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Late chronotypes, late mealtimes. Chrononutrition and sleep habits during the COVID-19 lockdown in Italy

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ABSTRACT

The emerging field of chrononutrition provides useful information on how we manage food intake across the day. The COVID-19 emergency, and the corresponding restrictive measures, produced an unprecedented change in individual daily rhythms, possibly including the distribution of mealtimes. Designed as a cross-sectional study based on an online survey, this study aims to assess the chrononutrition profiles (Chrononutrition Profile Questionnaire, CP-Q) in a sample of 1298 Italian participants, during the first COVID-19 lockdown, and to explore the relationship with chronotype (reduced Morningness-Eveningness Questionnaire, rMEQ), sleep quality (Pittsburgh Sleep Quality Index, PSQI) and socio-demographics. Our findings confirm a change in eating habits for 58% of participants, in terms of mealtimes or content of meals. Being an evening chronotype and experiencing poor sleep imply a higher likelihood of changing eating habits, including a delay in the timing of meals. Also, under these unprecedented circumstances, we report that the timing of breakfast is a valuable proxy capable of estimating the chronotype. From a public health perspective, the adoption of this straightforward and low-cost proxy of chronotype might help in the early detection of vulnerable subgroups in the general population, eventually useful during prolonged stressful conditions, as the one caused by COVID-19 pandemic.

1. Introduction

Chrononutrition is an emerging field, born as an epidemiological branch from the combination of chronobiology and nutrition science (Pot, 2018) and addressing the circadian regulation of nutritional aspects.

Its main research topics are dietary patterns, the frequency of meals, the regularity in meals timing and the health consequences deriving from specific chrononutritional patterns.

Chronobiology is a discipline investigating the circadian rhythms in human, animal and plant models (Kuhlman et al., 2018). The sleep-wake cycle is perhaps the most studied behaviour affected by circadian rhythms. Also, other paramount physiological functions, such as nutrition, follow a circadian regulation (Challet, 2019). The individual preference for behavioural and biological activities during the day is defined as chronotype or circadian typology (Horne & Östberg, 1977). Authors generally distinguish three main chronotypes, i.e., morning, intermediate and evening types, that are distributed among the general population so that both morning and evening chronotypes account for 15% each of the whole population, while the remaining 70% is represented by intermediate chronotypes. Moreover, chronotype (morningness) is positively correlated with age (Adan & Natale, 2002). Morning types (also known as larks) are those who prefer doing activities in the first part of the day, waking up earlier and going to bed earlier as compared to intermediate and evening types (also known as owls). Accordingly, morning types seem to adapt more easily to social routines compared to evening types. In fact, evening types are more likely to experience a mismatch between their biological clock (i.e., their spontaneous circadian preferences) and their social schedule (e.g., work or school timings, etc.), defined "social jet-lag" (Wittmann et al., 2006). As many other routinary activities, also the number and the content of meals, although strongly depending on cultural traditions and

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individual needs, are generally well scheduled along the day. Nutritionists recommend concentrating the highest caloric intake with the first eating event (Jakubowicz et al., 2013), not to skip breakfast (Uzhova et al., 2018), and to have dinner rather early (Gu et al., 2020), as these habits are associated with a lower propensity to develop cardiometabolic disorders and sleep disturbances, among others (Almoosawi et al., 2019). Some authors have recently introduced another behavioural recommendation for patients with metabolic disorders, namely time-restricted eating, which consists in reducing eating window, i.e., the time between the first and last eating event (Chaix et al., 2019). Despite these recommendations, evening chronotypes tend to spontaneously disregard these behavioural prescriptions. Indeed, eveningness is associated with breakfast skipping (Meule et al., 2012), delayed meal timings (Reutrakul et al., 2013), and with night eating behaviour (Kandeger et al., 2018), often resulting in poor sleep quality (Cheng et al., 2012) (Crispim et al., 2011). Nutritional and sleep habits are strongly influenced by contextual constraints, as it has been demonstrated during the last decades by imposing phenomena as globalization and urbanization (Pot, 2018). Recently, the COVID-19 outbreak, and the related restrictive measures adopted to face the epidemiological emergency, produced an unprecedented change in our daily routine and nutritional habits, possibly leading to overeating and weight gain (Mason et al., 2021). An increased consumption of unhealthy food, changes in physical activity practice and altered sleep patterns have been associated to weight gain (Di Renzo et al., 2020).

Previously, under non pandemic environmental conditions (Huseinovic et al., 2016), systematically assessed meal timings in a sample of 36.994 European responders, including 3952 Italian participants, from 1995 to 2000, focusing on differences in intake frequency, intake occasions during the day and daily energy intake across countries.

In the present study, we aimed to evaluate the potential association of chrononutrition patterns with chronotype and sleep quality, after controlling for anthropometric and socio-demographic variables during the COVID-19 lockdown in Italy. Consistently with previous studies, we expected to find significant differences in eating habits in relation to chronotype and sleep quality (Mazri et al., 2020) (St-Onge et al., 2017). Moreover, we tested whether the individual preference in the meal timing might provide sufficient information to predict chronotype. The COVID-19 outbreak and the restrictive measures adopted to face this planetary emergency offered the opportunity to analyse changes and adaptations in our habits, including physiological aspects such as nutritional patterns and the sleep-wake cycle.

2. Method

2.1. Sample

After removing duplicates (n = 2), answers from 1714 participants were collected from a survey distributed through social networks (LinkedIn, Facebook, Instagram, WhatsApp). Only participants who declared to be at least 18 years of age, fluent in Italian language, and resident in Italy at the time of data collection were considered for analysis. 391 participants were excluded because they did not correctly or entirely fill out the survey. 25 participants were excluded from the study because not resident in Italy. As a result, the final sample consisted of 1298 participants (mean age 39.17 ± 14.45 years). Since only one participant answered to the question "sex" in a non-binary way (male or female), we did not consider a third category for sex due to the limited sample size (n = 1), excluding the participant from the analysis.

