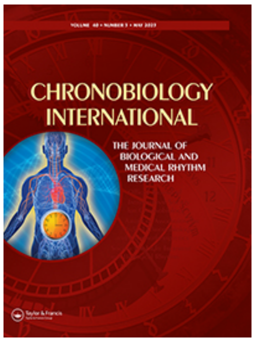


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ORIGINAL ARTICLE

# Validation of the Munich Chronotype Questionnaire (MCTQ) in Chinese college freshmen based on questionnaires and actigraphy

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**ABSTRACT**

The Munich Chronotype Questionnaire (MCTQ) was developed to determine an individual's chronotype, and it provides information about sleep and wake times separately for work and free days. However, the MCTQ has not been effectively verified using a large sample based on multiple questionnaires and actigraphy measures. Three sequential studies were conducted. Study 1 used a large sample (n = 1066) to investigate the chronotype of Chinese college freshmen and assess the validity of the MCTQ compared with the reduced Morningness-Eveningness Questionnaire (rMEQ), actigraphy, and other related questionnaires. Study 2 verified the MCTQ compared with a sleep diary. Study 3 examined the test-retest reliability of the MCTQ at the 2-year follow-up. The results showed that MCTQ parameters were significantly associated with rMEQ scores, the actigraphy-based mid-point of sleep, sleep quality, depression, and trait anxiety. In addition, all MCTQ variables were significantly related to the diary-based sleep mid-point. The test-retest reliability of the mid-point of sleep adjusted for sleep debt (MSFsc) and mid-point of sleep on free days (MSF) was acceptable. These results indicate that the MCTQ is a practical and efficient tool with good reliability. Its further development is important for the accurate assessment of chronotypes and clinical diagnoses of sleep.

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**KEYWORDS**
Chronotypes; sleep midpoint; sleep debt; circadian; alarm clock

## Introduction

An individual's unique biological clock influences their preferred and actual daily sleep and activity patterns (Roenneberg et al. 2019). A chronotype is defined as an individual's circadian preference (e.g., an evening chronotype) or their phase of entrainment (e.g., the mid-sleep point on free days) (Taylor and Hasler 2018). A chronotype comprises three circadian types: morning (larks), intermediate, and evening (owls). Morning chronotypes prefer to go to bed early and wake up early. Evening chronotypes tend to sleep later and get up later. Most individuals fall along the "intermediate" or "neither" chronotype (Adan et al. 2012). As a measure of individual differences in resting and activity time preference, the chronotype is becoming an increasingly important correlate of mental health (Levandovski et al. 2013). For example, having an evening chronotype increases the risk of sleep problems (Alvaro et al. 2014), mood disorders (Abreu and Braganca 2015; Adan et al. 2012; Au and Reece 2017), and metabolic disorders (Yu et al. 2015). Furthermore, people with evening chronotypes are more likely to engage in creative thinking (Giampietro and Cavallera 2007), and musicians have a tendency towards eveningness (Gjermunds et al. 2019).

Chronotype may also vary at different stages of development. Adolescence and young adulthood, which are transitional periods of substantial changes in sleep and circadian characteristics, tend to be associated with a later chronotype (Roenneberg et al. 2015). Meanwhile, college freshmen undergo significant changes during campus life, such as being free of parent-imposed constraints (Li et al. 2020). They are also in a unique transition stage from adolescence to mature adulthood, so they must deal with the new challenges of physiological changes, such as an intrinsic delay in the circadian rhythm (Qu et al. 2022). Furthermore, lifestyle factors associated with evening chronotypes, such as irregular sleep-wake schedule, increased use of alcohol, and increased use of electronics later at night (Fabbian et al. 2016), increase the risk of mental health problems (Li et al. 2020). Thus, to promote healthy development and inform a scientific schedule, it is necessary to evaluate college freshmen chronotypes in a timely and accurate manner.

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Objective and subjective measures have been developed to examine chronotypes. Dim light melatonin onset (DLMO) is considered the gold standard of measurement of circadian phases (Keijzer et al. 2014; Pandi-Perumal et al. 2007), and can be detected in saliva, periodic blood, and urine samples (Burgess and Eastman 2005). Although these collection methods may provide accurate chronotype information, they are time-consuming, cumbersome, and expensive. This drawback limits chronotype determination in laboratory experiments to small samples (Adan et al. 2012). Recently, self-reported chronotype-related questionnaires have become the most widely used measure in extensive sample studies because of their flexibility and practicality (Roenneberg et al. 2015). The Morningness-Eveningness Questionnaire (MEQ) is the most common and was developed by Horne and Ostberg (1976). A reduced version (rMEQ) containing five items has been tested (Adan and Almirall 1991; Danielsson et al. 2019). However, the MEQ has been criticized in previous studies suggesting that the items of the MEQ are subjective (e.g., "approximately what time would you get up if you were entirely free to plan your day?") and did not explicitly assess the actual sleep-wake behavior associated with chronotypes (Bauducco et al. 2020). Moreover, the MEQ ignores crucial indicators, such as weekday-weekend differences in sleep patterns (Allebrandt and Roenneberg 2008), a characteristic of individuals with evening chronotypes (Roepke and Duffy 2010).

