CHRONOBIOLOGY INTERNATIONAL
https://doi.org/10.1080/07420528.2022.2025821

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ORIGINAL ARTICLE

Validation of the Chinese version of the Munich Chronotype Questionnaire (MCTQ^{HK}) in Hong Kong Chinese youths

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ABSTRACT

Chronotype, referred to as an individual's diurnal preference of timing for rest and activity, can be subjectively measured using the Munich Chronotype Questionnaire (MCTQ). However, the validity of MCTQ has yet to be tested in the youth population. In addition, it remains uncertain if MCTQ is a good measure of chronotype in individuals with insomnia. The current study aimed to validate the Chinese version of MCTQ (MCTQ^{HK}) in the youth population and to explore the utility of MCTQ^{HK} in individuals with insomnia. The original MCTQ was translated into Chinese language using the translation-back-translation method. Part one of this study included 988 youths who completed a battery of self-report questionnaires online consisting of the MCTQ^{HK} and the morningness-eveningness questionnaire (MEQ) for the measures of circadian preference, Insomnia Severity Index (ISI) to assess insomnia symptoms, and Patient Health Questionnaire (PHQ-9) to measure depressive symptoms. Test–retest reliability was examined in 442 participants at one-month follow-up. Of the overall sample, 69 participants were randomly drawn to complete the second part of the study, which included prospective 7-day actigraphy monitoring and a further subset (n = 40) additionally completed a laboratory-based assessment of dim-light melatonin onset (DLMO) as a circadian phase marker. A total of 659 participants with valid responses were finally included in the analyses of the data collected from part one of the study (female = 67.7%; mean age: 20.7 ± 2.02). Results showed that MCTQ parameters, namely the midpoint of sleep on free days (MSF), midpoint of sleep on workdays (MSW), and midpoint of sleep adjusted for sleep debt (MSFsc), were significantly correlated with MEQ score (r = –.514 to –.650, $p < .01$). Test–retest reliability for MCTQ^{HK} was good (intraclass correlation = 0.75 to 0.84). Later MSFsc was significantly associated with greater insomnia and depressive symptoms after controlling for age and sex. All MCTQ parameters showed significant correlations with actigraphy-based midpoint of sleep and circadian rhythm parameters, i.e., acrophase and L5 onset (r = .362 to .619, $p < .01$), as well as DLMO (r = .393 to .517, $p < .05$). The associations remained significant after controlling for age. MSFsc derived from MCTQ was significantly correlated with MEQ score in both the healthy sleepers and participants with insomnia (as defined by ISI > 14), r = –.600, $p < .001$ and r = –.543, $p < .001$, respectively. The present study demonstrated that MCTQ^{HK} is suitable for assessing chronotype with good reliability and validity in Chinese youths and supported the utility of MCTQ^{HK} in individuals with insomnia.

ARTICLE HISTORY
Received 16 September 2021
Revised 24 November 2021
Accepted 16 December 2021

KEYWORDS
Adolescents; circadian; chronotype; dim-light melatonin onset; insomnia; Munich Chronotype Questionnaire

Introduction

Chronotype refers to the individual differences in preference of timing for rest and activities on a morningness-eveningness continuum. Previous research indicated that chronotype is an independent contributing factor of physical and mental wellbeing (Adan et al. 2012; Fabbian et al. 2016; Kivelä et al. 2018; Taylor and Hasler 2018), where later chronotype is associated with a greater risk of sleep problems (Alvaro et al. 2014), mood disorders (Au and Reece 2017), cardiovascular problems, and Type 2 diabetes (Merikanto et al. 2013). Youth is a unique transitional stage associated with substantial changes in sleep and circadian characteristics, including an increased prevalence of eveningness. Due to the biological factors, there is an intrinsic delay of circadian rhythm during adolescence, which is often further exacerbated by other psychosocial and environmental factors (e.g., increased electronic media use in the evening) (Crowley et al. 2014; Randler et al. 2017, 2016). The increase in prevalence in eveningness in adolescents is often associated with a constellation of negative consequences, such as a higher risk for sleep and mental health

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problems (Gau et al. 2007; Li et al. 2018), poorer academic performance (Preckel et al. 2011), and an increased risk for suicidality (Chan et al. 2020). As such, there is a need for timely and accurate assessment of chronotype in order to address this circadian issue in the context of youth mental health.

Chronotype can be measured objectively using circadian biomarkers and subjectively via self-report. Objectively, chronotype can be estimated using dim-light melatonin onset (DLMO) as a biomarker (Lewy and Sack 1989; Pandi-Perumal et al. 2007). The timing of DLMO reflects an individual's circadian phase. Despite being the gold-standard assessment of chronotype, DLMO assessment is a costly procedure that is time- and labor-intensive. It is consequently impractical to conduct routine laboratory DLMO assessments in the clinical settings and in the large epidemiological studies. The Morningness-Eveningness Questionnaire (MEQ) (Horne and Östberg 1976) represents one of the most frequently used self-report measures of chronotype. However, it has been criticized that the MEQ technically measures an individual's preference of circadian timing rather than the actual sleep-wake behavior associated with chronotype (Bauducco et al. 2020). In addition, the MEQ may have the limitation of overlooking the differences in sleep patterns between free days and workdays, which are particularly common in youths (Hysing et al. 2013) and individuals with late chronotype (Duffy and Roepke 2010; Wittmann et al. 2006).

