afternoon snack, dinner, and after dinner snack time<br>• % of energy intake from breakfast, | **Chronotype**<br>• MEQ<br>**Temporal patterns of eating**<br>• Notepad to record meals over 7 days of normal living, including food intake and times of consumption | • E-types had significantly later lunch and mid-afternoon snack times than M-types.<br>No difference in % of energy intake from breakfast, lunch, dinner, snack, and before 15:00 h between E-types and M-types in any group.<br>For women who were normal weight, E-types had a higher % of energy intake after 15:00 h than M-types (p=0.008). |

**Table 1.** *(Continued)*

| Author & Year, Country, Study type | Population | Outcome measures | Measurement tools | Results |
|---|---|---|---|---|
| | n=39<br>Age: 30.8±8.7 years<br>E-types:<br>n=16<br>Age 33±9.8 years | lunch, dinner, and snack by weight<br>• % calories before and after 15:00 h | | |
| **Yoshizaki *et al.*, 2016**[42]<br>Japan<br>Cross-sectional study | Female nurses<br>Day workers: n=39<br>Shift workers: n= 123<br>Age: 21-63 years | **Chronotype**<br>• Morningness-eveningness preference<br>**Temporal patterns of eating**<br>• Temporal eating pattern score | **Chronotype**<br>• Japanese version of the MEQ<br>**Temporal patterns of eating**<br>• Eating Behaviour Questionnaire of habits in the previous month assessing “temporal eating pattern” | • Lower ME score associated with higher temporal eating pattern score after variables of demographic characteristics between the groups were controlled for ($r=-0.338$, $p<0.001$). |
| **Zerón-Rugerio *et al.*, 2019**[37]<br>Spain & Mexico<br>Cross-sectional study | Undergraduate and postgraduate students<br>n=1106<br>Female: 78%<br>Age: 21±2.5 years | **Chronotype**<br>• MSF<br>**Temporal patterns of eating**<br>• Eating jetlag (difference between eating midpoint on weekends and eating midpoint on weekdays)<br>• Breakfast/lunch/dinner jetlag (difference between time of breakfast/lunch/dinner on weekends and on weekdays) | **Chronotype**<br>• MCTQ<br>**Temporal patterns of eating**<br>• Questionnaire of habitual breakfast, lunch, and dinner times on weekdays and weekends | • Evening chronotype is significantly associated with breakfast ($\beta=0.32$), lunch ($\beta=0.1$), dinner ($\beta=0.073$), and eating jetlag ($\beta=0.11$). |
| **Zerón-Rugerio *et al.*, 2020**[61]<br>Mexico<br>Cross-sectional study | Female university students<br>n=133<br>Age: 19.9±1.9 years | **Chronotype**<br>• Midpoint of sleep (average over 7 days)<br>• Early-bedtime (<23:48 h)/Early-rise (<07:12 h) (EE): 02:49 h<br>• Late-bedtime (≥23:48 h)/Early-rise (<07:12 h) (LE): 03:44 h<br>• Early-bedtime (<23:48 h)/Late-rise (≥07:12 h) (EL): 03:52 h<br>• Late-bedtime (≥23:48 h)/Late-rise (≥07:12 h) (LL): 04:56 h<br>**Temporal patterns of eating**<br>• Breakfast, lunch, dinner time.<br>• Elapsed time between dinner and the midpoint of sleep | **Chronotype**<br>• 6-day sleep diary (on consecutive days including 3 weekdays and 2 weekend days)<br>**Temporal patterns of eating**<br>• 6-day food logs (on consecutive days, including the weekend) | • LL group had a significantly later breakfast time than the other groups ($p<0.001$).<br>• Lunch and dinner times were not statistically different between groups.<br>• Elapsed time between dinner and midpoint of sleep of EE< EL<LE<LL group ($p<0.001$ between groups except for between LE and EL, p-trend=0.011). |

\g, grams; MEQ, Morningness-Eveningness Questionnaire; M-type, morning chronotype; E-type, evening chronotype; $MSF_{SC}$, mid-sleep time on free days self-corrected for sleep debt; I-type, intermediate chronotype; CSM, Composite Scale of Morningness; MSF, mid-sleep time; BiB-PQ, Bipolar Biobank Patient Questionnaire; REAP-S, Rapid Eating Assessment for Participants – Shortened Version; PSQI, Pittsburgh Sleep Quality Index; aOR, adjusted odds ratio; DTS, Diurnal Type Scale; ASA24, Automated Self-Administered 24-h Dietary Assessment Tool.

**Table 2.** Details of chronotype questionnaires and original cut-offs points to determine chronotype

| Chronotype Questionnaire | Components | Range and cut-offs |
|---|---|---|
| **MEQ**(64) | Consists of nineteen questions to assess morningness-eveningness based on participants' preferred times for sleep and activity, level of hunger, alertness and fatigue at various times of the day, and personal judgement of morningness-eveningness | Score: 16–86<br>16–30: definite evening type<br>31–41: moderately evening type<br>42–58: neither type<br>59–69: moderately morning type<br>70–86: definite morning type |
| **Shortened six-item MEQ**(65) | Consists of six questions (items 4, 7, 9, 15, 17, 19) from the original MEQ of participants' preferred times to perform activities such as wake-up, work, and physical tasks. These six items accounted for 83% of the total variance of the score from the original MEQ | Score: 6–27<br>6–12: evening type<br>13–18: intermediate type<br>19–27: morning type |
| **DTS**(66) | Consists of seven questions to assess morningness-eveningness based on participants' preferred times for wake and sleep, difficulty to rise and sleep at certain times, time of fatigue, and personal judgement of morningness-eveningness. | Not stated |
| **CSM**(67) | Consists of nine questions from the MEQ (items 1, 2, 4, 5, 7, 9, 10, 11 and 19) and four items from the DTS (items 1, 4, 6 and 7) | Score: 13–55<br>13–22 evening type<br>23–43: intermediate type<br>44–55: morning type |
| **MCTQ**(68) | Asks about times of wake and sleep on workdays and free days to determine mid-sleep time on free days, corrected for sleep debt over the work week ($\text{MSF}_{\text{SC}}$) | ≤03:59 h: morning type<br>4:00–4:59 h: intermediate type<br>≥05:00 h: late type(69) |

MEQ, Morningness-Eveningness Questionnaire; DTS, Diurnal Type Scale; CSM, Composite Scale of Morningness; MCTQ, Munich Chronotype Questionnaire; $\text{MSF}_{\text{SC}}$, mid-sleep time on free days self-corrected for sleep debt.

be a good proxy of DLMO(73), that is, better than the MEQ(16). An extension of the MCTQ for shift workers ($\text{MCTQ}^{\text{Shift}}$) allows MSF calculation for morning, evening and night shifts, with the recommendation that the evening shift calculation best represents chronotype in shift workers(74). Thirteen additional studies estimated chronotype based on 'midpoint of sleep' or inactivity, using a range of study-specific questionnaires and interviews about sleep and wake times ($n = 5$)(32,46,50,52,57), sleep diaries ($n = 3$)(27,29,63), actigraphy ($n = 2$)(27,43), the MCTQ ($n = 2$)(58,62) and the Pittsburgh Sleep Quality Index (PSQI) ($n = 2$)(22,51) (Table 3). To chronotype, studies used either mid-sleep time across the week or only on free days, with or without correcting for sleep debt over weekdays (Table 3).