All participants were recruited during the lockdown period in Italy, which started from March the 9th, and the restrictions encompassed the data collection. Indeed, the survey was disseminated from April 29th to May 17th, 2020, and each participant was asked to fill it only once within this time window. The items within the surveys could refer to a) actual habits during the lockdown, b) habits before the lockdown (retrospective data), c) hypothetical preferred habits. The present study has been approved by the Bioethical Committee of the University of Pisa on April the 28th 2020, with protocol number 0040387/2020. Participants electronically expressed their informed consent to join by ticking a mandatory box before starting to fill in the survey. Participants did not receive any kind of compensation for their participation.

2.2. Measures

The survey consisted of two different parts. In the first part, data about demographics (age, sex, level of education, etc.) and daily routines (such as the practice of physical activity, hobbies, outdoor and indoor space availability at home during the confinement, etc.) were explored. Part two consisted instead of three validated questionnaires, assessing chrononutrition profile, chronotype and sleep quality, respectively (details are reported in the following paragraphs, see 2.3 and 2.4).

Once expressed their informed consent, participants were asked to provide information about their habits during the lockdown, including coffee consumption, smoke habit, and use of sleep-promoting drugs. Data acquired about demographics are reported in Table 1, and include age, sex, level of education, residence, Body Mass Index (BMI), work condition and an indicator of free time, which helped also distinguish a subgroup of schedule-free participants. To disentangle the circadian regulation of sleep-wake cycle from the effect of sleep pressure, free runners are often evaluated in chronobiology and sleep research, as it is assumed that free runners follow their spontaneous rhythms (Webb, 1994). In this study, we aimed to test the correlation between chronotype and meal timing reducing the interference of external constraints (see section 2.5). Although it was not possible to reproduce a condition of complete free running, the lockdown provided the unique opportunity of collecting data from individuals who were free from most social and work constrains, here defined as "schedule-free". Schedule-free participants were identified through a two-step procedure. First, we selected participants who reported having 24 free hours a day (N = 74). After cross-checking the questions regarding employment status, free time, and hours of sleep during workdays and free days, we added other two participants who declared to not be employed at that time, and who did not report the hours of sleep as free time. A final subsample of 76 schedule-free subjects was finally considered for analysis.

2.3. Chrononutrition profiles during the COVID-19 first lockdown

To assess their eating habits and chrononutrition profiles, participants were asked to complete the Chrono-Nutrition Profile

Table 1
Main characteristics of the study sample (N = 1298).

		Absolute frequency (%)
Sex (female)		803 (61.9%)
Degree level education	Middle School	37 (2.9%)
	High School	424 (32.7%)
	Bachelor's degree	227 (17.5%)
	Master's Degree	407 (31.4%)
	Postgraduate	202 (15.6%)
Residence	North	414 (31.9%)
	Centre	724 (55.8%)
	South	148 (11.4%)
	Islands	12 (0.9%)
BMI	<18.5 kg/m2	69 (5.3%)
	18.5–24.9 kg/m2	851 (65.6%)
	25–29.9 kg/m2	306 (23.6%)
	30–34.9 kg/m2	54 (4.2%)
	≥35 kg/m2	17 (1.3%)
Work condition	Remote working	779 (60.0%)
	Working in presence	209 (16.1%)
	Not working	310 (23.9%)
Daily schedule	Schedule-free	76 (5.9%)
	No schedule-free	1222 (94.1%)

Questionnaire (CP-Q) (Veronda et al., 2020).

This 18-item scale explores chrononutrition patterns together with individual preferences as far as food intake timing. CP-Q evaluates six dimensions of chrono-nutrition, intimately related to health: (i) breakfast skipping; (ii) largest meal; (iii) evening eating; (iv) evening latency; (v) night eating; (vi) eating window. Also, questions about sleep onset and off-set time are included in the questionnaire. CP-Q consists of four parts. The first exploring preferred sleep and meal timing if participants were free to plan a day. Part two assesses the usual largest meal during the week, and the weekly frequency of: (a) having breakfast, (b) having a snack after the last meal, and of (c) night eating. The third part investigates the timing of sleep onset and off-set and of the three main eating events in a typical workday or school day. The last part repeats the questions of part three with respect to a typical weekend day or free day (Veronda et al., 2020). For part two and part three, exploring a typical workday or school day and a typical weekend day or free day respectively, we asked to participants to consider the period from the beginning of the lockdown (i.e., actual habits during the lockdown).

We also added two *ad hoc* questions to the CP-Q: one exploring the change in nutritional habits during the first lockdown, and the other assessing the preferred timing for lunch if the participants were free to plan their day. In fact, the CP-Q only asks lunch time for actual mealtimes.

Since the CP-Q does not provide a final score, the authors propose a scoring guide to calculate a series of chrononutrition parameters in addition to the six dimensions mentioned above. For a complete overview of the possible scores suggested see (Veronda et al., 2020). For the present study, we focused on meal timing, considering the values extracted from part one, two and three, and the eating window (i.e., the time interval between the first and the last eating event in a day). We also considered two measures of misalignment, i.e., eating window misalignment and sleep duration misalignment, computed as the difference between preferred timings and actual timings (see formulae 1 and 2).

$$\text{Eating window misalignment} = (\text{preferred eating window}^{b}) - (\text{actual eating window}^{b}) \quad (1)$$

[b]eating window = time interval between the first eating event and the last eating event (measured as weighted average between workdays and free days) (hours:minutes)

$$\text{Sleep duration misalignment} = (\text{preferred sleep duration}) - (\text{actual sleep duration}) \quad (2)$$

Given the absence of an index for the misalignment between free days and workdays timings, we added to the analysis such a metric for each eating event, i.e., first eating event misalignment, last eating event misalignment and lunch event misalignment, expressed as a difference between the eating event timing during free days minus the timing of that eating event during workdays (hours:minutes).

$$\text{eating event misalignment} = (\text{eating event during free days}) - (\text{actual eating event during workdays}) \quad (3)$$

2.4. Chronotype and sleep quality during the COVID-19 first lockdown

To assess chronotype, participants were asked to fill the Italian version of the reduced (5-item) form of the Morningness-Eveningness Questionnaire (rMEQ). The rMEQ is a self-report questionnaire with a final score ranging from 4 to 26: according to the scale, a score <11 indicates an evening type (ET); 11–18 a neither or intermediate type (NT); >18 a morning type (MT). The reliability of the Italian translation was assessed by (Natale, 1999) (Natale et al., 2006).