In this regard, the Munich Chronotype Questionnaire (MCTQ) provides a more viable alternative to a quantifiable proxy to reflect the endogenous circadian rhythm. Developed by Roenneberg and colleagues (Roenneberg et al. 2003), the MCTQ collects data on the timing of sleep and wake independently for free days (i.e., with no obligation to social schedule) and workdays during the week. Sleep parameters including the timing of sleep onset and offset, total time in bed, and total sleep time for free days and workdays separately can be extracted from the questionnaire. The midpoint of sleep (midway between sleep onset and sleep offset) during free days (MSF) is considered as the parameter of chronotype. However, as compensatory sleep for sleep debt during the week is common on a free day, MSF as a chronotype marker might be inaccurately overestimated due to extended sleep during a free day. Hence, the midpoint of sleep adjusted for sleep debt accumulated during the workdays (MSFsc) is often used as the core marker of chronotype if sleep duration on a free day is longer than that of workdays. It has been recommended that MSFsc should only be computed when respondents do not use an alarm clock during a free day to reflect a more accurate entrained phrase without the influence of social constraints (Ghotbi et al. 2020).

MCTQ has been previously translated and validated in different countries, such as Japan (Kitamura et al. 2014), Poland (Jankowski 2016), South Korea (Ryu et al. 2018; Suh et al. 2018), and more recently in Portugal (Reis et al. 2020) and Czech Republic (Fárková et al. 2020). Some studies selectively utilized different circadian measures in the validation process, but none has comprehensively incorporated multiple subjective and objective circadian measures simultaneously. Furthermore, previous validation studies were conducted in samples with a wider age range (13–81 years) or in mixed age groups, with none focusing on the youth population. Given that the circadian presentation of youths (e.g., increased eveningness tendency) is expected to be different from that of other age groups (Crowley et al. 2014; Randjelovic et al. 2021), the lack of validation of chronotype measures in youth may hinder the development of circadian research in this population. In addition, recent community-based studies found that up to 37% of youths reported having at least one insomnia symptom (Chan et al. 2020; Li et al. 2018). Growing evidence also suggested that there is a strong bidirectional relationship between evening chronotype and insomnia (Flynn-Evans et al. 2017; Yazdi et al. 2014). Individuals with insomnia tend to have large day-to-day variability in sleep timing (Bei et al. 2016; Suh et al. 2012) and longer sleep onset latency (Natale et al. 2009). These sleep characteristics could potentially interfere with chronotype assessment, making it difficult to reliably assess circadian features via self-report in youth, which represents an age group with increased vulnerability to developing insomnia and eveningness. A previous study has shown that the concordance of chronotype classification between the MEQ and MCTQ was weaker in individuals with insomnia compared to healthy sleepers (Suh et al. 2017). This could be due to the differences in the constructs measured by the two scales. While the MEQ measures the individual preference of circadian timing, the MCTQ measures one's sleep-wake behaviors and timing. Longer sleep onset latency in people with insomnia could potentially influence the measure of chronotype when using the MCTQ. Given the high prevalence of insomnia in youths, there is a need for further research to explore the utility of MCTQ in assessing chronotype in young people with insomnia.

To address the existing research gaps, the primary aim of the current study was to validate a Chinese version of MCTQ (hereinafter as $MCTQ^{HK}$) in a community sample of youths by comparing it with subjective measures (i.e., MEQ and sleep diary) and objective measures (i.e., actigraphy and DLMO) of chronotype. Secondly, the present study also aimed to explore the utility of $MCTQ^{HK}$ in youths with insomnia symptoms.

Methods

The current study was approved by the Human Research Ethics Committee at The University of Hong Kong (EA1903024), and all the participants provided their written informed consent.

Scale translation and pilot study

Two trilingual research assistants fluent in English, Cantonese, and Mandarin completed the initial translation and back-translation of the original scale. The author (FC) reviewed the back-translated scale and compared the comprehensibility and the semantic meaning of the translated scale and adjusted the wordings to fit the local context. A pilot study was conducted with the translated Chinese version ($MCTQ^{HK}$). Twenty-two participants (female = 68%, mean age = 22.3 ± 2.46) took part in the pilot study and each was individually interviewed after completing the questionnaire to review their understanding of the semantic meaning of the questions. Although two previous validation studies based on Asian language translations (Japanese and Korean) reported that participants were often confused by the difference between time for getting into bed (Item 1: "I go to bed at . . . o'clock") and time to sleep (Item 2: "I actually get ready and fall asleep at . . . o'clock") (Kitamura et al. 2014; Suh et al. 2018), this was not observed in the current sample of the pilot study. The $MCTQ^{HK}$ was subsequently used in the validation study.

Part I – validation of MCTQ against MEQ

Participants and procedure

Potential participants were recruited from the community via social media promotion, flyers, and mass email circulated in the local institutions. The target study participants were youths aged 12–24 in the local secondary schools and universities. This age range was chosen to cover a wider developmental range of youth. Exclusion criteria included: being shift-workers and individuals who had trans-meridian travels in the past month. Eventually, 988 youths responded to the recruitment and completed an online questionnaire battery hosted on Qualtrics. The questionnaire battery included chronotype related measures (i.e., $MCTQ^{HK}$, MEQ), and the measures of insomnia (i.e., insomnia severity index [ISI] Bastien et al. 2001) and mood symptoms (i.e., Patient Health Questionnaire [PHQ-9] Kroenke et al. 2001). Among the respondents, 67 were excluded due to their age, nine shift workers were excluded, and 10 respondents were also excluded due to unrealistic and improbable responses (e.g., reporting both sleep time and wake time at 23:30 h). To align with previous validation studies, the chronotype proxy from MCTQ could only be accurately derived if the person indicated that they did not use an alarm clock during their free days. As such, 239 responses which indicated the use of an alarm clock on a free day were further excluded from the analysis, resulting a final sample of 663 participants. All the participants were invited through emails and phone calls to complete a one-month follow-up. The study flowchart is presented in Figure 1.