## *Assessment of temporal patterns of eating*

Amongst the studies reviewed, temporal patterns of eating were identified and pooled into eight categories (Supplementary material: Eight categories of temporal patterns of eating). They include (i) meal timings ($n = 22$)(22,27,28,30–32,34,35,40,41,43,44,48,50,52,54,56–58,60,62,63), (ii) meal skipping ($n = 14$)(27,29,33,34,38,40,46,47,50–54,59), (iii) energy distribution across the day ($n = 9$)(22,27,35–37,39,41,42,60), (iv) meal frequency ($n = 6$)(27,29,32,34,35,41), (v) time interval between meals, or meals and wake/sleep times ($n = 5$)(27,38,51,57,63), (vi) midpoint of food/energy intake ($n = 3$)(55,56,62), (vii) meal regularity ($n = 2$)(51,61) and (viii) duration of eating window ($n = 1$)(32).

The dietary assessment tools used to capture these temporal patterns of eating include study-specific questionnaires and interviews ($n = 18$)(28–30,33,34,38,40,43,44,47,48,50–52,58,59,61,62), dietary recalls (24–48 h) ($n = 11$)(22,31,32,36,37,39,41,46,54–56) and food records (3–7 d) ($n = 7$)(27,35,36,42,57,60,63); one study did not state the method used(53). Of the studies that used study-specific questionnaires, eleven studies did not state the period of recall(28–30,33,34,38,47,48,51,58,62); the remaining seven studies specified a period of the last 1 week(44), 2 weeks(43,52) or 1 month(40,50,59,61). Only three studies used a single study-specific questionnaire that captured both chronotype and temporal patterns of eating together(40,50,52).

Nine studies described their definition of meals. Teixeira, Mota, and Crispim(54), Zerón-Rugerio(63), and Baron(27) *et al.* allowed classification of breakfast, lunch and dinner to be based on participants' perception, while Takeuchi *et al.*(53) defined them as nutritionally rich meals (including carbohydrates, protein, vitamins and minerals). Reutrakul and colleagues defined breakfast and dinner meals as entries including at least one food item (i.e. excluding drink-only entries) and late evening snacks as any caloric intake between last meal and sleep onset(22). Nimitphong *et al.* defined last mealtime as the latest food intake of the day(41). However, these studies did not specify a minimum calorie requirement for consideration of a meal, which was done by three other studies. Teixeira *et al.*(55) defined an eating episode as ≥21 kJ, while Lucassen *et al.*(35) ≥84 kJ, and Gontijo *et al.*(32) ≥209 kJ. The latter two studies additionally stipulated a time gap between eating occasions; ≥30 min by Lucassen *et al.*(35) and ≥15 min by Gontijo *et al.*(32). Despite not providing definitions of meals, the majority of the studies used conventional meal labels, such as breakfast, lunch and dinner, with only five studies(27,32,35,43,57) using neutral labels like first and last eating episode/meal/occasion.

## *Temporal patterns of eating in relation to chronotype*

Findings from the eight categories of studies described above (meal timings; meal skipping; energy distribution across the day; meal frequency; time interval between meals, or meals

**Table 3.** Summary of methods and cut-off points studies used to determine chronotype of individuals

| Tool to identify chronotype | Study | Cut-off | Notes |
|---|---|---|---|
| **Morningness-eveningness preference** | | | |
| MEQ | Costa *et al.*, 1987(28) | No detail on cut-off used to distinguish between chronotypes | Italian version of the MEQ |
| | Gangwar *et al.*, 2018(30) | • Group 1: definite evening chronotype<br>• Group 2: intermediate chronotype<br>• Group 3: definite morning chronotype<br>*No detail on cut-off score used to distinguish between chronotypes | |
| | Garaulet *et al.*, 2013(31) | Analysed as chronotype by time of lunch | |
| | Ishihara, Miyasita, and Inugami., 1985(34) | • M-type: 59–86 points<br>• E-type: 16–41 points<br>*Intermediate types excluded | Japanese version of the MEQ |
| | Lucassen *et al.*, 2013(35) | • M-type: 50–86 points<br>• E-type: 16–49 points | |
| | Meule *et al.*, 2012(38) | • M-type: $\geq$55 points<br>• E-type: $\leq$44 points<br>*Cut-off based on upper and lower 20% of distribution | |
| | Munoz *et al.*, 2017(39) | • M-type: >51 points<br>• E-type: $\leq$51 points<br>*Cut-off based on median score | |
| | Ruiz-Lozano *et al.*, 2016(48) | • M-type: >57 points<br>• E-type: $\leq$57 points<br>*Cut-off based on median score | |
| | Teixeira, Mota, and Crispim., 2018(54) | • E-type: 16–41 points<br>• I-type: 42–58 points<br>• M-type: 59–86 points | Brazil version of the MEQ |
| | Teixeira *et al.*, 2019(55) | • E-type: 16–41 points<br>• I-type: 42–58 points<br>• M-type: 59–86 points | Brazil version of the MEQ |
| | Vera *et al.*, 2018(56) | • E-type: ME score <53<br>• M-type: ME score $\geq$53<br>*Cut-off based on median score | |
| | Yasuda *et al.*, 2018(59) | Analysed as chronotype by frequency of breakfast consumption | |
| | Yazdinezhad *et al.*, 2019(60) | • E-type: 16–51 points<br>• M-type: 52–86 points<br>*Cut-off based on median score | |
| | Yoshizaki *et al.*, 2016(61) | Analysed as continuous variable for correlation with temporal pattern of eating | Japanese version of the MEQ |
| Study-specific questionnaires and interviews that contain components of the MEQ | Nakade *et al.*, 2009(40) | Analysed as chronotype by frequency and time of breakfast consumption | Integrated questionnaire of habits in the previous month, including Japanese version of the MEQ |
| | Östberg, 1973(42) | No detail of cut-off used to distinguish between chronotypes | Questionnaire concerning personal preference and habits to discriminate between extreme morning and evening types. No detail on questionnaire used |
| | Romo-nava *et al.*, 2020(47) | • E-type: response of 'Definitely an evening type'<br>• Non-E-type: response of 'Definitely a morning type', 'More a morning than an evening type', 'More an evening than a morning type', 'Neither describes me' | BiB-PQ including a single self-report item on chronotype preference derived from item 19 of the MEQ |
| CSM | Halsey *et al.*, 2011(33) | Analysed as continuous variable for correlation with temporal pattern of eating | |
| | | • E-type: <45 points | Thai version of the CSM |