Sleep quality was instead evaluated through the Pittsburgh Sleep Quality Index (PSQI), a self-administered 19-item questionnaire that assesses sleep quality over a one-month time interval (Buysse et al., 1989). The sum of the score ranges from 0 to 21. A global score >5 is an index of poor sleep quality. We used the Italian version of the questionnaire, translated and adapted by (Curcio et al., 2013).

2.5. Main planned analyses

First, changes in eating habits before *vs* during the lockdown were described. The distribution of socio-demographics variable, chronotype and sleep quality in relation to changes in eating habits were described using traditional descriptive statistics. Second, we reported socio-demographics variables according to chronotype and sleep.

For each of the three main eating events (first eating event, lunch and last eating event) we considered (i) the actual timing reported for both workdays and free days, and (ii) the preferred or desired timing.

Chi-square test and Kruskal-Wallis test were used to assess differences among groups for categorical and continuous variables respectively, while the Wilcoxon test was used to assess differences between mealtimes during workdays and free days as well as between actual and preferred timings; Friedman test was used to compare meal timings across the 3 different conditions (during workdays, free days and preferred schedules). To test the role of chronotype (i.e., rMEQ total score) as a possible predictor of meal timing, we performed three linear regression models (one for each of the meal considered: first eating event, lunch and last eating event), controlling for sex, age, BMI, and work condition ("remote working", "working in presence", and "not working"). The Spearman correlation coefficient was used to explore the relation between the timing of the first eating event and rMEQ score only in the subgroup of schedule-free subjects, in order to reduce the interference effect produced by social constraints. The reason why we selected the first eating event - i.e., breakfast - during free days is twofold. On the one hand, we assumed that meal timings during free days are closer to preferred timings also in the general population, useful in the attempt of generalizing our results. On the other hand, breakfast showed the greatest difference between free days and workdays as compared to lunch and the last eating event.

Finally, after calculating "eating window misalignment" and "sleep duration misalignment" (as in formulas 1 and 2, see 2.3), we tested their association with chronotype and sleep quality in the entire sample by means of the Kruskal-Wallis test. We then used linear regression to evaluate possible predictors of this variable such as MEQ score, age, sex and BMI. P-value <0.05 was considered for statistical significance. All the analyses were performed with R 4.0.4.

3. Results

3.1. Sample and changes in eating habits during the COVID-19 first lockdown

A final sample of 1298 participants recruited through social media was considered for the analysis. Sample characteristics are shown in Table 1. With respect to the first question exploring a possible change in nutritional habits (*see Methods 2.2*), we reported that 41.8% of participants declared they did not change their eating habits after the beginning of the lockdown. Instead, 12.9% self-reported a change in the timing of meals, 17.9% a change in the content of meals, while the remaining 27.4% reported a change of both the timing and the content of meals as compared to their usual habits preceding the lockdown. Moreover, there was a significant difference in the average age across different strategies of adaptation in eating habits (no change: 41.02 ± 15.95; change in timing: 40.11 ± 15.64; change in content: 36.86 ± 13.55; change in timing and content: 37.40 ± 13.50, p-value = 0.031). Specifically, a post-hoc analysis (Dunn test) revealed a statistically significant difference between those who did not change their habits compared to both those who changed only the content of their meals (p-value = 0.001) and those who changed both the timing and the content of their meals (p-value = 0.011).

Table 2 summarizes descriptive statistics for demographics, working condition, sleep quality (PSQI) and chronotype (rMEQ) according to changes in eating habits during the lockdown.

Considering the change in eating habits (either timing or content of meals, or both) as a binary variable ("no change" vs "changed"), we observed that subjects resistant to changes reported a significant shift towards eveningness and significantly worse sleep than those participants who reported eating behavioural changes (Kruskal-Wallis test, rMEQ score = 15.47 ± 3.73 for "no change" and rMEQ score = 14.75 ± 3.72 for "changed", p-value <0.001; PSQI score = 5.06 ± 2.94 for "no change" and PSQI score = 5.99 ± 3.35 for "changed", p-value <0.001).

3.2. Meal timing, chronotype and sleep quality

In the overall sample, with regard to meal timings, we found that the timing of the first and the last eating event was significantly different between workdays and free days (8:25 ± 1:39 and 9:45 ± 1:41, first eating event during workdays and free days respectively; 21:01 ± 1:21 and 21:10 ± 1:34, last eating event during workdays and free days respectively; Wilcoxon test, $p < 0.001$ for both first and last eating events), while such difference did not hold true for lunch time (Wilcoxon test, $p = 0.170$).

3.2.1. Meal timing and chronotype

In line with previous studies, significant differences emerged in terms of age, being evening types (ET) younger as compared to both intermediate types (NT) and morning types (MT) (see Table 3a). Table 3b shows that, as expected, MT consumed their meals on average earlier than NT, who in turn ate earlier than ET. These differences are consistent across both preferred and actual reported mealtimes, and they are all statistically significant with the only exception of lunch during workdays. Also, we showed that all chronotypes tend to have their first eating event and lunch during free days later than desired (Wilcoxon test, first eating event: $p < 0.001$ for all chronotypes; lunch: $p < 0.001$ for MT and NT, $p = 0.07$ for ET), while they have the last eating event before than desired (Wilcoxon test, $p = 0.085$ for MT, $p < 0.001$ for NT and $p = 0.001$ for ET).