The Munich Chronotype Questionnaire (MCTQ), designed by Roenneberg et al. (2003), compensates for this deficiency of the MEQ. The MCTQ is composed of the mid-sleep on free days (midway between sleep onset and sleep offset) corrected for sleep debt on weekdays (MSFsc), the mid-sleep point on free days (MSF), and mid-sleep on workdays (MSW). The great advantage of the MCTQ is that it evaluates chronotypes based on local time and an individual's actual behavior. The questionnaire can gather information about sleep and activity times separately for work and free days per week (Roenneberg et al. 2015). Additionally, MSF may be overestimated as a chronotype marker because most people tend to compensate for sleep debt on a - free day. Therefore, MSFsc, the mid-sleep on free days (midway between sleep onset and sleep offset) corrected for sleep debt on weekdays, was suggested as the most important chronotype index, with higher scores representing a stronger evening tendency. Importantly, MSFsc can be computed when people do not use an alarm clock during a free day, considering the impact of alarm clocks, thereby identifying a more accurate entrained chronotype without social constraints. To promote the development and use of the MCTQ in the Chinese population, we examined the validity of the MCTQ against subjective questionnaires (sleep quality, depression, and trait anxiety) and objective measures (i.e., actigraphy). Previous evidence has shown an association between chronotype and sleep quality, depression, and anxiety (Bauducco et al. 2020; Taylor and Hasler 2018; Tian et al. 2020). Moreover, MCTQ variables have shown a good correlation with actigraphy parameters (Cheung et al. 2022). In the current study, we hypothesized that the MCTQ would have good validity against subjective variables (sleep quality, depression, and trait anxiety) and objective measures (i.e., actigraphy).

Although much evidence has shown the validity of the MCTQ in different cultures (Cheung et al. 2022; Farkova et al. 2020; Jankowski 2016; Kitamura et al. 2014; Suh et al. 2018), no study has systematically compared the advantages and disadvantages of the MCTQ parameters (MSFsc, MSF, and MSW), and identified which parameter is the most appropriate for measuring chronotype. Therefore, we investigated which parameter is the most suitable for measuring chronotype amongst MSFsc and MSF. Most studies have used the MCTQ to calculate chronotypes, excluding people who used alarm clocks according to the use principle of the MCTQ (Cheung et al. 2022; Reis et al. 2020; Suh et al. 2018). However, this argument is inconsistent. It should be determined whether to adopt the standard alarm clock according to the sample of participants. The main reasons for this are as follows. First, previous evidence suggests no substantial differences in the relationship between MSFsc and other circadian measures when data from alarm clock users were also included (Cheung et al. 2022). It is theoretically possible to calculate chronotypes based on people who use alarm clocks on free days (Ghotbi et al. 2020). Additionally, alarm clock use is prevalent, and excluding the use of alarm clocks might limit the generalization of the MCTQ. Finally, Chinese college students generally live in four- or six-room dormitories (Wei and Chen 2019), and they usually have the same curriculum arrangement. The wakefulness of other roommates is similar to that of an alarm clock, making it less critical to use an alarm clock. Therefore, we did not determine whether the participants used alarm clocks in this study.

In summary, we aimed to: (1) explore the chronotype characteristics of college freshmen, (2) examine the validity of the MCTQ against subjective questionnaires, (3) validate the MCTQ against objective measures (e.g., actigraphy), and (4) explore whether adding alarm clocks has any effect on the results.

## Methods

### Translation of the MCTQ

After consulting the original author and obtaining consent, the English version of the questionnaire was translated into Chinese by a bilingual psychologist. When translating, it is very important to try not to change the semantic meaning and comply with local context expression habits. Subsequently, according to this principle, a second translator completed the back-translation into English. A pilot study was conducted using the initial Chinese version of the MCTQ. Twenty undergraduate students completed the initial version. We modified the language of the scale again according to the feedback and verified the semantic validity. After reviewing the back-translated English version and repeated comparisons such as comprehensibility, the final version of the MCTQ in Chinese was the questionnaire used in this study (see Supplementary Material).

### Participants and procedure

The sample for this study was derived from the Behavioral Brain Research Project of Chinese Personality (BBP) (Wang et al. 2022). All participants were recruited from Southwest University in Chongqing, China. Participants completed a set of self-report online questionnaires between September 2019 and January 2022. In the initial survey, 1245 college freshmen completed the questionnaires and wore an actigraph for 5 days. This study was approved by the appropriate Ethics Committee of Southwest University (H20059). All participants provided written informed consent after a detailed explanation of the study. If they felt uncomfortable, they were allowed to withdraw from the study at any time.

Three sequential studies were conducted in total. In Study 1, we examined the chronotype of college freshmen (sleep mid-point) and assessed the validity of MCTQ using subjective questionnaires and objective measures. One hundred and seventy-nine participants were excluded because they did not complete the questionnaire items. The final sample comprised 1066 college freshmen (69.6% female, mean age 21.12 years). Study 2 used daily sleep diary records to verify the MCTQ. Six hundred and seventy-eight participants completed the morning sleep diary (see Measurements for more details) between October 2020 and January 2021. Only 464 people (female = 71.0%; mean age = 20.63 ± 1.77 years) completed a prospective 5-day sleep diary. The participant retention rate was 68.44%. For Study 3, to verify the test-retest reliability of the MCTQ, 336 students were assessed 2 years later (October 2021). Seventy-five percent of the subjects were females (mean age = 21.38 ± 0.81 years).