**Table 3.** (*Continued*)

| Tool to identify chronotype | Study | Cut-off | Notes |
|---|---|---|---|
| | Nimitphong *et al.*, 2018(41) | • M-type ≥45 points<br>*Cut-off based on median score | |
| | Randler and Jankowski, 2014(44) | Analysed as continuous variable for correlation with temporal pattern of eating | |
| Shortened six-item MEQ | Maukonen *et al.*, 2017(36) | • M-type: 6–12 points<br>• I-type: 13–18 points<br>• E-type: 19–27 points | |
| | Maukonen *et al.*, 2019(37) | • M-type: 6–12 points<br>• I-type: 13–18 points<br>• E-type: 19–27 points | |
| DTS | Takeuchi *et al.*, 2015(53) | • E-type: 7–12 points<br>• I-type: 13–16 points<br>• M-type: 17–28 points<br>*Cut-off based on quartiles of DTS score | Japanese version of the DTS for students |
| **Midpoint of sleep/inactivity** | | | |
| Study-specific questionnaires and interviews that contained questions about sleep and wake times | Gontijo *et al.*, 2018(32) | • $MSF_{SC}$<br>*Analysed as continuous variable for correlation with temporal pattern of eating | Survey of usual sleep habits on weekdays and weekends during pregnancy |
| | Reutrakul *et al.*, 2014(46) | • $MSF_{SC}$<br>*Analysed as continuous variable for correlation with temporal pattern of eating | Self-reported usual bedtime, wake-up time, and sleep onset latency on weekdays and weekends in the previous month |
| | Sato-mito *et al.*, 2011(50) | • Midpoint of sleep on weekdays<br>• Q1: 02:32 ± 0:23 h<br>• Q2: 03:10 ± 0:08 h<br>• Q3: 03:37 ± 0:07 h<br>• Q4: 04:11 ± 0:13 h<br>• Q5: 05:31 ± 0:55 h | Twelve-page lifestyle questionnaire of habits in the previous month, including usual wake and sleep times on weekdays |
| | Silva *et al.*, 2016(52) | • $MSF_{SC}$<br>*Analysed as continuous variable for correlation with temporal pattern of eating | Structured questionnaire of habits in the last 2 weeks, including usual wake and sleep times on weekdays and weekends |
| | Xiao, Garaulet, and Scheer, 2019(57) | • $MSF_{SC}$<br>• M-type: <03:04 h<br>• E-type: >03:04 h<br>*Cut-off based on median $MSF_{SC}$ | Self-reported rise and bedtimes over 7 d |
| Sleep diary | Baron *et al.*, 2011(27) | • Midpoint of sleep (average over 7 d)<br>• Average sleep times: between 01:00 h and 05:29 h<br>• Late sleep times: after 05:30 h<br>*Cut-off based on median midpoint of sleep | 7-d sleep logs |
| | Zerón-Rugerio *et al.*, 2020(63) | • Midpoint of sleep (average over 7 d)<br>• EE: early-bedtime (<23:48 h)/early-rise (<07:12 h)<br>• EL: early-bedtime (<23:48 h)/late-rise (≥07:12 h)<br>• LE: late-bedtime (≥23:48 h)/early-rise (<07:12 h)<br>• LL: late-bedtime (≥23:48 h)/late-rise (≥07:12 h)<br>*Based on median splits of bedtimes and wakeup times | 6-d sleep diary (on consecutive days including three weekdays and two weekend days) |
| | Friborg *et al.*, 2014(29) | • $MSF_{SC}$<br>*Analysed as continuous variable for correlation with temporal pattern of eating | 7-d sleep diary |
| Actigraphy | Baron *et al.*, 2011(27) | • Midpoint of sleep (average over 7 d)<br>• Average sleep times: between 01:00 h and 05:29 h | |

**Table 3.** (*Continued*)

| Tool to identify chronotype | Study | Cut-off | Notes |
|---|---|---|---|
| | | • Late sleep times: after 05:30 h<br>*Cut-off based on median midpoint of sleep | |
| | Quante *et al.*, 2019[43] | • L5 midpoint (time of peak inactivity, average over 7 d)<br>*Analysed as continuous variable for correlation with temporal pattern of eating | |
| MCTQ | Yadav and Singh, 2013[58] | Participants were asked to rate themselves among seven chronotype classes from ‘extremely early’ to ‘extremely late’, with intermediate type in between. All M-types were grouped together and all E-types were grouped together, resulting in three groups: M-types, I-types and E-types<br>*No detail on cut-off used to distinguish between chronotypes | |
| | Zerón-Rugerio *et al.*, 2019[62] | • MSF<br>*Analysed as continuous variable for correlation with temporal pattern of eating | |
| PSQI | Reutrakul *et al.*, 2013[22] | • MSF$_{SC}$<br>• Q1: 01:30 ± 0:46 h<br>• Q2: 02:48 ± 0:20 h<br>• Q3: 03.54 ± 0:17 h<br>• Q4: 05:50 ± 1:30 h | PSQI of sleep patterns in the previous month |
| | Shimura *et al.*, 2020[51] | • MSF$_{SC}$<br>• Evening chronotype: late third of the distribution of MSF$_{SC}$ | Japanese version of the PSQI for sleep schedule on work and free days |

MEQ, Morningness-Eveningness Questionnaire; M-type, morning chronotype; E-type, evening chronotype; I-type, intermediate chronotype; BiB-PQ, Bipolar Biobank Patient Questionnaire; CSM, Composite Scale of Morningness; DTS, Diurnal Type Scale; MSF$_{SC}$, mid-sleep time on free days self-corrected for sleep debt; MCTQ, Munich Chronotype Questionnaire; MSF, mid-sleep time on free days; PSQI, Pittsburgh Sleep Quality Index.

and wake/sleep times; midpoint of food/energy intake; meal regularity; and duration of eating window) are considered in relation to chronotype, in turn, in the following section.

### Meal timings

Twenty-two studies considered aspects of meal timings; twenty compared mealtimes between chronotypes, while two compared mealtimes of chronotypes between day type (weekday versus weekend; college days versus vacation days). Seventeen studies used conventional meal labels (i.e. breakfast, lunch dinner), whereas five used non-conventional labels such as first/last meal or eating occasions.