We observed that chronotype significantly predicted all meal timings, both during workdays and free days. Also, age and sex are significant predictors of meal timings (see Table 4a and Table 4b for predictions on mealtimes during workdays and free days, respectively). With respect to work condition, we showed a significant contribution in explaining the time of meals. In fact, during workdays, first eating event is significantly anticipated in subjects working in presence compared to remote working ones. On the contrary, lunch is delayed in the former compared to the latter ones (see Tables 4a and 4b for details).

Results from regression analysis held true even when repeated separately in the subgroup of participants who declared to have changed their nutritional habits after the lockdown onset as well as in the subgroup of those who did not (data not shown).

3.2.2. Chronotype and breakfast

To test whether the timing of a meal might be associated with the chronotype, we examined the degree of correlation between the timing of the first eating event (i.e., breakfast) and the rMEQ score. For this purpose, we first considered the actual timing of breakfast during free days in schedule-free subjects (*see Methods 2.2 for further details)*. A strong negative correlation ($r = -0.708$, $p < 0.001$) is displayed in Fig. 1A. A similar correlation was reported also for the preferred times for breakfast expressed by schedule-free subjects ($r = -0.652$, $p < 0.001$, see Fig. 1B). The same correlation analysis was repeated in the overall sample for the actual timing of the first eating event during both workdays and free days, as well as for the preferred timing of breakfast. Results highlight a similar negative correlation between rMEQ score (i.e., the chronotype) and the timing of the meal, although such relationship was weaker when participants reported their actual times during workdays compared to free days and to the desired ones (respectively, $r = -0.325$, $p < 0.001$; $r = -0.469$, $p < 0.001$; and $r = -0.395$, $p < 0.001$) (see Table 5).

3.2.3. Meal timing and sleep quality

As reported in Table 6a, the relationship between meal timing and sleep quality (comparing poor sleepers (PSQI score >5) and good sleepers (PSQI score <5)) emerged as significant only with respect to preferred meal timings. Indeed, no significant differences were reported in the real timing of meals during workdays or free days based on sleep quality. Instead, when preferred timings are considered, poor sleepers show to desire to have both the first and the last eating event significantly later as compared to good sleepers (respectively, first eating event: 9:09 ± 1:33 vs 8:59 ± 1:31, p-value = 0.021; last eating event: 21:29 ± 1:32 vs 21:11 ± 1:25, $p = 0.001$). Moreover, there was a significant difference in the gender distribution among poor sleepers (69% were females) against among good sleepers (56.7% were females) (Chi-square's test, $p < 0.001$). Finally, with respect to work condition, the prevalence of not working participants among poor sleepers was significantly higher than among good sleepers (21.1% vs 15.4%; Chi-square test, p-value < 0.001) (see Table 6b).

3.3. Eating and sleep habits misalignment: associations with chronotype and sleep quality

Considering the difference between preferred and actual eating timings, we observed that all participants showed a preference for an eating window wider as compared to the actual one, as well as for additional time to sleep. To test the hypothesis that chronotype might explain the individual misalignment between preferred timings and actual timings, we considered the measures of CP-Q "eating window misalignment" and "sleep duration misalignment" (see formulas 1 and 2). As showed in Table 7, irrespective of chronotype and sleep quality, both eating window and sleep duration misalignment assumed a positive value, confirming participants' preference for a wider eating and sleep duration windows as compared to their actual ones. The entity of eating window misalignment was significantly wider for ET compared to

Table 2
Descriptive statistics for demographics, chronotype (rMEQ) and sleep quality (PSQI) according to changes in eating habits.

		No change	Change in timing	Change in content	Change in timing and content
Overall sample		543 (41.8%)	167 (12.9%)	232 (17.9%)	356 (27.4%)
Sex	Females	337 (42.0%)	103 (12.8%)	135 (16.8%)	228 (28.4%)
	Males	206 (41.6%)	64 (12.9%)	97 (19.6%)	128 (25.9%)
Work condition	Remote working	290 (37.1%)	104 (13.5%)	158 (20.0%)	227 (29.4%)
	Working in presence	105 (50.2%)	21 (10.1%)	36 (17.4%)	47 (22.2%)
	Not working	148 (49.8%)	42 (13.9%)	38 (12.2%)	82 (24.1%)
Daily schedule	Free	31 (40.8%)	8 (10.5%)	12 (15.8%)	25 (32.9%)
	Not free	512 (41.9%)	159 (13.0%)	220 (18.0%)	331 (27.1%)

PSQI: Pittsburgh Sleep Quality Index; reduced version of MEQ: Morningness–Eveningness Questionnaire.
Values are reported as mean values (±SD) for continuous variables and absolute frequency (%) for categorical variables.

Table 3a
Comparisons of age, sex and work condition among chronotypes.

	Age (n = 1298)	Sex (female) (n = 1298)	Work condition			
			Remote working (n = 1298)	Working in presence (n = 1298)	Not working (n = 1298)	Schedule-free (n = 1298)
Overall sample	39.17 ± 14.95	803 (61.9%)	770 (59.3%)	207 (15.9%)	245 (18.9%)	76 (5.9%)
MT	47.80 ± 14.73	157 (61.8%)	128 (50.4%)	49 (19.3%)	67 (26.4%)	10 (3.9%)
NT	38.05 ± 14.52	552 (62.9%)	539 (61.4%)	137 (15.6%)	157 (17.9%)	45 (5.1%)
ET	31.87 ± 11.38	94 (56.6%)	103 (62.0%)	21 (12.7%)	21 (12.7%)	21 (12.7%)
(df) p-value	(2) <0.001	(2) 0.315	(2) 0.005	(2) 0.170	(2) <0.001	(2) <0.001

MT: morning type; NT: neither (intermediate) type; ET: evening type.
Chi-square's test was used to compare the distribution of sex and working condition, while for the other variables Kruskal-Wallis test was used for comparisons among chronotypes.