### Measurements

Subjective measures in this study included basic demographics (age and sex), daily sleep diaries, the MCTQ, rMEQ, and external validity variables. The objective measures included actigraphy (wGT3×-BT; Actigraph, Pensacola, FL). Participants were asked to wear the actigraph for 5 consecutive days, from Friday evening to Wednesday evening of the following week (24 h per day).

### Munich chrono type questionnaire

The MCTQ estimates chronotype by measuring actual sleep timing separately for work and free days (Roenneberg et al. 2003). Chronotype parameters included MSFsc, MSF, and MSW, which were calculated based on the timing of sleep onset (SO) and sleep end (SE). The mid-point of sleep was mid-way between sleep onset and offset. For example, if the sleep onset was at 10:00 pm and the offset was at 7:00 am, the mid-point of sleep was 2:30 am. In addition, the time was converted to numeric values by taking hours plus minutes as a fraction of 60. For example, 2:30 is equal to 2.5. We used the same method to calculate the mid-point of sleep in a sleep diary. MSF was used as a chronotype marker if sleep duration on workdays was longer than or equal to sleep duration on free days, and if sleep duration on free days was longer than on workdays, MSFsc was used as the core chronotype marker. The MCTQ was used in all three studies.

### Reduced morningness-eveningness questionnaire

The 19-item original MEQ can take time to respond; therefore, shorter MEQ versions were introduced, including four items (Jankowski 2013), five items (Adan and Almirall 1991), and six items (Hätönen et al. 2008). We used the 5-item rMEQ version in this study (Adan and Almirall 1991). It consists of five items evaluating an individual's chronotype rated on a 4- or 5-point-Likert scale. Each item was summed to generate aggregate scores between 4 and 25, with higher scores representing a stronger morning preference. Individuals were categorized as evening-type (scores between 4 and 11), neutral-type (scores between 12 and 17), or morning-type (scores between 18 and 25). The Chinese version of the rMEQ has been shown to have good psychometric properties (Carciofo et al. 2012). The rMEQ was used only in Study 1.

### Actigraphy

Objective sleep measurements were obtained using the wGT3×-BT, an actigraphy device with good reliability and validity against polysomnography estimates (Wang et al. 2021). ActiLife software and manufacturer algorithms for detecting sleep based on 60-second epochs were used to score the sleep data. Specifically, whether the epoch was identified as "wake" or "sleep" was determined by comparing counts for epochs in question and those immediately surrounding it to a threshold value following the formula validated by the Cole – Kripke algorithm (Cole et al. 1992). In this study, participants were asked to wear the actigraph from 19:00 h on Friday to 19:00 h on the following Wednesday. The mean mid-point of sleep, as calculated by actigraphy ($MS_{actigraphy}$), was the average of the mid-points of sleep over 5 days. Epoch-by-epoch activity data were exported for circadian rhythm computation using nonparametric analyses. The least active 5-h midpoint (L5) and the most active 10-h mid-point (M10) were calculated from the nonparametric analysis (Ferreira et al. 2019). Actigraphy parameters including $MS_{actigraphy}$, L5, and M10 were used in Study 1.

### Measures of external validity variables

We used the following three scales to test the external validity of the MCTQ. The Pittsburgh Sleep Quality Index (PSQI) was used to measure participants' sleep quality during the past month. This scale includes seven dimensions: subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction. The total score ranges from 0 to 21, with higher scores reflecting poorer sleep quality. The Chinese version of the PSQI has been widely used and has shown good psychometric properties in previous studies (Liu et al. 1996).

The Self-rating Depression Scale (SDS) consists of 20 items and is a 4-point Likert scale that evaluates an individual's mood symptoms in the past week. The scores for each of the 20 items were added to obtain the raw score, and the standard score was equal to the raw score multiplied by 1.25. The Chinese version of the SDS has shown good reliability and validity in previous studies (Shao et al. 2020; Zhang et al. 2020).

The State-trait Anxiety Inventory Trait version (STAI) measures state and trait anxiety. It consists of 40 items (Spielberger and Gorsuch 1970). The 20-item Trait Anxiety Version was used in this study. All items are rated on a 4-point Likert scale, with higher scores representing more severe anxiety tendencies. The Chinese version of the STAI has good psychometric properties (Han et al. 2020).

### Sleep diary

In Study 2, participants were asked to fill out a sleep diary immediately after waking each day to maximize their recall accuracy. Most of the participants in this study attended classes from Monday to Friday and were asked to complete a sleep diary from Friday evening to the following Wednesday (5 consecutive days). We classified Wednesdays through Fridays as workdays and Saturdays through Sundays as free days. The sleep diary includes standard sleep parameters, such as bedtime, sleep onset latency, sleep, and wake time, which were used to calculate the time elapsed from reported bedtime to rise time minus awake time (in hours), and the mid-point of sleep.