Nineteen of the twenty studies showed one or more meals were consumed later during the day among evening types; the exception was the study by Gontijo *et al.*(32) in pregnant women (Fig. 2). Eight studies involved university students, of which evening types had later breakfast times in seven studies, later lunch times in five studies, and later dinner times in six studies. Five other studies included community-dwelling adults outside the student population, and consistently found evening types had later times of food intake across the day(27,28,43,57,60). Six studies included individuals with type 2 diabetes, or who were overweight or obese; in all of them, evening types had later times of one or more main meals than morning types(22,31,35,41,48,56). Fig. 3 illustrates timing of eating occasions for morning, intermediate and evening chronotypes (data from studies including clock times).

Two studies compared differences in times of food intake between weekdays and weekends (i.e. breakfast/lunch/dinner jetlag, or meal lag)(62), or college and vacation days(58). Zerón-Rugerio *et al.*(62) found evening types to be exposed to meal lag across all three meals, while Yadav and Singh reported no clear pattern in times of food intake between chronotypes between college and vacation days(58).

In summary, evening chronotypes tend to have later times of breakfast, lunch and dinner, as well as first and last eating meals/occasions.

### Meal skipping

Fourteen studies investigated meal skipping. Six studies categorised subjects on the basis of whether breakfast was skipped or consumed, while eight studies examined the frequency of occurrence of main meal (breakfast, lunch and/or dinner) skipping.

Five out of six studies reported that breakfast skippers tend to be evening chronotypes(34,38,46,52,54), with one study showing no difference in whether evening and morning chronotypes were breakfast skippers(27). These studies segregated breakfast eaters from skippers based on one day's worth of food intake using a 24-h recall of dietary intake(46) and a questionnaire(38) ($n = 2$), breakfast skippers as eating breakfast ≤2 times a week based on a 7-d food record(27) and a question on habitual intake(54) ($n = 2$), and questionnaires on habits of breakfast skipping or consumption, with no details stated on how that is defined(34,52) ($n = 2$).

Eight studies extended the tendency to skip main meals to include frequency of occurrence of main meal skipping. This was either based on a Likert scale rating (e.g. always, often, rarely, never) ($n = 3$)(40,47,51) or on number of times a week ($n = 4$)(29,33,50,53,59). Altogether, evening chronotypes tend to skip breakfast, lunch and/or dinner at a greater frequency compared with other chronotypes(29,33,40,47,50,51,53,59), although frequency of lunch and dinner skipping was only examined in three studies(29,50,53). It must, however, be noted that, in Friborg and colleagues' study, frequency of meal skipping is interpreted based on a combined 'lower eating habit score' with the number of meals a person has in a day(29). Thus, their results on meal skipping may be skewed by meal frequency, and future tools should segregate collection of these data.

### Energy distribution across the day

Nine studies assessed energy distribution across the day (Fig. 4).

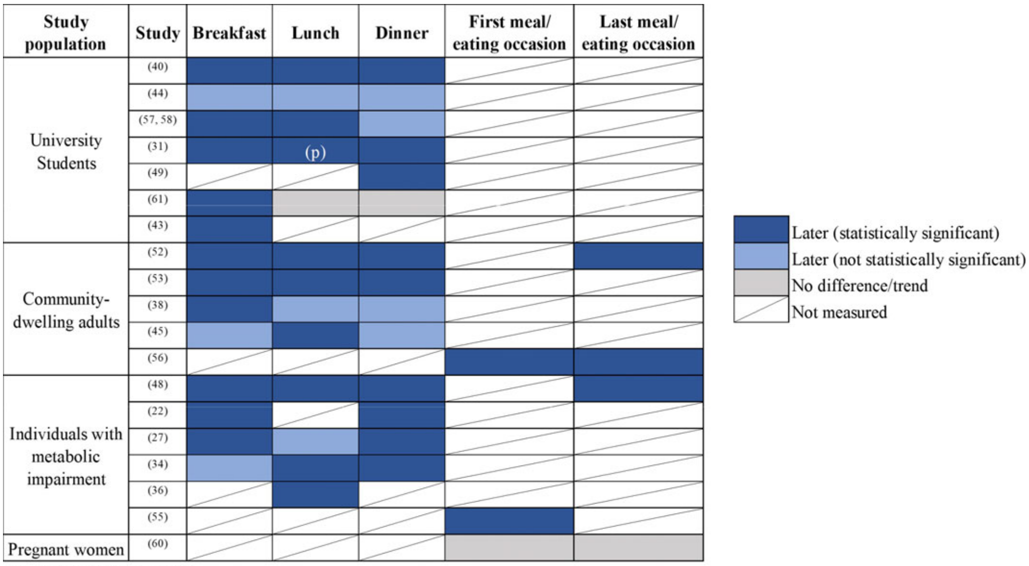
Five studies analysed energy distribution based on cut-off times of 20:00 h ($n = 4$)(27,35–37) or 15:00 h ($n = 1$)(60); they all found later chronotypes to have a greater energy intake than earlier chronotypes after the stipulated cut-off times, with the exception of the overweight subpopulation of Yazdinezhad and colleagues' study(60).

Five studies reported energy distribution across main meals and/or snacks, with results across the studies shown to be inconsistent. Reutrakul *et al.*(22) and Baron *et al.*(27) found later chronotypes had significantly greater energy intake at dinner, while Nimitphong *et al.*(41) and Yazdinezhad *et al.*(60) both found no differences in energy distribution amongst breakfast, lunch, dinner and snacks between morning types and evening types. In a study where participants were separated on weight status, normal weight evening types were found to have a significantly lower percentage of total energy intake at lunch, but more at mid-evening snack compared with morning types, while overweight evening types had a significantly lower percentage of total energy intake at breakfast and lunch, but higher at mid-morning snack(39).

Of the three studies examining cumulative energy intake across the day, evening types were consistently shown to catch up in energy intake later in the day compared with morning types(27,36,42). In summary, evening chronotypes distributed their energy intake towards later times of the day compared with morning chronotypes, although the trend of energy distribution between meals and snacks was inconsistent.

### Meal frequency

Five studies looked at daily meal frequency (number of meals in a day) in relation to chronotype. Results were inconsistent, with three studies reporting no difference between chronotypes in frequency of food intake(27,32,41) and two reporting that evening chronotypes had fewer meals(29,35). Of interest is that, of the studies where evening chronotypes had fewer meals, one consisted of individuals who were obese(35), while the other based this outcome on an 'eating habit score', a sum score of the number of meals a day and the number of days a week that participants ate their main meals(29). Hence, these results may be skewed by population-specific traits and other eating habits, respectively.