Table 3b
Comparisons of mealtimes among chronotypes and daily conditions (workdays, free days, preferred schedules).

	First eating event			p-value	Lunch			p-value	Last eating event			p-value
	workdays (n = 988)	free days (n = 1297)	preferred (n = 1295)		workdays (n = 980)	free days (n = 1292)	preferred (n = 1296)		workdays (n = 989)	free days (n = 1264)	preferred (n = 1293)	
Overall sample	8:25 ± 1:39	9:45 ± 1:41	9:05 ± 1:31	<0.001	13:24 ± 0:53	13:21 ± 0:48	13:10 ± 0:47	<0.001	21:01 ± 1:21	21:10 ± 1:34	21:22 ± 1:30	<0.001
MT	7:53 ± 1:46	8:41 ± 1:35	8:18 ± 1:25	<0.001	13:20 ± 0:50	13:11 ± 0:41	13:02 ± 0:44	<0.001	20:34 ± 0:57	20:34 ± 1:12	20:42 ± 1:05	<0.001
NT	8:26 ± 01:31	9:48 ± 1:28	9:06 ± 1:24	<0.001	13:24 ± 0:52	13:22 ± 0:45	13:08 ± 0:39	<0.001	21:00 ± 1:17	21:10 ± 1:27	21:20 ± 1:25	<0.001
ET	9:09 ± 1:53	11:07 ± 1:48	10:12 ± 1:36	<0.001	13:32 ± 1:00	13:35 ± 1:04	13:32 ± 1:13	<0.001	21:45 ± 1:50	22:10 ± 2:02	22:31 ± 1:52	<0.001
(df) p-value	(2) <0.001	(2) <0.001	(2) <0.001		(2) 0.230	(2) <0.001	(2) <0.001		(2) <0.001	(2) <0.001	(2) <0.001	

MT: morning type; NT: neither (intermediate) type; ET: evening type.
Kruskal-Wallis test was used for comparisons among chronotypes, and Friedman test for comparisons of meal timings across the 3 different conditions (during workdays, during free days and preferred schedules).

Table 4a
Multivariate linear model predicting mealtimes during workdays.

	First eating event workdays				Lunch workdays				Last eating event workdays			
	$R^2 = 0.099$				$R^2 = 0.052$				$R^2 = 0.088$			
	β	Std.err	p-value	C.I.	β	Std.err	p-value	C.I.	β	Std.err	p-value	C.I.
rMEQ (score)	−0.004	0.001	<0.001	[-0.006, −0.003]	−0.0014	0.0003	<0.001	[-0.002, −0.001]	−0.003	0.001	<0.001	[-0.004, −0.003]
Age	−0.001	0.0002	0.006	[-0.001, −0.0001]	0.0003	0.0001	0.001	[0.0001, 0.0005]	−0.0004	0.0001	0.009	[-0.0006, −0.0001]
Sex (males)	0.016	0.005	0.001	[0.007, 0.025]	−0.008	0.002	0.001	[-0.013, −0.004]	0.013	0.004	<0.001	[0.006, 0.021]
BMI	0.0003	0.001	0.638	[-0.001, 0.002]	−0.0004	0.0003	0.234	[-0.001, 0.0003]	−0.001	0.0005	0.038	[-0.002, −0.00001]
Remote working (vs working in presence)	0.015	0.005	0.005	[0.005, 0.026]	−0.012	0.003	<0.001	[-0.018, −0.006]	−0.004	0.004	0.338	[-0.013, 0.004]
Not working (vs working in presence)	−0.015	0.068	0.829	[-0.148, 0.118]	−0.039	0.036	0.274	[-0.110, 0.031]	−0.016	0.054	0.762	[-0.123, 0.090]

rMEQ: reduced Morningness–Eveningness Questionnaire.
Dependent variables: first eating event, lunch and last eating event during workdays.

MT (0:35 ± 2:21 vs 0:03 ± 2:06; p = 0.03), while the entity of sleep duration misalignment was significantly wider for poor sleepers compared to good sleepers (0:45 ± 1:21 *vs* 0:32 ± 1:00; p < 0.001).

Performing a linear regression model, considering eating window misalignment as a dependent variable, we observed that chronotype influences eating window misalignment, independently from sex, age and BMI, so that the misalignment is positively associated with eveningness ($R^2 = 0.021$, beta = −0.0015 or −00:02:09, p = 0.043). Also, males report a greater misalignment as compared to females (beta = 0.0237 or 00:34:08, p < 0.001).

On the contrary, chronotype is not associated to sleep duration misalignment in the univariate model (data not shown) but it becomes significantly associated to sleep duration misalignement in the multivariate model with sleep quality, age, sex, and BMI as covariates ($R^2 = 0.049$, beta = −0.0008 or −00:01:09, p-value = 0.043). Sleep quality instead significatively predicts sleep duration misalignment (beta = 0.0017 or 00:02:27, p-value < 0.001). Females show a greater sleep duration misalignment compared to males (beta = −0.0174 or

Table 4b
Multivariate linear model predicting mealtimes during free days.