### Statistical analysis

First, the descriptive characteristics of the sample were summarized. A paired sample t-test was used to compare the statistical differences between the two variables. The effect sizes of the significant differences were tested in terms of Cohen's $d$ value, with Cohen's $d$ indicating small ($d > 0.2$), medium ($d > 0.5$), and large effects ($d > 0.8$). A Pearson correlation analysis between MCTQ, rMEQ, mid-sleep point of actigraphy, external validity variables, and mid-sleep point of a sleep diary was used to evaluate the validity of MCTQ parameters. Moreover, the association of MCTQ parameters and circadian measures with or without alarm clocks was used to explore whether adding alarm clocks affected the results. Additionally, the test-retest reliability of the MCTQ parameters was performed. Finally, the advantages and disadvantages of MSFsc and MSF were compared. Data analyses were completed using SPSS software (version 25.0; IBM, Armonk, NY).

## Results

### Study 1: validity of the MCTQ against rMEQ, actigraphy, and external validity variables

#### Sample characteristics

Table 1 shows the descriptive statistics for the MCTQ sleep and circadian parameters. For college freshmen, the mean MSFsc was 4.32, the average MSF score was 4.70, and the average MSW score was 3.77. The data show that participants slept later on weekends than on

**Table 1.** Descriptive statistics of multiple chronotype variables (n = 1066).

| Variables | Measures | Minimum | Maximum | Mean (*SD*) |
|---|---|---|---|---|
| MSFsc | MCTQ | 1.39 | 9.94 | 4.32(0.84) |
| MSF | MCTQ | 2.46 | 10.00 | 4.70(0.94) |
| MSW | MCTQ | 1.50 | 6.25 | 3.77(0.58) |
| rMEQ | rMEQ | 5.00 | 22.00 | 13.58(2.80) |
| $MS_{actigraphy}$ | Actigraphy | 2.41 | 7.90 | 4.26(0.72) |
| L5 | Actigraphy | 2.00 | 11.00 | 4.41(0.72) |
| M10 | Actigraphy | 11.00 | 23.00 | 16.40(1.91) |

MSFsc = midpoint of sleep on free days corrected for sleep debt accumulated through weekdays; MSF = mid-sleep on free days; MSW = mid-sleep on workdays; rMEQ = reduced Morningness-Eveningness Questionnaire; $MS_{actigraphy}$ = the mid-sleep point of actigraphy; L5 = the least active 5-hour midpoint; M10 = the most active 10-hour midpoint.

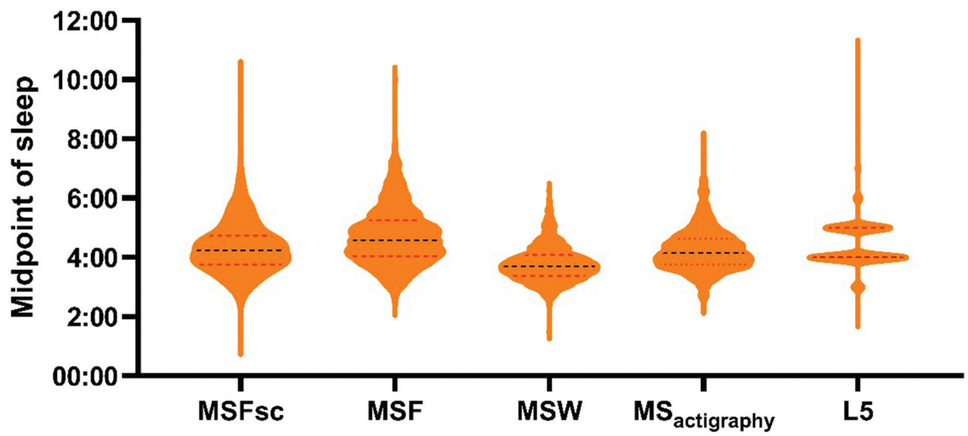


**Figure 1.** The violin plot of the mid-sleep point variables.

weekdays. MCTQ parameters displayed an approximately normal distribution. As shown in Figure 1, the mid-point of sleep was significantly delayed by nearly an hour on free days ($t_{1065} = 41.50$, $p < 0.001$, Cohen's $d = 1.27$) than on workdays. MSF scores were significantly higher than MSFsc scores ($t_{1065} = 34.57$, $p < 0.001$, Cohen's $d = 1.06$). L5 scores ($t_{1065} = 3.22$, $p < 0.01$, Cohen's $d = 0.99$) were significantly lower than MSFsc scores. MSF ($t_{1065} = 17.35$, $p < 0.001$, Cohen's $d = 0.53$) and MSFsc ($t_{1065} = 2.82$, $p < 0.01$, Cohen's $d = 0.09$) scores were significantly lower than $MS_{actigraphy}$ scores. Except for the small effect size between the MSFsc and $MS_{actigraphy}$ groups, the effect sizes between the other groups were medium and large. $MS_{actigraphy}$ and L5 were the closest to MSFsc.

### *Validity of MCTQ against rMEQ*

The correlations between MCTQ parameters and rMEQ scores (n = 1066) are presented in Table 2. Higher rMEQ scores, indicating morningness, were significantly related to earlier MSW ($r = -0.45$, $p < 0.01$), MSF ($r = -0.55$, $p < 0.01$), and MSFsc ($r = -0.51$, $p < 0.01$). MSF showed the strongest association with rMEQ scores compared with MSFsc.