Measurements

Munich Chronotype Questionnaire (MCTQ). The MCTQ collected time variables (presented as clock time, hh:mm) of sleep and wake time separately for workdays and free days. Parameters reflecting chronotype included the midpoint of sleep during workdays (MSW) and during free days (MSF). MSW and MSF were calculated based on timing for sleep onset (SO) and sleep end (SE), where:

$$MSW = SO_w + (SE_w - SO_w)/2 \quad (1)$$

$$MSF = SO_f + (SE_f - SO_f)/2 \quad (2)$$

MSF corrected for sleep debt accumulated during the work week (MSFsc) was further adjusted using the weighted averaged sleep duration ($SD_{w.avg}$) during the week if sleep duration during free days (SD_f) were longer than that of workdays, where:

$$MSFsc = MSF - (SD_f - SD_{w.avg})/2 \quad (3)$$

MSFsc would be the same as MSF for individuals who had their sleep duration during free days the same or shorter than their sleep duration during workdays.

Morningness Eveningness Questionnaire (MEQ). The MEQ consisted of 19 items tapped into individuals' time preferences for completing certain social activities (Horne and Östberg 1976). The aggregate scores range from 16 to 86, where lower scores represent a higher tendency for eveningness. MEQ has been validated against other circadian measures (e.g., the composite scale of morningness, actigraphy) (Thun et al. 2012), and has been translated and validated in the Chinese population (Li et al. 2011). The internal consistency of MEQ for the current sample was $\alpha = 0.80$.

Measures on insomnia and mood symptoms. The 7-item ISI is a commonly used self-report scale designed to assess global symptom severity of insomnia. Aggregate scores range from 0 to 28, where higher scores indicate more severe insomnia

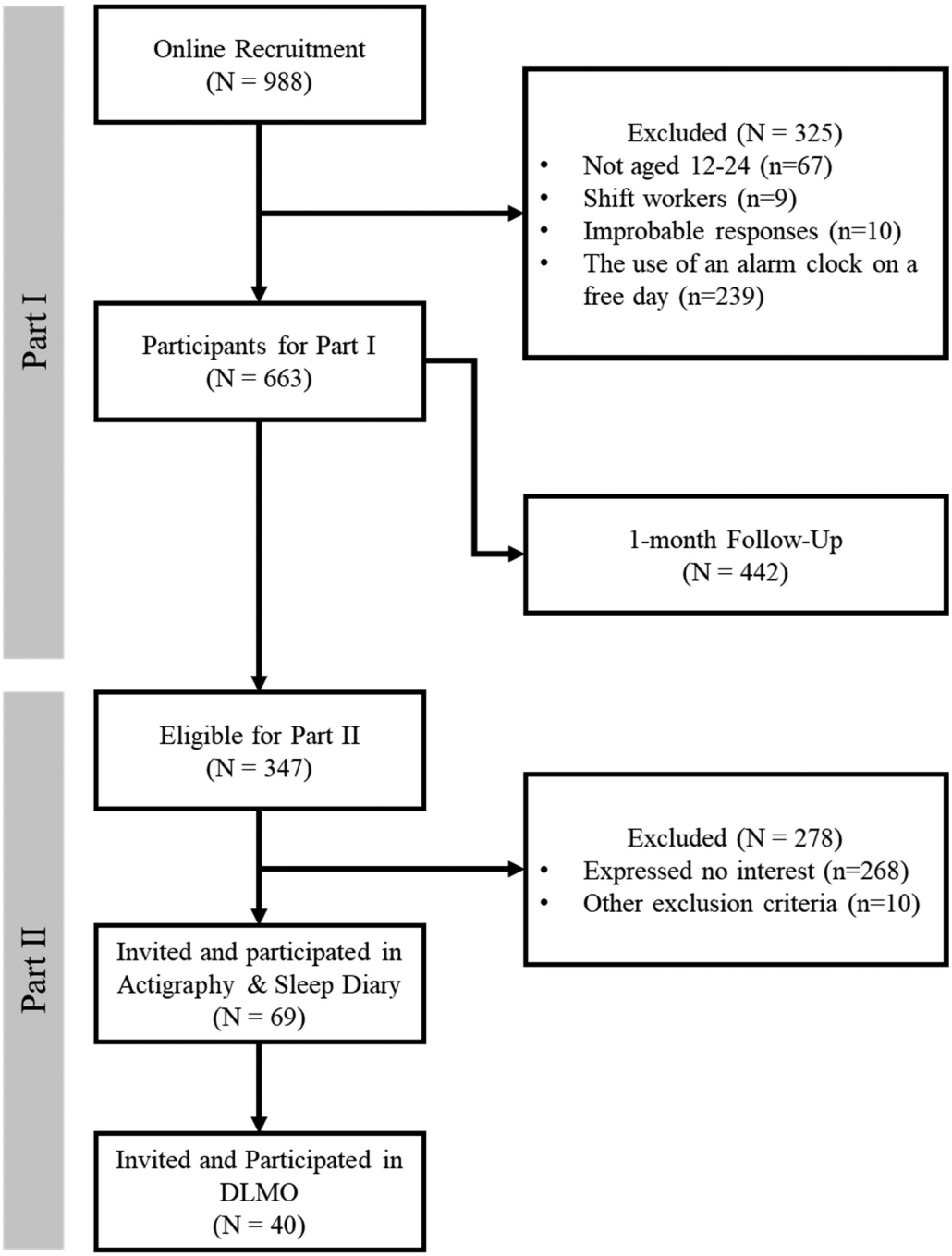

Figure 1. Study flowchart.

symptoms. A score of 14 or above on ISI indicated clinical insomnia (Bastien et al. 2001). The internal consistency of ISI for the current sample was α = 0.86. PHQ-9 is a widely used self-report scale that assesses depressive symptoms. The total scores range from 0 to 27, where higher scores indicate more severe depressive symptoms. The internal consistency of PHQ-9 for the current sample was α = 0.89.