| Study population | Study | Breakfast | Lunch | Dinner | First meal/ eating occasion | Last meal/ eating occasion |
|---|---|---|---|---|---|---|
| University Students | (40) | ■ | ■ | ■ | ╱ | ╱ |
| | (44) | ▤ | ▤ | ▤ | ╱ | ╱ |
| | (57, 58) | ■ | ■ | ▤ | ╱ | ╱ |
| | (31) | ■ | ■ (p) | ■ | ╱ | ╱ |
| | (49) | ╱ | ╱ | ■ | ╱ | ╱ |
| | (61) | ■ | ░ | ░ | ╱ | ╱ |
| | (43) | ■ | ╱ | ╱ | ╱ | ╱ |
| Community-dwelling adults | (52) | ■ | ■ | ■ | ╱ | ■ |
| | (53) | ■ | ■ | ■ | ╱ | ╱ |
| | (38) | ■ | ▤ | ▤ | ╱ | ╱ |
| | (45) | ▤ | ■ | ▤ | ╱ | ╱ |
| | (56) | ╱ | ╱ | ╱ | ■ | ■ |
| Individuals with metabolic impairment | (48) | ■ | ■ | ■ | ╱ | ■ |
| | (22) | ■ | ╱ | ■ | ╱ | ╱ |
| | (27) | ■ | ▤ | ■ | ╱ | ╱ |
| | (34) | ▤ | ■ | ■ | ╱ | ╱ |
| | (36) | ╱ | ■ | ╱ | ╱ | ╱ |
| | (55) | ╱ | ╱ | ╱ | ■ | ╱ |
| Pregnant women | (60) | ╱ | ╱ | ╱ | ░ | ░ |

■ Later (statistically significant)
▤ Later (not statistically significant)
░ No difference/trend
╱ Not measured

(p), Polish arm of the study.

**Fig. 2.** Studies that examined mealtimes amongst chronotypes; presented by mealtimes that were statistically significantly later (dark blue), not statistically significantly later (light blue), or had no difference/trend (grey) amongst evening types compared with morning types. A strikethrough indicates mealtimes that were not measured.

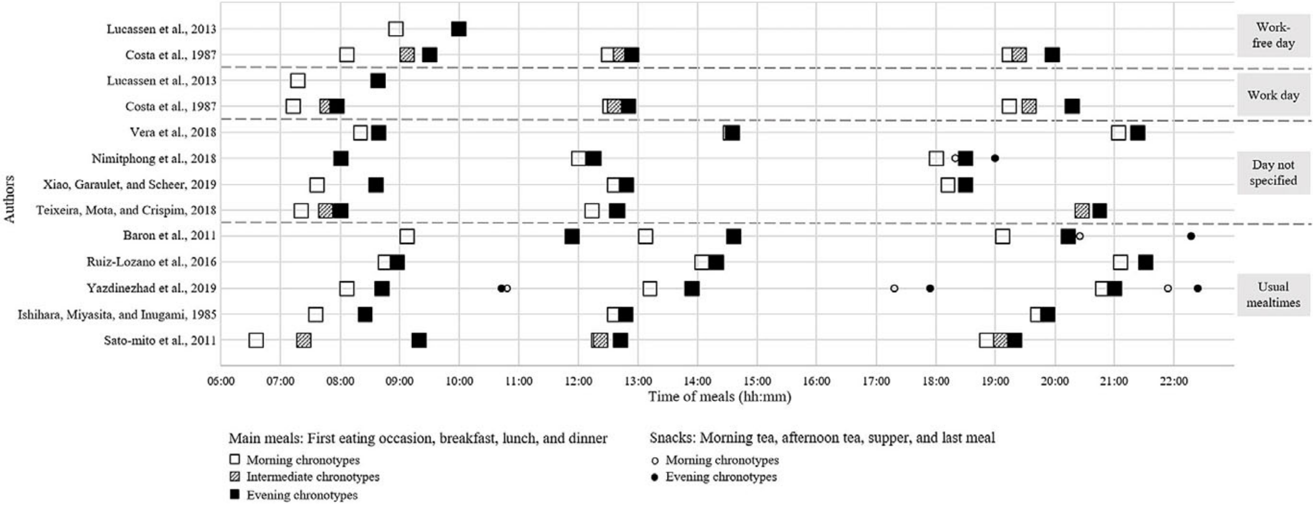


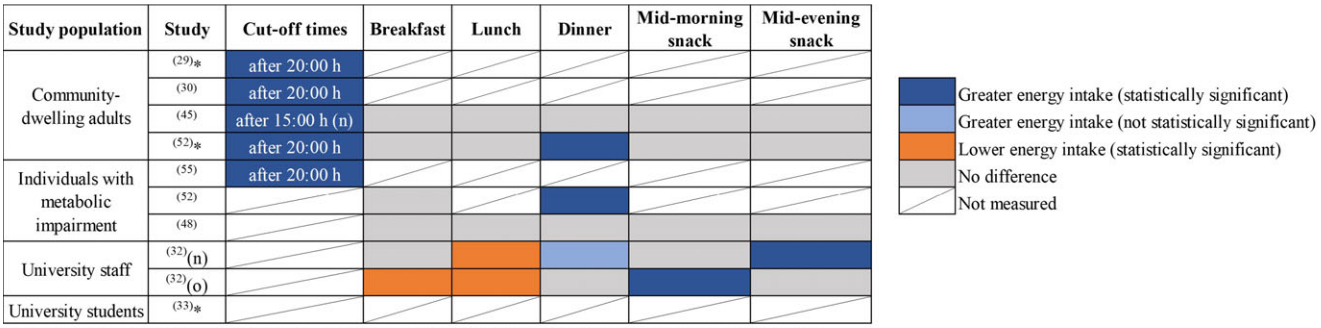
**Fig. 3.** Studies that reported clock times of eating occasions of morning, intermediate and evening chronotypes over 24 h. Squares depict main meals, which include first eating occasion, breakfast, lunch and dinner; circles depict snacks, which include morning tea, afternoon tea, supper and last meal. Empty squares/circles represent morning chronotypes, filled squares/circles represent evening chronotypes, and shaded squares represent intermediate chronotypes.

## *Time interval between meals, or meals and wake/sleep times*

Two studies investigated time intervals between meals. Baron *et al.*(27) found that evening types had shorter durations between breakfast and lunch, as compared with morning types. Meule and colleagues surveyed individuals in the morning (08:00–11:00 h) and the evening (16:00–19:00 h), regarding the number of hours that have passed since their last meal. When surveyed in the morning, evening types had significantly more hours since last meal compared with morning types, suggesting a longer gap between dinner and breakfast time(38). However, when surveyed in the evening, there was no difference in time from last meal between both chronotypes, suggesting similar lunch times.

Four studies examined time intervals between meals and wake/sleep times. Xiao, Garaulet and Scheer(57) found that evening types had less time between awakening and breakfast and, along with three other studies of community-dwelling adults, university students and company employees consistently reported that evening chronotypes had longer intervals between dinner/time of last meal and bedtime/midpoint of sleep(27,51,57,63).