### *Validity of MCTQ against objective measures: actigraphy*

Table 3 and Figure 2 show the relationships between MCTQ parameters and sleep variables based on actigraphy. The average mid-point of sleep computed from actigraphy ($MS_{actigraphy}$) was also significantly and

**Table 2.** Association of MCTQ parameters and rMEQ (n = 1066).

| Variables | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1. MSFsc | 1.00 | | | |
| 2. MSF | 0.93** | 1.00 | | |
| 3. MSW | 0.67** | 0.64** | 1.00 | |
| 4. rMEQ | −0.51** | −0.55** | −0.45** | 1.00 |

MSFsc = midpoint of sleep on free days corrected for sleep debt accumulated through weekdays; MSF = mid-sleep on free days; MSW = mid-sleep on workdays; rMEQ = reduced Morningness-Eveningness Questionnaire. ***p* < 0.01.

**Table 3.** Association of actigraphy and validity measures with MCTQ parameters.

| Variables | MSFsc | MSF | MSW |
|---|---|---|---|
| **Objective measures** | | | |
| $MS_{actigraphy}$ | 0.53** | 0.53** | 0.49** |
| L5 | 0.44** | 0.44** | 0.44** |
| M10 | 0.14** | 0.15** | 0.12** |
| **Subjective measures** | | | |
| PSQI | 0.24** | 0.27** | 0.27** |
| SDS | 0.14** | 0.15** | 0.12** |
| STAI-T | 0.13** | 0.13** | 0.13** |
| $MS_{diary}$ | 0.54** | 0.52** | 0.47** |

MSFsc = midpoint of sleep on free days corrected for sleep debt accumulated through weekdays; MSF = mid-sleep on free days, MSW = mid-sleep on workdays; $MS_{actigraphy}$ = the mid-sleep point of actigraphy; L5 = the least active 5-hour midpoint; M10 = the most active 10-hour midpoint; PSQI = Pittsburgh Sleep Quality Index; SDS = Self-rating depression scale; STAI-S = State-Trait Anxiety Inventory-State version; $MS_{diary}$ = the mid-sleep point of sleep diary. ***p* < 0.01.

positively correlated with all MCTQ parameters (MSW: r = 0.49; MSF: r = 0.53; MSFsc: r = 0.53; all $p < 0.01$). Earlier $MS_{actigraphy}$ was associated with earlier MSW, MSF, and MSFsc. L5 and M10 correlated with MSW, MSF, and MSFsc (r = 0.13 to 0.73, all $p < 0.01$). Earlier L5 and M10 were related to earlier MSW, MSF, and MSFsc. Indeed, MSF and MSFsc showed consistent correlations with $MS_{actigraphy}$ (r = 0.53) and L5 (r = 0.44). MSF showed a stronger association with M10 than MSFsc [(MSF:0.15) (MSFsc:0.14)].

### *Validity of MCTQ against external validity variables*

Table 3 shows the association between the MCTQ parameters and external validity variables. The MSFsc, MSF, and MSW scores from the MCTQ were significantly positively correlated with sleep quality, depression, and trait anxiety. Later MSFsc, MSF, and MSW were found to be related to worse sleep quality, more depression, and trait anxiety. The MSFsc was significantly correlated with sleep quality (r = 0.24, $p < 0.01$), depression (r = 0.14, $p < 0.01$), and trait anxiety (r = 0.13, $p < 0.01$). The MSF was significantly correlated with sleep quality (r = 0.27, $p < 0.01$), depression (r = 0.15, $p < 0.01$), and trait anxiety (r = 0.13, $p < 0.01$). MSW was significantly associated with sleep quality (r = 0.27, $p < 0.01$), depression (r = 0.12, $p < 0.01$), and trait anxiety (r = 0.13, $p < 0.01$) scores. It is worth noting that MSF showed a stronger association with depression than did MSFsc and MSW.

### *Use of alarm clocks*

In Study 1, participants were divided into a group that used alarm clocks on free days (n = 600, 56.29%) and a group that did not use alarm clocks (n = 466, 43.71%). The associations between MCTQ parameters and circadian measures with non-alarm and alarm clocks are shown in Table 4. The results showed no substantial