	First eating event free days				Lunch free days				Last eating event free days			
	R2 = 0.271				R2 = 0.036				R2 = 0.127			
	β	Std.err	p-value	C.I.	β	Std.err	p-value	C.I.	β	Std.err	p-value	C.I.
rMEQ (score)	−0.007	0.001	<0.001	[-0.008, −0.006]	−0.002	0.0003	<0.001	[-0.002, −0.001]	−0.005	0.0005	<0.001	[-0.005, −0.004]
Age	−0.001	0.0001	<0.001	[-0.002, −0.001]	0.0002	0.0001	0.03	[0.00001, 0.0003]	−0.001	0.0001	<0.001	[-0.001, −0.0004]
Sex (males)	0.005	0.004	0.164	[-0.002, 0.013]	−0.00002	0.002	0.993	[-0.004, 0.003]	0.010	0.004	0.009	[0.002, 0.017]
BMI	0.001	0.0005	0.018	[0.0002, 0.002]	−0.001	0.0003	0.007	[-0.001, −0.0001]	−0.0001	0.0005	0.798	[-0.001, −0.001]
Remote working (vs working in presence)	0.003	0.005	0.525	[-0.007, 0.013]	−0.004	0.003	0.886	[-0.005, 0.005]	0.002	0.005	0.714	[-0.008, 0.011]
Not working (vs working in presence)	0.014	0.006	0.014	[0.003, 0.025]	−0.002	0.003	0.409	[-0.008, 0.003]	0.007	0.006	0.197	[-0.004, 0.018]

rMEQ: reduced Morningness–Eveningness Questionnaire.
Dependent variables: first eating event, lunch and last eating event during free days.

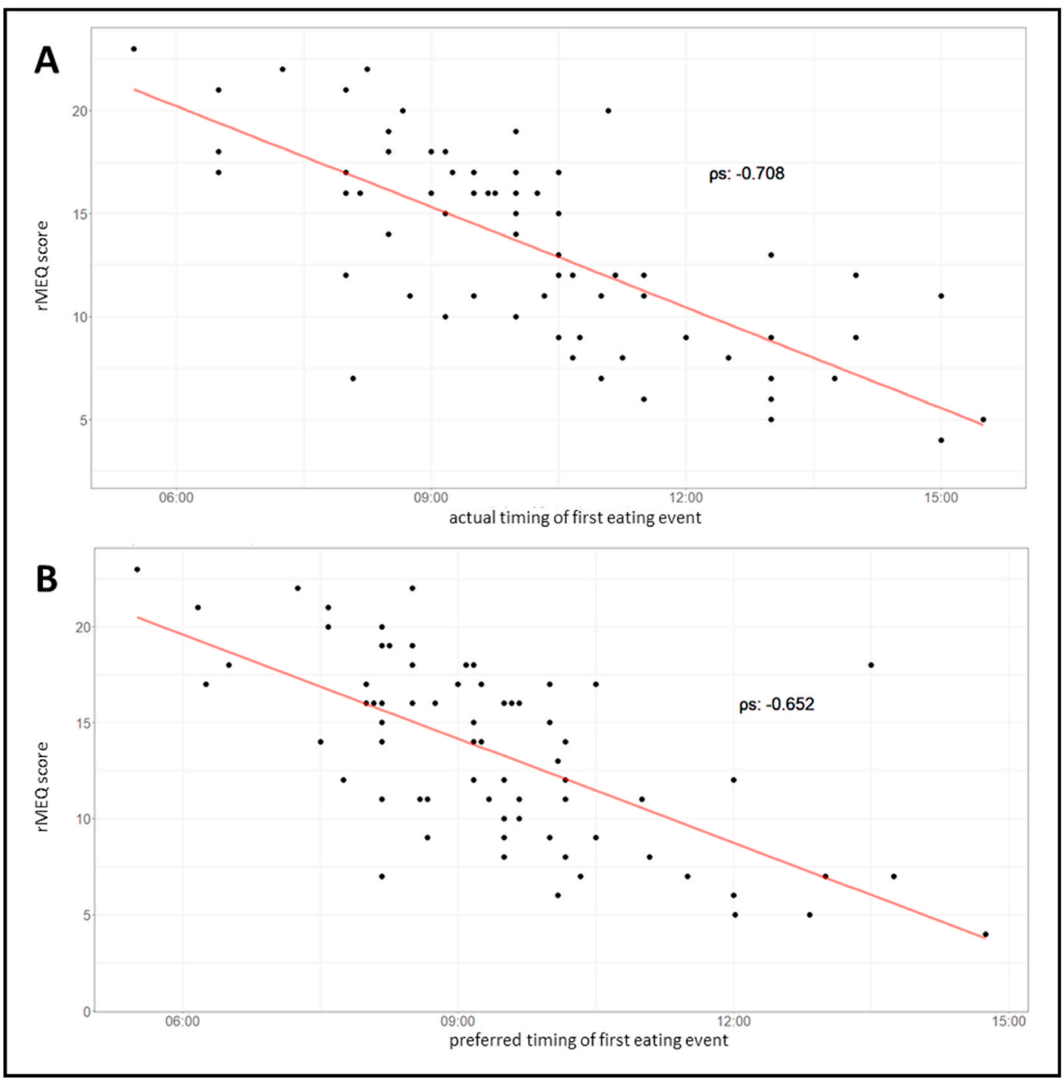

Fig. 1. Correlation analysis in schedule-free subjects (n = 76) between first eating event and chronotype (rMEQ score).

Table 5
Correlation analysis in schedule-free subjects (n = 76) and in the overall sample (n = 1222) between first eating event and chronotype (rMEQ score).

	Free-schedule subjects		Overall sample		
	Actual First Eating Event	Preferred First Eating Event	Actual First Eating Event during workdays	Actual First Eating Event during free days	Preferred First Eating Event
Chronotype (rMEQ score)	−0.708 (p < 0.001)	−0.652 (p < 0.001)	−0.325 (p < 0.001)	−0.469 (p < 0.001)	−0.395 (p < 0.001)

Spearman's rank correlation coefficient (p-value).

−00:25:03, p-value < 0.001).