In summary, these studies show evening chronotypes tend to have longer durations between dinner/time of last meal and bedtime/midpoint of sleep. However, there are insufficient studies to identify trends in times intervals between wake times and breakfast or between meals amongst chronotypes.



| Study population | Study | Cut-off times | Breakfast | Lunch | Dinner | Mid-morning snack | Mid-evening snack |
|---|---|---|---|---|---|---|---|
| Community-dwelling adults | (29)* | 🟦 after 20:00 h | ⧄ | ⧄ | ⧄ | ⧄ | ⧄ |
| | (30) | 🟦 after 20:00 h | ⧄ | ⧄ | ⧄ | ⧄ | ⧄ |
| | (45) | 🟦 after 15:00 h (n) | ▒ | ▒ | ▒ | ▒ | ▒ |
| | (52)* | 🟦 after 20:00 h | ▒ | ▒ | 🟦 | ▒ | ▒ |
| Individuals with metabolic impairment | (55) | 🟦 after 20:00 h | ⧄ | ⧄ | ⧄ | ⧄ | ⧄ |
| | (52) | ⧄ | ▒ | ⧄ | 🟦 | ⧄ | ⧄ |
| | (48) | ⧄ | ▒ | ▒ | ▒ | ▒ | ▒ |
| University staff | (32)(n) | ⧄ | ▒ | 🟧 | ▨ | ▒ | 🟦 |
| | (32)(o) | ⧄ | 🟧 | 🟧 | ▒ | 🟦 | ▒ |
| University students | (33)* | ⧄ | ⧄ | ⧄ | ⧄ | ⧄ | ⧄ |

🟦 Greater energy intake (statistically significant)
▨ Greater energy intake (not statistically significant)
🟧 Lower energy intake (statistically significant)
▒ No difference
⧄ Not measured

*, studies where evening types caught up in cumulative energy intake of morning types later in the day; (n), normal weight subpopulation; (o), overweight subpopulation.

**Fig. 4.** Studies that examined energy intake either after study-specified cut-off times during the day (i.e. after 15:00 h or 20:00 h) or at meal/snack times amongst chronotypes; presented as energy intake that was statistically significantly greater (dark blue), not statistically significantly greater (light blue), statistically significantly lower (orange), or had no difference (grey) after the cut-off times or at mealtimes amongst evening types compared with morning types. A strikethrough indicates mealtimes that were not measured.

### *Midpoint of food/energy intake*

Three studies examined midpoint of food/energy intake – defined as either the time point between first and last eating episodes, or the median point of energy intake in a day, which suggests at the spread of food/energy intake in the day. Two studies reported that evening types had significantly later midpoint of intake than morning types(55,56), whereas Zerón-Rugerio *et al.* examined the difference between midpoint of food intake on weekends compared with weekdays, described by the authors as eating jetlag, and found that, compared with morning types, evening types had a greater difference in time of midpoint of intake on weekends compared with weekdays(62).

### *Meal regularity*

Two studies in Japan examined meal regularity, using a questionnaire about habitual food intake, in relation to chronotype. In Shimura and colleagues' study, compared with morning types, evening types had higher odds of reporting irregular mealtimes(51). This was supported by Yoshizaki and colleagues' study, which found more irregular meal timing for those who are more evening types(61).

### *Duration of eating window*

Only one study investigated chronotype in relation to duration of eating window. This study, in pregnant women, showed no association between duration of eating window and chronotype(32).

## Discussion

Of the thirty-six studies included in this review, thirty-two were published in the last 10 years – evidence of an increased interest in meal timing and health. This review found that evening chronotypes had later timing of meals (either conventional or first/last eating occasions) in nineteen studies and distributed a greater amount of energy and nutrient intake to the later part of the day, especially after 20:00 h, indicating a propensity for energy loading later in the day. Apart from eating later, it was consistently demonstrated that evening chronotypes also had a greater tendency to skip breakfast, lunch and dinner than other chronotypes. Less convincing were data that reported on meal regularity, midpoint of food/energy intake, meal frequency, intervals between meals or meals and sleep/wake times, and duration of eating window owing to a smaller number of included studies. In terms of identifying chronotype, the morningness-eveningness questionnaire was the preferred tool. On the other hand, temporal patterns of eating were primarily captured through study-specific questionnaires/interviews, followed by validated dietary assessment tools such as 24-h dietary recall and food diaries.

### *Temporal patterns of eating amongst chronotypes: implications for future studies and recommendations*

Evening chronotypes have nocturnal lifestyle habits, and this is supported by their temporal patterns of eating. Apart from their greater likelihood and frequency of breakfast skipping, they also show signs of greater frequency of lunch and dinner skipping, which could explain their later timing of main meals (Fig. 3), energy loading towards the latter half of the day, and a longer interval between time of last meal and bedtime. These findings are of relevance as there are epidemiological data that show an association between breakfast skipping and/or late meals and cardiometabolic health(1), although the relationship of interval between time of last meal and bedtime on health outcomes has not been well studied(75). Importantly, these temporal aspects of eating may all be measured using a single method – the actual timing of meals (clock time), rather than patterns of meal skipping, or intervals relative to wake or sleep times. Collecting data on meal timing enables data to be scrutinised, allowing the generation of meal pattern analyses that can then be linked to health outcomes. Using this approach, future studies can easily identify temporal patterns or cut-off times after which food intake may be detrimental to health of particular chronotypes. Additionally, they provide insight into the duration of eating window, the importance of which is discussed next.

Only one study examined participants' duration of eating window in relation to chronotype, and this was in pregnant women. Duration of eating window is important given that metabolic processes such as glucose tolerance and insulin sensitivity peak in the morning and decrease towards the night(3), and night-time eating is associated with perturbed glucose and lipid metabolism(4,76), thus increasing risk of cardiovascular disease and type 2 diabetes(1,77). Meanwhile, minimising eating occasions by reducing the duration of eating period through time-restricted feeding has beneficial implications for metabolic health even in the absence of weight loss(78,79). Research has shown how limiting the eating window through time-restricted feeding trials have benefits on fat oxidation, blood pressure, glucose levels and inflammation(78,80–82). Failure to account for one's duration of eating window may explain why studies of other temporal aspects of eating such as breakfast skipping have found conflicting results on cardiometabolic health outcomes(31,83,84). Additionally, as evening chronotypes have late wake and sleep times, exploring if a late restricted feeding window provides health benefits may prove to be a feasible strategy to suit their lifestyle. Conversely, if the metabolic benefits of time-restricted feeding are only seen with earlier (relative to body clock timing) eating windows, this is important information for health recommendations for those with greater eveningness(85).