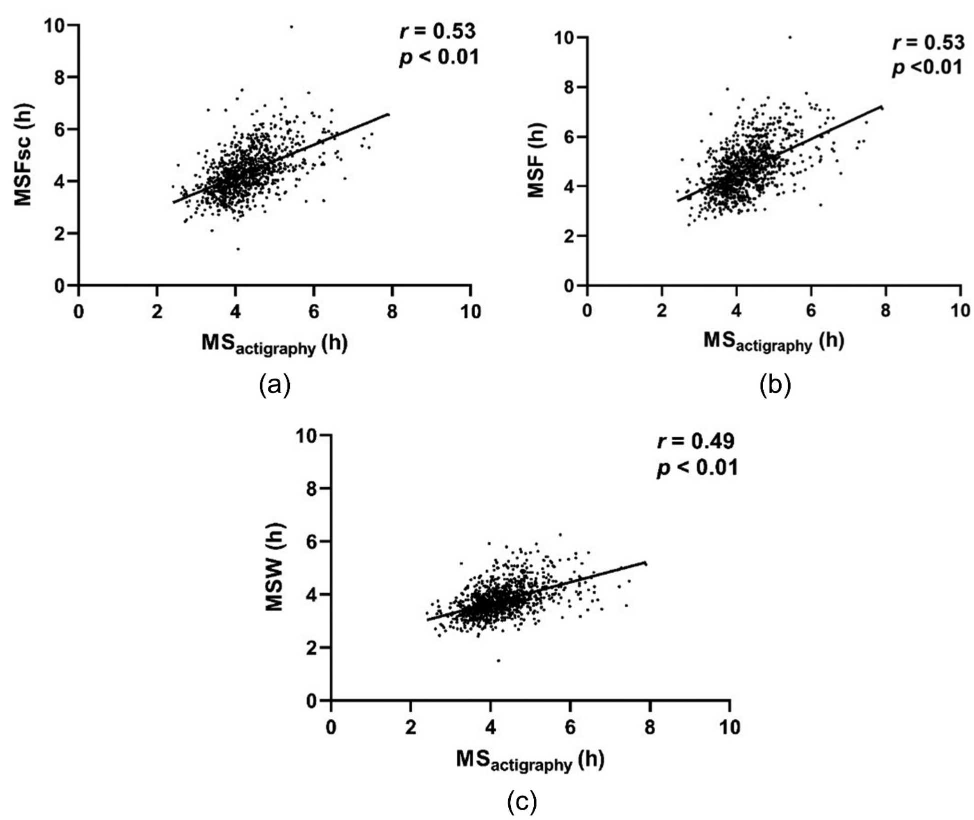


**Figure 2.** The correlation of MSactigraphy with MCTQ parameters.

**Table 4.** Association of MCTQ parameters and circadian measures with or without alarm clocks.

| Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Without alarm clocks (n = 600) | | | | | | | |
| 1. MSFsc | 1.00 | | | | | | |
| 2. MSF | 0.92** | 1.00 | | | | | |
| 3. MSW | 0.67** | 0.64** | 1.00 | | | | |
| 4. rMEQ | −0.53** | −0.58** | −0.49** | 1.00 | | | |
| 5. $MS_{actigraphy}$ | 0.51** | 0.52** | 0.47** | −0.40** | 1.00 | | |
| 6. L5 | 0.44** | 0.42** | 0.45** | −0.33** | 0.72** | 1.00 | |
| 7. M10 | 0.15** | 0.16** | 0.13** | −0.07 | 0.20** | 0.12** | 1.00 |
| With alarm clocks (*n* = 466) | | | | | | | |
| 1. MSFsc | 1.00 | | | | | | |
| 2. MSF | 0.93** | 1.00 | | | | | |
| 3. MSW | 0.68** | 0.64** | 1.00 | | | | |
| 4. rMEQ | −0.47** | −0.51** | −0.38** | 1.00 | | | |
| 5. $MS_{actigraphy}$ | 0.55** | 0.55** | 0.52** | −0.34** | 1.00 | | |
| 6. L5 | 0.46** | 0.46** | 0.44** | −0.28** | 0.75** | 1.00 | |
| 7. M10 | 0.14** | 0.15** | 0.12** | −0.18** | 0.23** | 0.14** | 1.00 |

MSFsc = midpoint of sleep on free days corrected for sleep debt accumulated through weekdays; MSF = mid-sleep on free days; MSW = mid-sleep on workdays; rMEQ = reduced Morningness-Eveningness Questionnaire; $MS_{actigraphy}$ = the mid-sleep point of actigraphy; L5 = the least active 5-hour midpoint; M10 = the most active 10-hour midpoint. ***p* < 0.01.

difference between people who used alarm clocks and those who did not.

### *Study 2: validity of MCTQ against subjective measures: sleep diary*

The Pearson correlation analysis between MCTQ parameters and sleep diary variables (n = 464) is shown in Table 3. The mean mid-point of sleep derived from the sleep diary ($MS_{diary}$) was significantly and positively correlated with MSFsc (r = 0.54, $p < 0.01$), MSF (r = 0.52, $p < 0.01$), and MSW (r = 0.47, $p < 0.01$). Interestingly, MSFsc showed a stronger association with $MS_{diary}$ than with MSF.

### *Study 3: test-retest reliability of the MCTQ*

The test-retest reliability of the MCTQ is shown in Table 5. Specifically, the MCTQ variables were highly correlated between baseline (T1) and 2-year follow-up (T2) [MSFsc (r = 0.51, $p < 0.01$); MSF (r = 0.58, $p < 0.01$); and MSW (r = 0.29, $p < 0.01$)]. The test-retest reliability of the MSF was higher than that of the MSFsc.

## Discussion

In this study, we used a large sample to investigate the chronotype of college freshmen (sleep mid-point) and assess the validity of the MCTQ. In Study 1, the MCTQ was significantly associated with the rMEQ, $MS_{actigraphy}$, circadian rhythm parameters including L5 and M10, and external validity variables, including sleep quality, depression, and trait anxiety. We compared the validity of the MCTQ against the sleep diary in Study 2, demonstrating that all MCTQ variables were significantly associated with $MS_{diary}$. In addition, we examined the test-retest reliability of the MCTQ variables in Study 3, and the test-retest reliability was acceptable. In conclusion, the MCTQ is a vital instrument and an excellent chronotype assessment tool.