Part II – validation of MCTQ against sleep diary, actigraphy, and dim light melatonin onset (DLMO)

Participants and procedure

A subset of eligible participants who took part in Part I of the study were randomly selected and further invited to participate in Part II of this study. Participants were deemed eligible if they completed Part I of the study and agreed to take further follow-up assessment conducted

by the research team. Participants were excluded if they had a medical condition that is known to affect normal hormone regulations (e.g., hypothyroidism), current or regular use of medications that might interfere with the melatonin rhythms (e.g., exogenous melatonin, NSAIDs, oral contraceptives), or if they were visually impaired (e.g., severe cataract, blindness). Of the 347 suitable participants, 69 were randomly selected and invited, and all agreed to partake in the second part of the study. All participants were asked to complete prospective 7-day actigraphy and sleep diary, and a further subset of these participants (n = 40) additionally completed a laboratory-based DLMO assessment. The median number of days between the completion of questionnaires and DLMO assessment was 8 days. Participants were given HK $500 (~ US $65) as an incentive for completing Part II of the study.

Measurement

Sleep diary. A consensus sleep diary (Carney et al. 2012) was provided to participants, and they were asked to complete the sleep diary immediately after they got up on a daily basis to maximize their recall accuracy. Participants were asked to self-declare whether they had any commitment in the next morning to classify the day into either a "free day" or a "workday." For a direct comparison with MCTQ, the midpoint of sleep derived from sleep diary (MST_{diary}) was calculated based on the same formula used in the MCTQ chronotype calculation, where free days and workdays midpoint of sleep were accounted for any sleep debt accumulated during the workdays.

Actigraphy. Actiwatch Spectrum Plus (Philips Respironics, Bend, OR) was used to monitor daytime activity and sleep in conjunction with a sleep diary. Activity was logged at a 1-min epoch with a sampling frequency of 32 Hz. Participants were instructed to wear the device on their non-dominant arm at all times except for the occasions where the device would be expected to submerge in water (e.g., taking a shower, swimming). Actogram visualization and data analysis were completed using Philips Actiware 6.1 low threshold algorithm. The start and end of the rest intervals were manually set following a scoring protocol reported by Patel et al. (2015) using the inputs in the following order of importance: (1) event marker, (2) sleep diary entries, (3) white light intensity, and (4) activity level. The midpoint of sleep derived from actigraphy (MST_{act}) was also corrected for sleep debt accumulated during the week and was calculated using the same formula as that of MCTQ.

Epoch-by-epoch activity data were further exported for circadian rhythm computation using cosinor and nonparametric analysis (Goncalves et al. 2014; Tong 1976). Cosinor analysis fits an individual's activity in a sinusoidal pattern using the least-square method (Ancoli-Israel et al. 2003). The acrophase from the analysis was extracted to represent the clock time of maximum activity. The onsets of the five least active hours (L5) and the 10 most active hours (M10) were extracted from the nonparametric analysis and used to estimate the circadian phase. Data were excluded on a daily level (00:00 h-23:59 h) if there were more than 33% of missing data within the 24 hours. Cosinor analysis was completed using the "consor" R package (Sachs 2014), while nonparametric analysis was completed using the "nparACT" R package (Blume et al. 2016).

Dim-light melatonin onset (DLMO). DLMO assessment was performed in the Sleep Laboratory at the University of Hong Kong immediately after the prospective 7-day sleep diary (i.e., a week after completing the questionnaire battery). Participants stayed in a room with ambient light level below 10 lux throughout the procedure as confirmed by a digital light meter (the detailed protocol is available in the supplementary information). Salivary samples were collected every half an hour, starting from 6 h before the participant's habitual bedtime and continuing until 2 h after the habitual bedtime, resulting in 17 samples per participant. Salivary specimens were assayed using liquid chromatography-tandem mass spectrometry. Clock time of DLMO was calculated with linear interpolation when the concentration of salivary melatonin exceeded and remained above an absolute threshold of 12.9 pmol/L for at least two additional samples (Benloucif et al. 2008; Crowley et al. 2016; Pandi-Perumal et al. 2007).

Statistical analysis

Three key parameters of MCTQ, namely MSW, MSF, and MSFsc, were tested for normality using the Kolmogorov–Smirnov test. Test–retest reliability of MCTQ parameters was tested using a two-way mixed model with absolute agreement intraclass correlation coefficient (ICC) based on the guideline by Koo and Li (2016). Validity of MCTQ was tested using Pearson's correlation coefficients to examine the associations of MCTQ parameters with other circadian related measures and clinical variables. Given the effect of age on sleep timing (Randler et al. 2017), partial correlations controlled for age on MCTQ parameters were also calculated. Photoperiod, defined as the time between sunrise and sunset on the day of DLMO assessments, was

additionally controlled when examining the correlations between DLMO-related variables. Associations of MCTQ parameters with clinical measures (i.e., ISI and PHQ-9) were tested using multivariate linear regression after controlling for age and sex. The strength of the associations of these variables between insomnia group and healthy sleeper group were examined using Fisher's Z transformation. All the analyses were completed using SPSS version 25 (IBM, Armonk, NY), and the graphs figures were created using R package "ggplot2" in R Studio (Wickham 2016).

Results

Part I – scale translation and validation against MEQ

Sample characteristics

MCTQ parameters showed a non-normal distribution. Extreme values outside the range of −3 and 3 standard deviations from the mean were subsequently removed from the analyses (n = 4), resulting in 659 samples in the final analyses (female = 67.7%; mean age: 20.7 ± 2.02, range: 15–24). The distribution of MSW, MSF, and MSFsc is presented in Figure 2. Descriptive statistics for MCTQ sleep and circadian parameters are presented in Table 1. Age was significantly correlated with MSW, MSF, and MSFsc (r = −.182, −.165, and −.147, respectively, all p < .001). There were no sex differences in any MCTQ parameters. Insomnia group scored significantly higher on PHQ-9 compared to healthy sleeper group (12.99 ± 5.95 vs. 6.27 ± 5.09, p < .001).