Energy distribution across the day has implications for metabolic health because consuming food at night can exacerbate circadian misalignment(86), which results in impaired glucose tolerance, inflammatory markers and blood pressure in healthy adults(7,8,87). Whilst five studies in this review suggest that evening chronotypes distribute a greater percentage of their energy intake towards later parts of the day(36,37,43,57,60), three did not present data on dinner intake(36,37,43), which means food intake at this time of the day could have consisted of a large dinner meal or may have been smaller snacks. Regardless, this behaviour of night-time eating poses health concerns as intervention studies have demonstrated that individuals who consumed dinner later rather than earlier had higher triacylglycerol and cholesterol levels(88), as well as raised glucose levels after breakfast the next day(5,89). At the same time, a review found that individuals who consume food late in the night tend to choose foods rich in carbohydrates, including refined sugars(90), while a separate study found that foods consumed between 22:00 h and 01:59 h to be the most energy dense of the day(91), suggesting at the poor quality of food consumed in the late night. Strategies to minimise these risks include modifying the energy content or macronutrient composition of food consumed at night. This was demonstrated in studies by Jakubowicz *et al.*, where limiting dinner intake to 837 kJ at 19:00 h(92), or between 18:00 h and 21:00 h(93), has beneficial effects on weight outcome and glycaemic control. Similarly, consuming a high-protein meal compared with a standard meal at night alleviated increases in postprandial glucose levels(94). Therefore, providing guidance to evening chronotypes on limiting energy intake at night and careful consideration of food choice may be helpful.

A small number of studies included in this review explored factors such as meal regularity and variability in weekday and weekend food intake. Evening types were found to have more irregular meal timings(51,61), previously defined as a generally inconsistent frequency and spacing of eating occasions across the day(10). As meal irregularity has been associated with increased risk of metabolic syndrome, and increased body mass index (BMI) and waist circumference(95,96), the ability to identify irregular from regular meal eaters is crucial. Whilst regularity of meals has been linked to frequency, we found no clear relationship between chronotype and meal frequency. As the evidence linking meal frequency with cardiometabolic health status has been inconsistent(1), a key question lies in whether meal frequency is a relevant temporal pattern of eating that warrants further investigation, and inadvertently, does meal frequency mask relevant details such as the aforementioned duration of eating window, spacing between meals, or regularity. Because of the lack of detail data on meal frequency provides, these other temporal factors should take precedence over data on meal frequency, or at least be analysed in relation to it. In terms of variability between weekday and weekend food intake, only two studies looked at it in terms of mealtimes and meal frequency. Compared with morning chronotypes, evening chronotypes had a larger difference between weekdays and weekends in terms of meal times (later meals on weekends)(62) and frequency (trend of greater frequency on weekends)(35). Firstly, this highlights a large gap where future studies may investigate differences between weekday and weekend habits; if temporal patterns of eating are found to be worse on certain days of the week, intervention studies may then be targeted towards addressing them first. Secondly, later meal times on weekends have been associated with greater social jetlag(62) (the difference between midpoint of sleep on work and work-free days(97)), while also suggesting at meal irregularity across the week. Therefore, future studies should also consider the implications of sleep regularity, including timing and duration of sleep, on meal timing and regularity.

### *Inclusion of other study populations*

Whilst the health implications that morning and evening chronotypes face as a result of their mealtimes are apparent, results are not easily generalisable across populations because of cultural differences in food and eating patterns(98). In this review, almost half the studies conducted in Europe practice siesta(28,31,39,48,56,63), but none highlighted how the presence of a siesta influences dinner times. From this review, in Spain, while evening chronotypes were found to still have later dinners than morning chronotypes(48,56), the negative consequences to health attributed to evening types for their late meals may also be shared by morning types in this population, whose dinner times were even later than that of evening types in the other study populations (refer to Ruiz-Lozano(48), and Vera and colleagues'(56) study in Fig. 3). This also applies to the religious practice of Ramadan, where Muslims fast between sunrise and sunset for a month, which may negate the difference usually observed in temporal patterns of eating between chronotypes. These cultural and religious differences reinforce the need for such studies to be conducted across populations, and for authors to identify and comment on cultural traits that could potentially diminish or amplify the differences in temporal patterns of eating between chronotypes, which could then alter effects on their health outcomes.

## *Assessment of chronotype: implications for future studies and recommendations*

The majority of studies in this review used questionnaires that identify 'morningness-eveningness preference' as an indicator of chronotype instead of 'midpoint of sleep'. While the former, which includes the MEQ, CSM and DTS, represents a psychological indicator of chronotype(99), the latter, which includes the MCTQ, represents a behavioural indicator of chronotype. The strengths and weaknesses of each of these questionnaires lie beyond the scope of this review, and have been comprehensively detailed in an earlier review paper(99).

A challenge for the field is that, despite multiple studies using the same tool, studies in this review employed a myriad of cut-off points in categorising chronotypes. Most studies used population specific cut-offs such as median, tertiles and quartiles, while few used the original thresholds suggested by questionnaire authors. This resulted in great variation in cut-off points where evening types were defined by an almost 2·5-h difference in mid-sleep time(27,57). A previous review has concluded that percentile-based cut-offs applied to the population are preferable as they reflect the spread of chronotypes specific to the population and its culture(100). However, the lack of standardisation in cut-off methods employed amongst studies in this review reduces comparability of outcomes.

A further challenge for studies that extrapolate concepts or components of original questionnaires such as the MEQ and the MCTQ into their study-specific questionnaires is the accuracy of data provided to chronotype participants. In this review, some study-specific questionnaires were used that asked participants to subjectively report sleep and wake times(32,46,50,52,57). While the MCTQ requests the same information, it has been validated as a whole, through correlation with sleep diaries, actigraphy, and melatonin rhythms(101). Furthermore, some studies(32,52,57) had a recall period of sleep and wake habits that were shorter than the recall period of 1 month used by the MCTQ. Out of thirteen studies, five did not chronotype based on $MSF_{SC}$, and instead used mid-sleep time on weekdays(50), mid-sleep time averaged across a 7-d week(27,43,63), or MSF without correcting for sleep debt(62), which can skew chronotype estimates. This raises questions about the validity of these study-specific questionnaires for estimation of chronotype, and applies equally to study-specific questionnaires that incorporate only an item from the MEQ as an indicator of chronotype(47). Limitations arising due to deviation from originally validated instruments could be overcome by further studies validating alternative, briefer instruments. Care must be taken to accurately capture the concept of chronotype using validated measures.

Lastly, for the purpose of identifying chronotype in relation to temporal patterns of eating, 'midpoint of sleep' may be a better choice compared with 'morningness-eveningness preference' as the latter considers personal preferences for activities at various points of the day that do not represent differences in individual circadian rhythm cycle. This shortcoming is addressed by the MCTQ, by factoring in and accounting for differences in sleep–wake patterns on work and work-free days(70). As results of the MCTQ are a point in time instead of a score on preference, it is a continuous trait(69), which makes it more adaptable for evaluation in relation to time points of meals. At the same time, in the process of obtaining $MSF_{SC}$, collection of data on wake and sleep times forms relevant datapoints to be analysed in relation to mealtimes or circadian phase.