4. Discussion

We investigated the relationship between chrononutrition profiles, i.e., meal timings, chronotype and sleep quality during the first COVID-19 lockdown in an Italian sample of 1298 participants. We also assessed whether eating habits (i.e., meal timings) changed in our sample during such an extraordinary period.

The lockdown period caused remarkable changes in daily routines in most of the general population: e.g., physical activities, eating habits (Renzo et al., 2020) and sleep/wake cycle (Cellini et al., 2020) have been challenged during the pandemic. People who worked or studied from home were left free to follow their spontaneous rhythms (Blume et al., 2020). As food intake obeys a circadian rhythmicity, we aimed to explore whether different chronotypes underwent chrononutrition changes during the lockdown.

We first showed that 58% of participants in our sample reported a change in eating habits during the lockdown, in terms of timing of their meals (12.9%), content of meals (17.9%), or both (27.4%). We observed that both chronotype and sleep quality significantly predicted the change in eating habits, so that eveningness and poor sleep were associated with a higher probability of changing eating habits.

Secondly, we went further showing that chronotype can predict all meal timings, so that evening types prefer to have their meals later as compared to morning types, both during workdays and free days. This result is in line with the literature (Vera et al., 2018). Also, age and sex are two good predictors of the timing of some of the meals, as well as work condition significantly influences mealtimes (i.e., first eating event and lunch) during workdays, so that people working in presence tend to have their first eating event earlier and their lunch later as compared to remote working people, respectively (see Table 4a). Previous studies reported that the tendency of evening chronotypes to have their meals late is associated with a higher incidence of cardiometabolic disorders (St-Onge et al., 2017), characterized by a high socio-economic burden (Roth et al., 2020). Other works demonstrated that evening chronotypes are more prone to be irregular in sleep/wake cycle, as well as they tend to skip breakfast, eat less fruit and vegetables, and consume food during nights (i.e., night eating) (Mazri et al., 2020). Also, beyond the

Table 6a
Comparisons of mealtimes between good and poor sleepers, and among daily conditions (workdays, free days, preferred schedules).

	First eating event			p-value	Lunch			p-value	Last eating event			p-value
	workdays (n = 911)	free days (n = 1185)	preferred (n = 1183)		workdays (n = 904)	free days (n = 1180)	preferred (n = 1185)		workdays (n = 912)	free days (n = 1182)	preferred (n = 1181)	
PSQI<5	8:28 ± 1:41	9:39 ± 1:35	8:59 ± 1:31	<0.001	13:24 ± 0:55	13:20 ± 0:43	13:10 ± 0:48	<0.001	20:58 ± 1:20	21:08 ± 1:27	21:11 ± 1:25	<0.001
PSQI>5	8:21 ± 1:35	9:46 ± 1:46	9:09 ± 1:33	<0.001	13:24 ± 0:52	13:21 ± 0:46	13:09 ± 0:46	<0.001	21:05 ± 1:26	21:10 ± 1:39	21:29 ± 1:32	<0.001
(df) p-value	0.329	0.384	0.021		0.741	0.82	0.882		0.326	0.298	0.001	

PSQI: Pittsburgh Sleep Quality Index.
Mann-Whitney test was used for comparisons between poor and good sleepers, and Friedman test for comparisons of meal timings across the 3 different conditions (during workdays, during free days and preferred schedules).

Table 6b
Comparisons of age, sex and work condition between poor and good sleepers.

	Age (n = 1186)	Sex (female) (n = 1186)	Work condition			
			Remote working (n = 1186)	Working in presence (n = 1186)	Not working (n = 1186)	Schedule-free (n = 1186)
PSQI<5	39.69 ± 15.15	383 (56.7%)	431 (63.8%)	108 (16.0%)	104 (15.4%)	33 (4.9%)
PSQI>5	39.49 ± 14.84	352 (69%)	280 (54.9%)	81 (15.9%)	118 (23.1%)	31 (6.1%)
(df) p-value	0.829	(1) <0.001	(1) 0.002	(1) 1	(1) <0.001	(1) 0.439

PSQI: Pittsburgh Sleep Quality Index.
Chi-square's test was used to compare the distribution of sex and working condition, while for the other variables Mann-Whitney test was used for comparisons between poor and good sleepers.

Table 7
Eating window misalignment and sleep duration misalignment split by chronotype and sleep quality.

	Overall sample	MT	NT	ET	n	(df) p-value	PSQI<5	PSQI>5	n	p-value
Eating window misalignment	0:16 ± 2:12	0:03 ± 2:06	0:16 ± 2:12	0:35 ± 2:21	1277	(2) 0.025	0:09 ± 2:04	0:20 ± 2:23	1166	0.061
Sleep duration misalignment	0:38 ± 1:10	0:31 ± 1:20	0:39 ± 1:08	0:42 ± 1:06	1283	(2) 0.495	0:32 ± 1:00	0:45 ± 1:21	1172	<0.001

MT: morning type; NT: neither (intermediate) type; ET: evening type; PSQI: Pittsburgh Sleep Quality Index.
Kruskal-Wallis test was used to compare the distributions in the various groups.

boundaries of eating behaviour, eveningness is associated with a higher vulnerability according to both emotional (Berdynaj et al., 2016) and cognitive dimensions (Taylor & Hasler, 2018). Recent studies demonstrated how the association of evening chronotype to low resilience levels was mediated by sleep quality during the lockdown (Bazzani et al., 2021). An early identification of vulnerable chronotypes during high-stressful situations, such as the COVID-19 pandemic and the restrictive measures adopted, can thus have a relevant impact from a public health perspective.

Third, as we observed that breakfast was the meal varying the most in timing among individuals, we hypothesized that monitoring breakfast time might offer an "easy to collect" candidate proxy of chronotype. We hence examined the correlation between the rMEQ score and the timing of breakfast during free days in the subgroup of schedule-free subjects, reporting a good correlation between the two measures. As expected, such relationship was weaker when considered in the overall sample, and especially for actual breakfast times during workdays, highly dependent on social and work constraints, as further confirmed in the model considering work condition as an independent variable, summarized in Table 4b.