Validity of MCTQ against MEQ

The mean MEQ score was 45.1 ± 8.7 and had a positively skewed distribution (skewness: 0.20). MEQ scores were significantly inversely correlated with all MCTQ parameters (MSW: r = −.514; MSF: r = −.650; MSFsc: r = −.592; all p < .01). The main results of the correlation analyses on MCTQ parameters are presented in Table 2. Further detailed correlation analyses can be found in Supplementary Information Figure S1.

Test-retest reliability of MCTQ

Four hundred and forty-two participants responded and completed the one-month follow-up (response rate = 67%). There were no significant differences between respondents and non-respondents in terms of age, MSF, and MSFsc. Non-respondents had a later MSW compared to those who completed the follow-up survey (04:59 vs. 04:42, p = .001). All the MCTQ parameters showed good test–retest reliability. Intraclass correlation was 0.75, 95% CI [.70, .80] for MSW; 0.84, 95% CI [.81, .87] for MSF; and 0.80, 95% CI [.76, .83] for MSFsc.

Criterion validity of MCTQ

After controlling for age and sex, later MSFsc (i.e., later chronotype) was significantly associated with more severe insomnia symptoms as measured by ISI (β = .153, p < .001) and depressive symptoms as assessed by PHQ-9 (β = .128, p = .002).

Validation of MCTQ in participants with insomnia symptoms

The current sample was dichotomized into two groups: healthy sleeper group (n = 567) vs. insomnia group (n = 92) based on the ISI cut-off (i.e., 14). MSFsc correlated significantly with MEQ scores in both groups (healthy: r = −.600, p < .001; insomnia: r = −.543, p < .001) and there were no significant differences among the correlations (Fisher's Z Test, z = −.743,

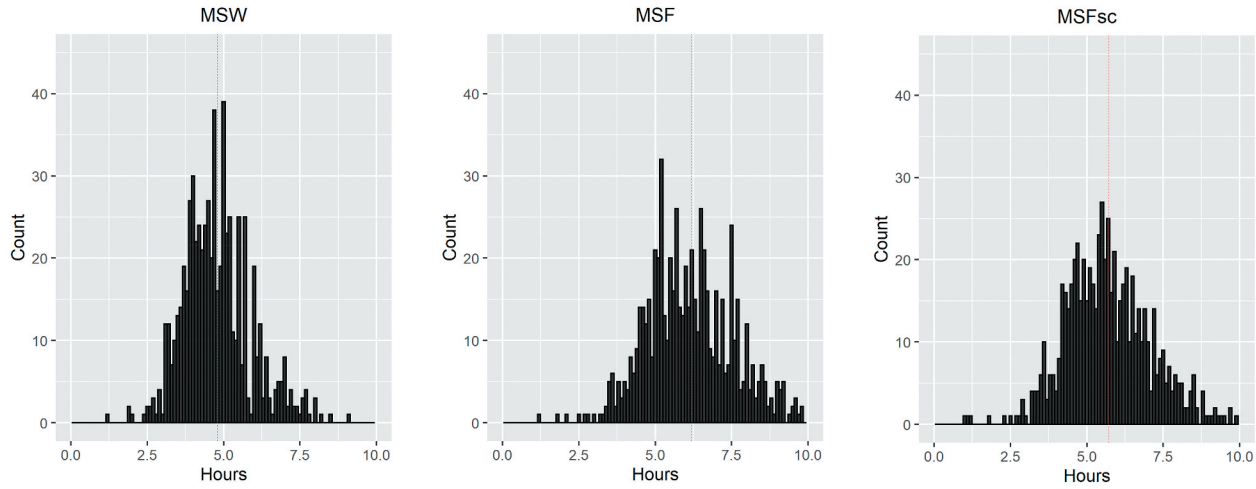

Figure 2. Distribution of MCTQ parameters.

Table 1. MCTQ sleep and circadian characteristics.

	Total (N = 659)
Sleep characteristics derived from MCTQ	
Sleep Onset (hh:mm)	
Free Days	02:09 (1:31)
School/Workdays	01:27 (1:20)
Sleep Offset (hh:mm)	
Free Days	10:40 (1:47)
School/Workdays	08:23 (1:18)
Sleep Duration (mins)	
Free Days	481.6 (86.0)
School/Workdays	399.1 (81.2)
Circadian Characteristics derived from MCTQ	
Chronotype Parameters (hh:mm)	
MSF	06:09 (1:27)
MSW	04:47 (1:06)
MSFsc	05:42 (1:24)
Social Jetlag (hh:mm)	
|SJL|	01:02 (0:58)
|SJLsc|	00:50 (0:45)

Data present as mean (SD).
Abbreviation: MCTQ = Munich Chronotype Questionnaire; MSF = midpoint of sleep on free days, MSW = midpoint of sleep on workdays, MSFsc = midpoint of sleep corrected for sleep debt, |SJL| = social jetlag, |SJLsc| = social jetlag corrected for sleep debt.
Social Jetlag is calculated as | MSW – MSF |. Social jetlag corrected for sleep debt is calculated according to Jankowski (2017).

p = .229). The comparison of the associations between MCTQ and other circadian measures in healthy sleepers and participants with insomnia is presented in Table 3.