## *Identifying temporal patterns of eating and creating the ideal questionnaire*

Choice of dietary method should depend on study objectives, including but not limited to the dietary aspect of interest, the requirement for absolute versus relative intake data, the time frame of interest, the extent of specificity in dietary data required, and resource availability(102). In this review, a variety of dietary assessment tools were used; most commonly, study-specific questionnaires or interviews, followed by 24-h dietary recalls, and food records. Dietary recalls and food records both capture temporal patterns of food intake, with the latter being the preferred tool as it captures differences in food intake across the days of the week and minimises recall bias since food intake is recorded on consumption(103). However, it places a large burden on participants, who have to fill in details of food types and portion sizes, and training of both researchers and participants is required to ensure accurate data collection(104). This renders food records to be a time-intensive form of dietary assessment, which, if not done properly, reduces the reliability of findings. To overcome these limitations, studies in this review used study-specific questionnaires that focused on obtaining the key points of interest – temporal patterns of eating, such as mealtimes or meal regularity. However, these questionnaires were not validated, and are lacking in their ability to capture all temporal patterns of eating. Forslund and colleagues recently developed a meal pattern questionnaire to collect data on frequency, type and time of meals(49). Whilst participants completed all the questionnaires that were returned, which suggests at the ease of filling in such a tool, it was not validated. Similarly, a Chrononutrition Profile Questionnaire (CP-Q) created by Veronda *et al.* identifies six components of chrononutrition likely to influence health(105). While its components were validated against the Automated Self-Administered 24-h Dietary Assessment Tool (ASA24), PSQI, and Night Eating Questionnaire (NEQ), it does not differentiate between workdays and work-free days across all temporal patterns of eating, nor does it collect information on chronotype. Making improvements to existing questionnaires to create a single instrument that captures all temporal patterns of eating in relation to chronotype and/or work schedules is relatively straightforward, and will result in a convenient tool that provides a wealth of information for use by future epidemiological studies in this area.

Further distinguishing factors between study-specific questionnaires include the presence or absence of a recall period, the duration of recall, and the definition used to define eating occasions. Amongst the questionnaires that stipulated a recall period, the majority used a duration of 1 month, which is helpful as a longer duration better reflects habitual intake. This duration also reflects the timeframe captured by the MCTQ, so a combination of the two will generate information on both chronotype and temporal patterns of eating. Questionnaires should also standardise the definition of meals between neutral labels

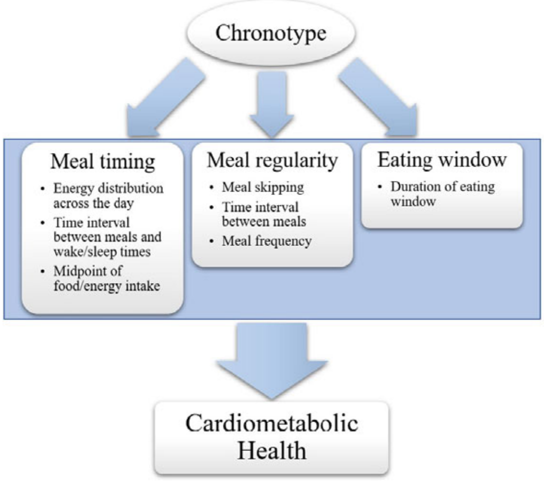


**Fig. 5.** The eight categories of temporal patterns of eating identified from the literature in this review, that is, (i) meal timings, (ii) meal skipping, (iii) energy distribution across the day, (iv) meal frequency, (v) time interval between meals, or meals and wake/sleep times, (vi) midpoint of food/energy intake, (vii) meal regularity, and (viii) duration of eating window, can be organised into three fundamental aspects of eating patterns that are influenced by chrononutrition and impact on cardiometabolic health outcomes: meal timing, meal skipping, and eating window. All of these aspects can be derived from a record of eating times. Creating a single, standardised, validated measure to investigate these factors in relation to chronotype will facilitate targeted recommendations for timing of food intake, tailored to individual body clock timing, in order to improve cardiometabolic health.

(i.e., eating occasion) or conventional labels (i.e., breakfast, lunch, dinner and snack). Neutral labels are more all-encompassing compared with conventional labels, which may hold different meanings to individuals with different cultural backgrounds(106) and work types (e.g., night shift workers may face difficulty in deciding which meal constitutes breakfast). Neutral labels have also been shown to best predict variance in total energy intake(107). Yet, meal size or caloric load consumed at midnight has been shown to impact on glucose response to breakfast the next morning(108). Hence, the ability to distinguish main meals from snacks as an indicator of size of meal or caloric load may prove to be useful when analysing the impact of timing of food intake on health outcomes. A method most commonly used in studies is the participant-identified method of distinguishing main meals from snacks(10), and would thus serve well for this purpose. Incorporating these elements to create a purposeful and customised validated questionnaire allows the collection of targeted and relevant information on temporal patterns of eating with ease, speed and convenience.

## Conclusion

This is the first review using systematic search techniques to present data on the temporal patterns of eating in relation to chronotype. The interaction between chronotype and timing and patterns of meals is important due to the impact of these relationships on cardiometabolic disease risk, as demonstrated in Fig. 5. Although the body of literature is sufficient to indicate key directions for future research, conclusive statements regarding findings are limited due to the large methodological variation across studies, with clear opportunities indicated for standardisation and validation. As epidemiological studies show evening chronotypes face increased risk of obesity and chronic diseases, it is important to understand which aspects of timing are driving health risk and how this translates for individuals with anomalies in circadian timing, including late chronotypes and shift workers. In this review, evening chronotypes tend to skip meals more frequently, have later mealtimes, and distribute more of their energy intake towards later times of the day than morning chronotypes. Future studies should analyse meal frequency in relation to meal timing, meal regularity and duration of eating window, and further explore chronotype-related differences in meal regularity and duration of eating window. Lastly, tools to collect data on chronotype and temporal patterns of eating are varied; they should be unified into a single assessment tool so future studies may identify these outcomes in a standardised manner. This will enable the development of more comprehensive and concise guidelines to optimise health outcomes through temporal patterns of eating.

## Acknowledgements

None.

## Financial Support

This research received no specific grant from any funding agency, or commercial or not-for-profit sectors.

## Conflict of Interest

None.

## Authorship

Conceptualisation, Y.P., M.R., M.B., J.D. and A.C.; methodology, Y.P.; validation, M.R., M.B., J.D. and A.C.; data curation, Y.P.; writing – original draft preparation, Y.P.; writing – review and editing, Y.P., M.R., M.B., J.D. and A.C.; supervision, M.R., M.B., J.D. and A.C.; project administration, Y.P.

## Supplementary material

To view supplementary material for this article, please visit https://doi.org/10.1017/S0954422421000123

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