### *Validity of MCTQ against rMEQ*

The MCTQ parameters MSFsc, MSF, and MSW were significantly correlated with the total rMEQ score, which is consistent with recent studies (Cheung et al. 2022; Reis et al. 2020). Specifically, although the correlation between MSW and rMEQ in this study was moderate (<0.5), both MSFsc and MSF were highly

**Table 5.** Test-retest reliability of MCTQ (*n* = 336).

| Variables | MSFsc_T1 | MSF_T1 | MSW_T1 | MSFsc_T2 | MSF_T2 | MSW_T2 |
|---|---|---|---|---|---|---|
| MSFsc_T1 | 1.00 | | | | | |
| MSF_T1 | 0.93** | 1.00 | | | | |
| MSW_T1 | 0.64** | 0.63** | 1.00 | | | |
| MSFsc _T2 | 0.51** | 0.54** | 0.33** | 1.00 | | |
| MSF_T2 | 0.52** | 0.58** | 0.33** | 0.92** | 1.00 | |
| MSW_T2 | 0.38** | 0.40** | 0.29** | 0.73** | 0.62** | 1.00 |
| Mean | 4.19 | 4.55 | 3.69 | 4.74 | 5.11 | 4.18 |
| SD | 0.71 | 0.81 | 0.51 | 0.75 | 0.86 | 0.62 |

MSFsc: midpoint of sleep on free days corrected for sleep debt accumulated through weekdays; MSF = mid-sleep on free days; MSW=mid-sleep on weekdays; T1 = baseline; T2 = two year follow up. ***p* < 0.01.

correlated with rMEQ, similar to the results of previous studies. The results indicated that the MCTQ and rMEQ had similarities and differences in many aspects. The most fundamental difference between them was that the MCTQ measures actual behavior and activity time, while the rMEQ measures individual chronotype preference, which is more subjective. It is reasonable to assume that the two results are not strongly correlated.

### Validity of the MCTQ against actigraphy

We found that the effect size of the difference between MSF and $MS_{actigraphy}$ was large. However, the effect size of the difference between MSFsc and $MS_{actigraphy}$ was small, suggesting that the difference between the mean value of the two groups may not be of practical significance. Notably, MCTQ variables were significantly correlated with circadian indicators, including objective ($MS_{actigraphy}$, L5, and M10) and subjective measures ($MS_{diary}$). Previous evidence supports the association between MCTQ and actigraphy parameters, including L5 and M10 (Jankowski 2016; Ruiz et al. 2020; Schneider et al. 2022). On the one hand, the results showed that MSF and MSFsc were highly correlated with $MS_{diary}$ and $MS_{actigraphy}$, indicating the chronotype's stability. Furthermore, compared to rMEQ, MCTQ parameters showed a much stronger correlation with the above circadian indicators. This comparison indicates that MCTQ parameters are more objective than rMEQ and can measure the characteristics of individuals' circadian rhythms.

On the other hand, correlations have confirmed evidence from more recent approaches showing that nonparametric circadian computation (L5 and M10) can provide accurate estimates of circadian characteristics (Van Someren et al. 1999; Xiao et al. 2022). Specifically, L5 showed a stronger association with MCTQ parameters than M10, which is consistent with recent evidence (Cheung et al. 2022). Because M10 measures the middle time of the most active 10-h period, it is more sensitive and affected by individual differences in active and sedentary lifestyles, and it may be less accurate in estimating the circadian phase.

### Validity of MCTQ against external validity variables

We also evaluated the external validity of the MCTQ. We found that the correlations between MCTQ variables and sleep quality, depression, and trait anxiety were significant. The later the individuals went to bed (and the more they tended to be nocturnal), the more sleep problems, depression, and restlessness they experienced. Consistent with previous studies, this outcome demonstrates that chronotypes are associated with sleep quality (Tian et al. 2020), depression (Bauducco et al. 2020), and anxiety (Taylor and Hasler 2018). Furthermore, college students with poor sleep quality, depression, and anxiety tend to experience more negative emotions, affecting their mental health. Therefore, it is vital to assess the relationship between chronotype and psychological disturbances to reduce the impact of nocturnal tendencies on mental health.

Our results suggest a more significant proportion of evening chronotype tendencies in college freshmen, consistent with previous findings that chronotype changes systematically with age, reaching a maximum nocturnal propensity at approximately 20 years of age (Roenneberg et al. 2004). New undergraduates must deal with challenges including new social environments, demanding classes, and homesickness (Zhou et al. 2020), and their lifestyles and general habits may affect their circadian rhythms. For instance, Chinese universities have at least four students in each dormitory. To maintain good interactions and relationships with roommates, individuals with other chronotypes may adjust to the circadian rhythms of others. Moreover, using mobile phones to play games, surf the Internet, and text in bed before sleep also leads to later sleep (Fossum et al. 2014). We focused only on college freshmen in this study, and the ratio of eveningness is likely to increase as they accumulate experience in college. Hence, it is indispensable for college freshmen to arrange their study and rest times reasonably, reduce staying up late, and form a good work and rest system.