Part II – validation against sleep diary, actigraphy, and dim light melatonin onset (DLMO)

Validity of MCTQ against sleep diary and actigraphy

The correlations between MCTQ parameters and sleep variables based on sleep diary and actigraphy are presented in Table 2. Actigraphy and sleep diary were completed by 69 participants (female = 62.3%; mean age: 19.8 ± 1.65, range: 17–24). The mean midpoint of sleep derived from sleep diary (MST_{diary}) was 06:02 h ± 01:23 h, which was significantly correlated with all the MCTQ parameters (MSW: r = .452; MSF: r = .641; MSFsc: r = .612; all p < .001). All the recruited participants (n = 69) completed 7-day actigraphy data collection. However, there were 10 participants with at least 1 day of data removed based on our exclusion criteria on a daily level: The day(s) were excluded from the analysis mainly because the participants did not wear the actigraphy device, resulting in no available activity data. In total, four participants' actigraphy data were removed from the analysis due to technical reasons, and four participants' actigraphy data were additionally excluded from the circadian computation because they had less than 5 days of valid data. The mean midpoint of sleep derived from actigraphy (MST_{act}) was similar to that of MST_{diary} (06:07 h ± 01:27 h) and also significantly correlated with all the MCTQ parameters (r = .449 to .619; all p < .001). The opposite of acrophase – bathyphase – which reflected the time of the sinusoid nadir (05:20 h ± 01:14 h) was slightly more advanced than that of the midpoint of sleep derived from sleep diary and actigraphy. The acrophase, L5 onset, and M10 onset all correlated positively with MCTQ parameters (r = .362 to

Table 3. Comparison of the correlations in healthy sleepers vs. participants with insomnia.

	Pearson's correlation with MSFsc				Fisher's Z test	
	Healthy sleepers (ISI ≤ 14)		Insomnia group (ISI > 14)		Z	p
Variables	n	r	n	r		
Subjective Measures						
MEQ	567	−.600**	92	−.543**	−0.743	.229
MST_{diary}	59	.567**	10	.617	−0.192	.424
Objective Measures						
MST_{act}	57	.523**	8	.860**	−1.525	.064
Acrophase	54	.323*	7	.805*	−1.498	.067
L5 Onset	54	.444**	7	.672	−0.649	.258
M10 Onset	54	.282*	7	.676	−1.024	.153
Time of DLMO	31	.326	8	.746*	−1.288	.099

Abbreviation: DLMO = dim-light melatonin onset; ISI = insomnia severity index; MEQ = morningness-eveningness questionnaire; MST_{diary} = midpoint of sleep derived from sleep diary; MST_{act} = midpoint of sleep derived from actigraphy; MSFsc = midpoint of sleep corrected for sleep debt; L5 = least 5 hours of activities; M10 = most 10 hours of activities.
**p = 0.01; *p = 0.05.

Table 2. Correlations of various circadian measures.

	Descriptive	Zero-order correlation				Partial correlation			
Variables	Mean (SD)	MEQ	MSW	MSF	MSFsc	MEQ	MSW	MSF	MSFsc
Subjective Measures									
MEQ (n = 659)	45.1 (8.7)	-	−.514**	−.650**	−.592**	-	−.515**	−.652**	−.592**
MST_{diary} (n = 69)	06:02 h (1:23 h)	−.569**	.452**	.641**	.612**	−.568**	.442**	.635**	.605**
Objective Measures									
MST_{act} (n = 65)	06:07 h (1:27 h)	−.521**	.449**	.619**	.597**	−.520**	.435**	.610**	.589**
Acrophase (n = 61)	17:20 h (1:14 h)	−.425**	.362**	.453**	.415**	−.423**	.346**	.440**	.402**
L5 Onset (n = 61)	03:00 h (1:27 h)	−.406**	.444**	.532**	.504**	−.404*	.427**	.519**	.492**
M10 Onset (n = 61)	12:10 h (1:56 h)	−.319	.206	.338**	.307*	−.317*	.172*	.313*	.284*
Time of DLMO (n = 39)	23:26 h (1:50 h)	−.514**	.393*	.517**	.495**	−.524**	.364*	.487**	.459*

Age was controlled in all partial correlations. Photoperiod was additionally controlled for correlations with DLMO time.
Abbreviation: DLMO = dim-light melatonin onset; MEQ = morningness-eveningness questionnaire; MST_{diary} = midpoint of sleep derived from sleep diary; MST_{act} = midpoint of sleep derived from actigraphy; MSW = midpoint of sleep on workdays; MSF = midpoint of sleep on free days; MSFsc = midpoint of sleep corrected for sleep debt; L5 = least 5 hours of activities; M10 = most 10 hours of activities.
**p = 0.01; *p = 0.05.

.532, all p < .001) except that M10 onset was not significantly correlated with MSW. All associations of MCTQ parameters with MEQ, sleep diary, and actigraphy parameters remained significant after controlling for age.

Validity of MCTQ against DLMO

Data from 39 participants (female = 61.5%; mean age: 20.3 ± 1.64, range: 17–24) were used in the analysis as five participants were removed due to the use of an alarm clock during a free day. Time of DLMO was normally distributed (D = .097, p = .20) with a mean of 23:26 h ± 01:50 h. All the participants had their salivary melatonin concentration exceeding the absolute threshold of 12.9 pmol/L before their habitual bedtime. However, there were large intra-individual variations in the DLMO to habitual bedtime-phase angle (range: 0.27–5.48 hours, median: 2.2 hours). The correlations between DLMO time and MCTQ parameters were all significant (Figure 3; MSW: r = .393; MSF: r = .517; MSFsc: r = .495). Due to the seasonality effect on melatonin in humans (Arendt 2019), photoperiod, calculated as the duration between sunrise and sunset on the day of DLMO assessment, was also controlled with age in the partial correlation analyses. The associations between MCTQ parameters with DLMO remained significant after controlling for age and photoperiod.