The simple monitoring of breakfast timing as a primary screening tool capable of identifying vulnerable subgroups in the general population might support a low-cost approach to the continuous monitoring of people mental and physical health.

Lastly, we also showed that people tended to have the first and last eating event later during free days as compared to the rest of the week (i.e., workdays). Moreover, participants reported to want more time to have their meals, as well as to sleep. In analogy with the concept of social jet lag, we tested whether the differences between mealtimes during workdays and weekends (i.e., free days) might depend on chronotype. Many authors indeed observed that evening chronotypes are forced to follow social schedules in contrast to their spontaneous rhythms, resulting in a sort of continuous phase delay, hence the expression social jet lag (Wittmann et al., 2006). In our sample, the difference between the desired and actual timing for meals, i.e., the eating window misalignment (see Methods 2.3), is influenced by chronotype, independently from sex, age and BMI, so that evening types suffer from a grater misalignment, as well as male participants (compared to females). This result is in contrast with previous evidence (Veronda & Irish, 2021). It is possible that this inconsistency emerges from the fact that in the present study the eating window misalignment was calculated by subtracting the actual eating window from the preferred eating window, where the actual eating window was computed as the weighted mean between workdays and free days, while Veronda and Irish computed two different measures of eating window misalignment, one for workdays and the other for free days. In parallel, in our sample the sleep duration misalignment, i.e., the difference between the desired and actual duration of sleep (see Methods 2.3), is wider in poor sleepers as compared to good sleepers. In this case, females suffer more from sleep duration misalignment than males.

Taken together our results confirm that late chronotypes and poor sleepers show unhealthy habits in terms of chrononutrition profiles. Moreover, as late chronotypes are more prone to risky decision-making (Wang & Chartrand, 2015) and unhealthy behaviours (ADAN, 1994), as compared to other chronotypes, this might contribute to a compromised management of prolonged and highly stressful situations. As a global – health, economic and social – crisis, the COVID-19 pandemic, and the restrictive measures adopted to face it, affected peoples' everyday life, including their eating habits. Evening chronotypes and poor sleepers can resort to chronobiological interventions and sleep hygiene to improve their lifestyle and adopt effective coping strategies.

The main limitation of the present study is that our findings pertain to a limited time window marked by unprecedent circumstances, i.e., COVID-19 pandemic. However, we showed how this extraordinary period provided us the opportunity to isolate a subgroup of schedule-free subjects, and to observe significant changes in daily activities, including chronutrition habits, otherwise difficult to test in a comparably large sample, under standard conditions. Another limitation is that we used only self-report measures. Moreover, participants provided retrospective data about mealtimes before the lockdown. As a consequence, these results should be interpreted with caution, and a longitudinal study should be conducted to confirm our findings. Also, to avoid any subjective bias, we suggest that future research activities should consider the implementation of objective tools to measure sleep and circadian rhythms, e.g., wrist actigraphy, as well as to collect data about mealtimes, e.g., mobile apps. Furthermore, to validate the timing of breakfast as a proxy of chronotype, future studies should include the golden standard measure of circadian rhythms, i.e., Dim Light Melatonin Onset (DLMO) (Lewy & Sack, 1989).

Finally, the online dissemination of the survey might have restricted our sample to young people (39 ± 17 years old) with high digital literacy and education, which might not be representative of the general population. However, as a first attempt to fill the gap concerning the lack of precedent evidence on chrononutrition profiles in Italy, we think that our findings can be considered as a starting point for future research activities in this promising field, eventually driving future interventional countermeasures.

5. Conclusion

The choice of meals timing, a relevant aspect of chrononutrition profiles, is influenced by chronotype and sleep quality. In parallel, we showed that a single mealtime, i.e., the timing of breakfast during free days, might be considered a good candidate proxy of chronotype. Our findings were obtained during the first COVID-19 lockdown in Italy. This unprecedented situation differed from any other previous condition because of the forced isolation to which people was subjected. Daily habits changed accordingly in many cases, and specific subgroups of the populations perhaps paid a higher price compared to others. Evening chronotypes turned out to be vulnerable to unhealthy habits, including late meal timings and breakfast skipping. Also, late chronotypes show lower levels of resilience as compared to early ones. For these reasons, in a public health intervention perspective, the timing of breakfast can provide an early detection system of high-vulnerable subjects: a valuable and low-cost tool for primary screening, especially when prolonged stressful conditions take place, such as the COVID-19 pandemic.

Ethics approval and consent to participate

Approved by the Bioethical Committee at the University of Pisa on April the 28th 2020, with protocol number 0040387/2020. Participants electronically expressed their informed consent to join by ticking a box before starting to fill the survey.

Availability of data and materials

Due to the nature of this research, according to the informed consent approved by the Bioethical Committee of the University of Pisa on April 28th, with protocol number 0040387/2020, data cannot be publicly shared; therefore, supporting data cannot be available.

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Authors' contributions

All the authors conceived the idea of the paper and designed the survey. AB drafted the manuscript. SM, SB and FCS collected data and contributed to the writing and the interpretation of results. GA and VL performed statistical analysis. UF, GT, PdA revised the manuscript and guided the interpretation of the results. All the authors approved the final article.

Declaration of competing interest

Not related to the present work, U.F. is president and co-founder of sleepActa s.r.l., a University of Pisa spin-off private company, focused on sleep wearable diagnostics. The other authors do not declare any conflict of interest.

Ethical statement

The present study has been approved by the Bioethical Committee of the University of Pisa on April the 28th 2020, with protocol number 0040387/2020. Participants electronically expressed their informed consent to join by ticking a mandatory box before starting to fill in the survey.

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