### Use of alarm clocks

As stated, to explore whether adding alarm clocks affected the results, participants who used alarm clocks were not excluded from the study ($n = 466$, 43.71%). Study 1 divided participants into a group that used alarm clocks on free days and a group that did not use alarm clocks. The results showed no substantial difference in the correlation between people who use alarm clocks and those who do not, especially the correlation between MCTQ variables and circadian measures (see Table 4), which was consistent with previous evidence (Cheung et al. 2022). On the one hand, Chinese college students often live in four- or six-room dormitories. As long as one person in the dormitory sets an alarm clock, other members will be affected by the alarm clock. Therefore, the use of alarm clocks did not have a significant impact on the sleep schedule. On the other hand, this finding supports the view that chronotypes can be calculated based on people who use alarm clocks on a free day. Frequent use of alarm clocks in modern society may limit the use of MCTQ in certain groups. If the influence of the alarm clock is not considered, it can promote the application of MCTQ to a wider range of population samples. In summary, more research is needed in the future to test and verify these results in different populations.

### *Test-retest reliability of the MCTQ*

To the best of our knowledge, previous studies have measured the test-retest reliability of the MCTQ with an interval of several months (e.g., 3 months) (Reis et al. 2020). However, the test-retest reliability assessments for the MCTQ in this study were performed over a long period of time, and good test-retest reliability was demonstrated over 2 years. Conceptually, MCTQ reflects the temporary state properties of chronotypes rather than a permanent trait (Roenneberg et al. 2019). The low stability of the current study (e.g., MSW = 0.29) may be due to the long interval between baseline and follow-up, during which college students changed their sleep time because of course schedules, life patterns, and other reasons. Course schedules varied from freshmen to senior students, with a progressive increase in course load at the expense of free time. However, after they enter their junior year, students have fewer courses (such as only a small number of internship courses) and more free time after their sophomore year. The test-retest reliability of the MSF was higher than that of the MSFsc. On the one hand, it may indicate the higher stability of MSF; on the other hand, possibly because college students usually have no classes on weekends, and even after a 2-year gap, they are not affected by the course schedule. The weekly schedule may be different, forcing college students to get up early on weekdays and accumulate sleep debt.

### *Comparison of the MSFsc and MSF*

According to Roenneberg et al. (2015), the MSFsc has two advantages. It considers the impact of sleep debt and controls the use of an alarm clock. Most studies have shown that MSF has a higher correlation with criteria other than MSFsc (Reis et al. 2020; Santisteban et al. 2018; Suh et al. 2018), whereas only one study from Japan showed a higher correlation between MSFsc and DLMO than MSF (Kitamura et al. 2014). In this study, we compared MSFsc and MSF. As reported in previous studies (Cheung et al. 2022; Di Milia et al. 2013), the correlation between MSF and rMEQ scores was more robust than MSFsc. The calculation of MSFsc may be significantly influenced by sleep debt. If there is a considerable discrepancy between weekday and weekend sleep, this may lead to a correlation difference between them. Moreover, interpreting simple correlations is challenging. Specifically, the advantages of MSFsc include the following: the effect size of the significant difference between MSFsc and $MS_{actigraphy}$ was small; MSFsc was closer to some objective parameters, such as $MS_{actigraphy}$ and L5; and MSFsc showed a stronger association with $MS_{diary}$ than MSF. The advantages of MSF include the following: the effect size of the significant difference between MSF and $MS_{actigraphy}$ was large; MSF had a stronger association with rMEQ scores than did MSFsc, and the test-retest reliability of MSF was higher than that of MSFsc. For MSFsc and MSF, the correlation does not become a criterion for measuring, which is better. However, the results demonstrated MSFsc as the core marker of chronotype in MCTQ if sleep duration on a free day is longer than that on a weekday. Furthermore, compensatory sleep is very common during free time on weekdays, especially among college students, which may lead to inaccurate overestimation of MSF as a chronotype marker due to the extension of free day sleep. Therefore, MSFsc may be more accurate than MSF in many applications.

## Limitations

This study had several limitations. First, although this study used actigraphy to confirm the validity of MCTQ, it did not accurately measure the circadian phase (e.g., DLMO). Although actigraphy may be less accurate than biochemical measurement owing to its algorithm and other reasons, it is affordable, easy to wear, and suitable for application in large-scale studies. Second, while this study provides insight into determining the chronotype of Chinese college students, caution should be exercised when generalizing these results to other samples. However, different samples need to be verified in future studies. Third, the data collection period was relatively long. Although all subjective questionnaires were collected on the same day, actigraphy and sleep diary collection might have been completed after an interval of 3 months. Nevertheless, we believe that individual characteristics such as chronotype and rhythm may have considerable stability in a specific environment. Fourth, the course arrangement of college freshmen, which had a significant impact on this study, was not collected in this study.

## Conclusion

The MCTQ was highly correlated with subjective measures (rMEQ, sleep diary, and external validity variables) and objective measures (actigraphy). Verification of the MCTQ with an interval of 2 years indicated good test-retest reliability. In addition, it is necessary to consider a sleep debt correlation, although MSF performs better than MSFsc on many related metrics. MCTQ is a good tool for measuring chronotypes and can be used in large-scale clinical and epidemiological studies. Its development is important for the accurate assessment of chronotypes and clinical diagnoses of sleep.

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