Discussion

The primary aim of the present study was to develop the Chinese version of MCTQ (MCTQ^{HK}) and to validate the MCTQ^{HK} for use in youths. We found that MCTQ^{HK} showed satisfactory convergent validity with both subjective and objective circadian measures (|r| > .393). The results also showed satisfactory test–retest reliability and criterion validity of the MCTQ^{HK} as reflected by the significant associations of its parameters with the measures of depression and insomnia symptoms. In addition, the current study demonstrated the potential utility of MCTQ^{HK} in individuals with insomnia.

As expected, all MCTQ parameters were significantly correlated with MEQ score (r = −.514 to −.650). The strength of the associations of MCTQ parameters with MEQ score was comparable with that of reported in the previous validation studies across different cultures (Fárková et al. 2020; Kitamura et al. 2014; Reis et al. 2020; Ryu et al. 2018; Suh et al. 2018). There was a consistent pattern that the midpoint of sleep during free days (MSF) was more strongly correlated with MEQ score than the MSF adjusted for sleep debt (MSFsc). This observation was similarly reported in the previous research and was explained by the lack of consideration of sleep variability between weekdays and weekends in MEQ (Di Milia et al. 2013). It is also possible that the construct assessed through the MEQ reflects one's ideal circadian preference, which may be more consistent with one's sleep-wake behavior observed during free days. Another possible explanation was that the current study encompassed a youth sample with a greater tendency for eveningness (i.e., MEQ scores were positively skewed). Compared to those with other circadian typologies, individuals with evening-type often show a larger discrepancy in weekday and weekend sleep duration, where sleep duration on weekends is extended to compensate for the sleep debt acuminated throughout the workdays (Duffy and Roepke 2010; Roenneberg et al. 2019). Indeed, the absolute mean duration of social jetlag (|SJL| = |MSW – MSF|) in the current sample was 83.8 ± 58.6 minutes, and

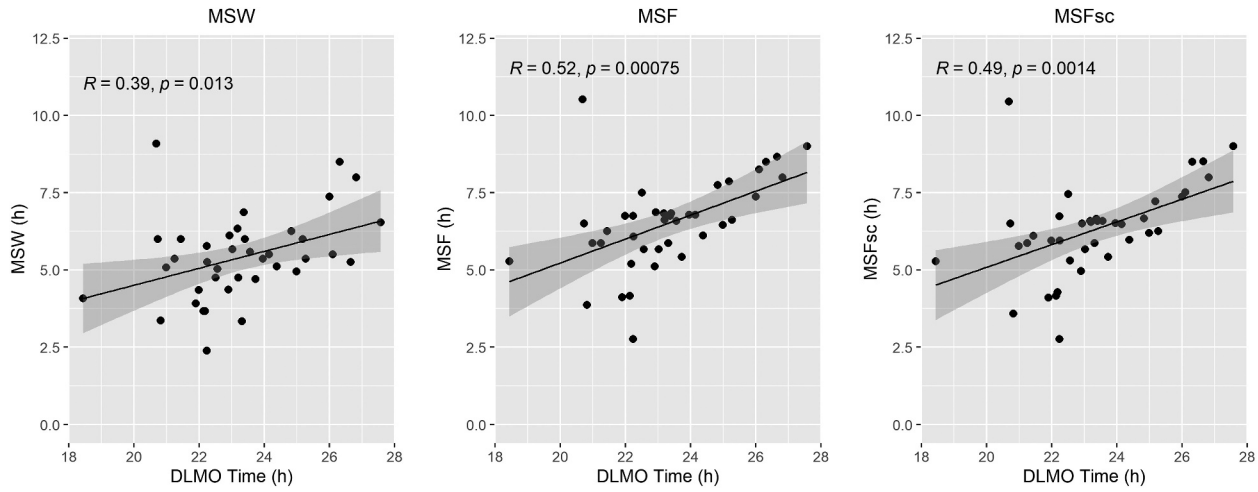

Figure 3. Correlation of DLMO time with MCTQ parameters.

that 61% of the participants had social jetlag of one hour or more. The duration of social jetlag remained long after adjusting for potential sleep debt resulting from sleep deprivation during workdays (50 ± 45 minutes) using the formula proposed by Jankowski (2017). The calculation of MSFsc could be much affected by the accumulated sleep debt especially when there was a large discrepancy of weekday-weekend sleep, and thus might explain the observation that MSF correlated stronger with MEQ compared to MSFsc in this sample.

The $MCTQ^{HK}$ showed a good test–retest reliability over a month (ICC = .75 to .84). High consistency in test–retest reliability was also similarly reported in other studies with a 3-month (Suh et al. 2018) and up to 5-year of follow-up (Lenneis et al. 2021). Conceptually, the MCTQ reflects the state-like properties of chronotype in contrast to a trait (Roenneberg et al. 2019). The high stability in the current study could be due to the short time lag between baseline and follow-up, during which participants have limited changes in their sleep timing.

MCTQ parameters correlated well with other means of circadian measures, including MST_{diary}, MST_{act}, acrophase, L5 and M10 onset, and time of DLMO. To the authors' best knowledge, no study has been conducted to validate the MCTQ against actigraphic data using the nonparametric circadian computation, which can provide more accurate estimates of the circadian characteristics compared to fitting non-sinusoidal sleep-wake pattern on a cosine waveform (Van Someren et al. 1999). Indeed, L5 onset showed the strongest association with MSFsc compared to M10 onset and acrophase. It is believed that M10 is more sensitive and subjected to the individual differences in active vs. sedentary lifestyle, thus producing a less accurate estimation of circadian phase. Regarding acrophase, the current findings on its association with MCTQ derived MSFsc (r = .415, $p < .01$) were comparable with those of the previous findings (i.e., r = 0.52 in Reis et al. 2020).

In this study, DLMO was also significantly correlated with all the MCTQ parameters (r = .393 to .517). Compared with the previous studies that assessed the association between DLMO and MCTQ (Facer-Childs et al. 2019; Ghotbi et al. 2020; Kantermann et al. 2015; Kitamura et al. 2014; Ruiz et al. 2020), our current finding (r = .497) was comparable to that of Ghotbi et al. (2020), given that the age range of the sample in both studies was similar. The strength of the association was significantly different from that of the study reported by Facer-Childs et al. (2019), where they found a strong correlation (r = 0.8) between DLMO and MSFsc. However, as Ghotbi et al. (2020) suggested, this could merely be due to the calculation of extreme values in Facer-Childs et al.'s study (2019). The differences in the strength of the associations between DLMO and MSFsc, and between DLMO and MEQ score were minimal (|r| = 0.50 vs. 0.51), suggesting that both MEQ and MCTQ could provide comparable estimates of endogenous circadian rhythm.

Previous studies showed that evening chronotype was associated with a greater risk of mood problems and suicidality (Norbury 2021), particularly in youths (Chan et al. 2020; Li et al. 2018). Therefore, it is important to develop a suitable and validated tool for assessing chronotype in the young population to facilitate future research on understanding the link between chronotype and mental health in this age group. In this regard, our findings collectively supported the validity of $MCTQ^{HK}$ in the use of youths. In line with previous research, the current study found a significant association between MSFsc as measured by $MCTQ^{HK}$ and depressive symptomology (β = .128, p = .002) based on a community sample of youth.

Previous studies showed a close relationship between chronotype and insomnia (Alvaro et al. 2014; Chan et al. 2014; Li et al. 2018). This observation was corroborated in the current study, where later chronotype as reflected by MCTQ parameter MSFsc was significantly associated with insomnia symptoms after controlling for sex and age (β = .153, $p < .001$). MSFsc was found to be associated with the MEQ and midpoint of sleep derived from sleep diary in both healthy sleeper and insomnia groups. The findings lent a preliminary support for the use of MCTQ to estimate chronotype in youths with insomnia. However, the current findings also showed larger differences in the strengths of association of MSFsc with objective measures between healthy sleepers and insomnia groups. The differences observed between the groups may be explained by greater sleep variability in sleep timing in people with insomnia (Bei et al. 2016; Suh et al. 2012). Previous research has shown that day-to-day variability in individuals with insomnia was seen in their physical activity level as measured by actigraphy and might result in inaccurate estimates when the data were averaged across the days (Fossion et al. 2017). In the present study, neither L5 onset nor M10 onset correlated significantly with MSFsc in the insomnia group. It has been suggested that L5 onset might not be considered as a suitable parameter to represent chronotype in individuals with insomnia because their time of sleep onset often varies due to the nature of insomnia symptoms. In contrast, M10 onset might be less sensitive to insomnia symptoms as M10 does not take into account sleep onset latency. Nonetheless, the current analyses were only exploratory due to limited samples, especially in the insomnia group. Future research should also validate the use of the MCTQ with a larger sample of clinically diagnosed insomnia.

The main strength of the current study included using multiple subjective and objective measures of chronotype to confirm the validity of the MCTQ^{HK}. In addition, two actigraphy circadian computation methods were compared. The study also adopted a laboratory-based DLMO assessment to enhance the rigor of our research findings. Despite the promising results, some limitations of the current study should be noted. First, compared to other studies on chronotype (Liu et al. 2020; Paine et al. 2006), the current sample comprised a larger percentage of evening-type individuals of similar age. Further circadian research should address the sampling method to capture a wider range of respondents with different circadian typologies. Second, a quarter (26.5%) of our total respondents, including five individuals who have completed DLMO, were excluded from the analysis during the validation process because of their use of an alarm clock during a free day. To accurately measure chronotype in MCTQ, an alarm clock should not be used during a free day as it would interrupt the natural timing of sleep habits. This approach of analysis was also commonly adopted in the previous research (e.g., 22.5% and 21% were excluded in the studies conducted by Reis et al. (2020) and Suh et al. (2018), respectively), but might limit the use of MCTQ in some groups of people given that alarm clock is often used in the modern society nowadays. Although conceptually speaking, MSFsc in alarm clock users might be distorted due to the influence of social constraints, supplementary analysis showed that there were no substantial differences in terms of the correlations between MSFsc and other circadian measures when the data from alarm clock users were also included (Supplementary Table S1). Meanwhile, in the recently validated ultra-short MCTQ (6-item), the instruction has been revised by asking participants to report their sleep timing of free days under the condition that no alarm clock was used (Ghotbi et al. 2020). A similar modification could potentially be applied to the standard MCTQ to facilitate its wider use in different populations. Finally, the current study was conducted on a sample comprising primarily students with a relatively narrow age range. Cautions should be taken when generalizing the current results and applications of MCTQ, particularly among insomnia patients.

Conclusion

The current study provided the support for the validity of MCTQ^{HK} as a measure of chronotype in youth. The MCTQ^{HK} provides a simple method to measure a wide range of sleep and circadian characteristics that are suitable for use even in large epidemiological studies. Finally, the findings provided a preliminary support for the use of MCTQ^{HK} in people with insomnia and could potentially facilitate the assessment of the circadian-related factors in the research on the interrelated relationships between chronotype, insomnia, and psychopathology.

Acknowledgements

The authors would like to thank Ms. Lai Hiu Yan Adrianne and Ms. Wong Yui Tung Crystal for their role in translating the initial questionnaire.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

Funding This work was funded by Seed Fund for Basic Research, University Research Committee (awarded to SX Li) and Early Career Scheme (Ref. 17608918, awarded to SX Li), Research Grants Council, University Grant Committee, Hong Kong SAR Government.

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Data availability statement

Data are available upon request to the corresponding author.

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