## The μMCTQ- an ultra- short version of the Munich ChronoType Questionnaire

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## Supplementary Material

Content:

## 1. Study 1: Correlation between stdMCTQ and µMCTQ

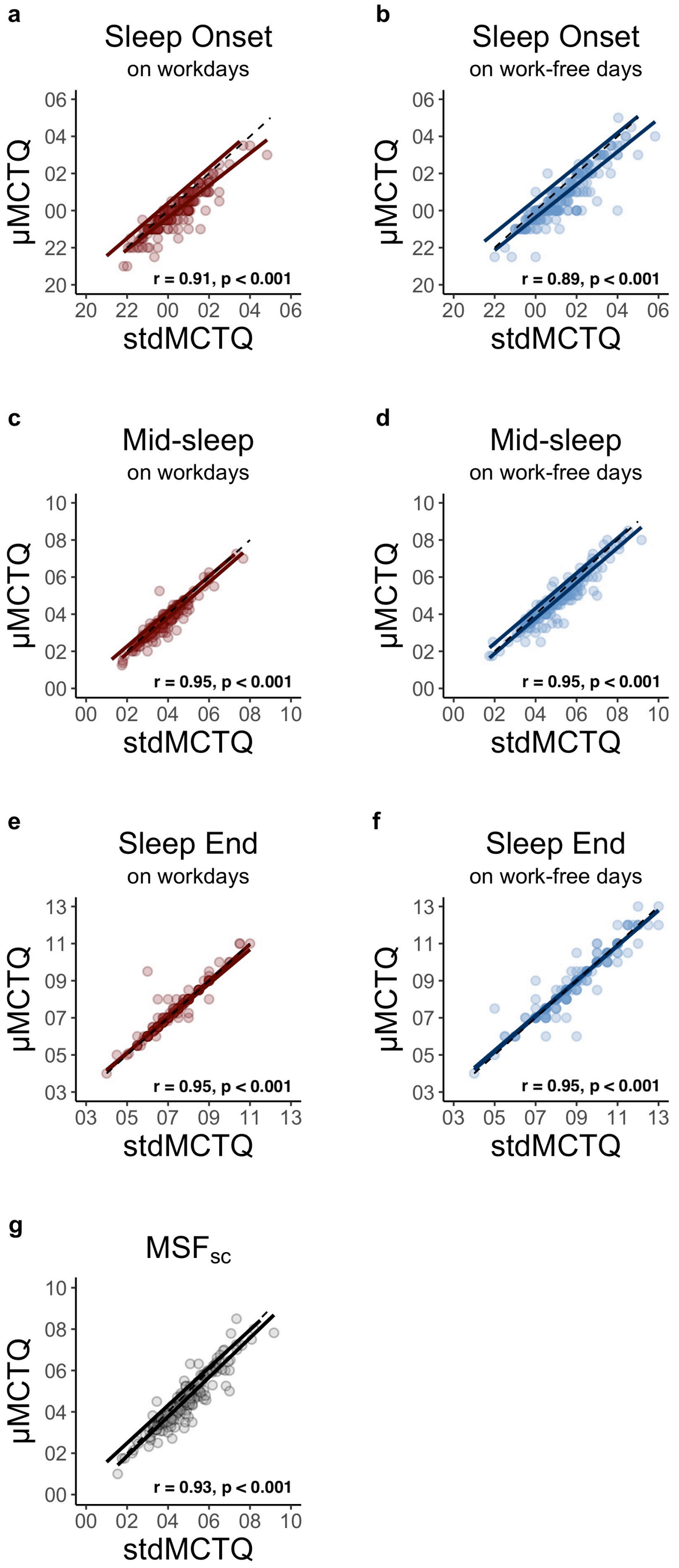


***Figure S1.*** *Associations between stdMCTQ and µMCTQ. (a) Sleep onset on workdays, (b) sleep onset on work-free days, (c) mid- sleep on workdays and on (d) mid- sleep on work- free days, (e) sleep end on workdays, (f) sleep end on work- free days, (g) MSFsc. Data are expressed in local time (hh). N = 213. Study 1: Validation of the µMCTQ against the stdMCTQ.*

## 2. Study 1: stdMCTQ Age Stratification of Sample

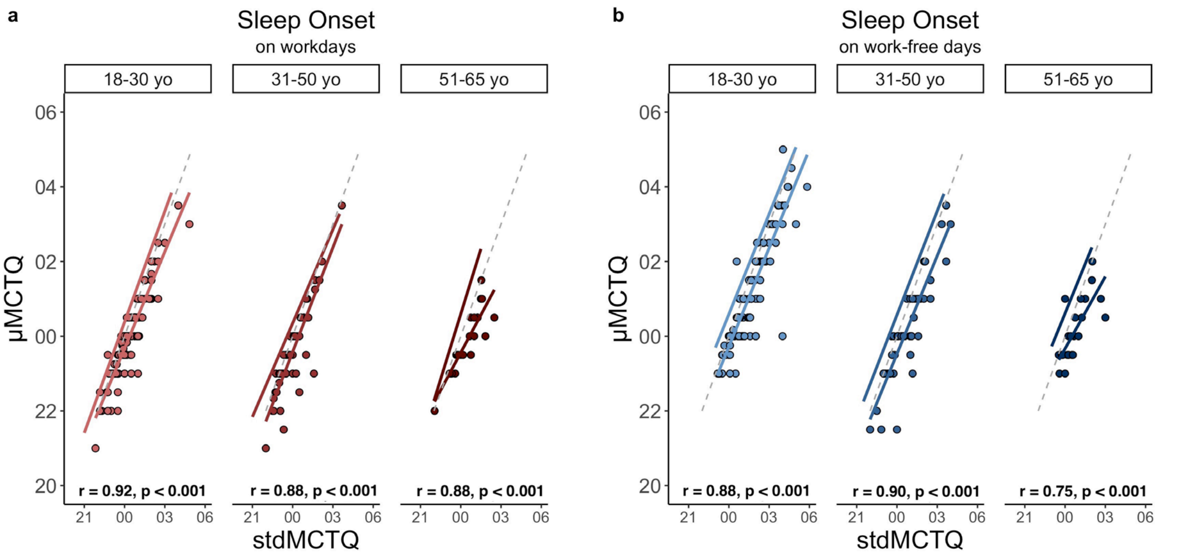


***Figure S2****. Associations between stdMCTQ and µMCTQ divided into age categories. Sleep Onset on workdays (a) and on work- free days (b). Blue/red lines represent xy and yx regression lines. Pearson. 18-30 yo: N = 132; 31-50 yo: N = 54; 51:65 yo: N =25. Data are expressed in local time (hh), and originated from Study 1: Validation of the µMCTQ against the stdMCTQ.*

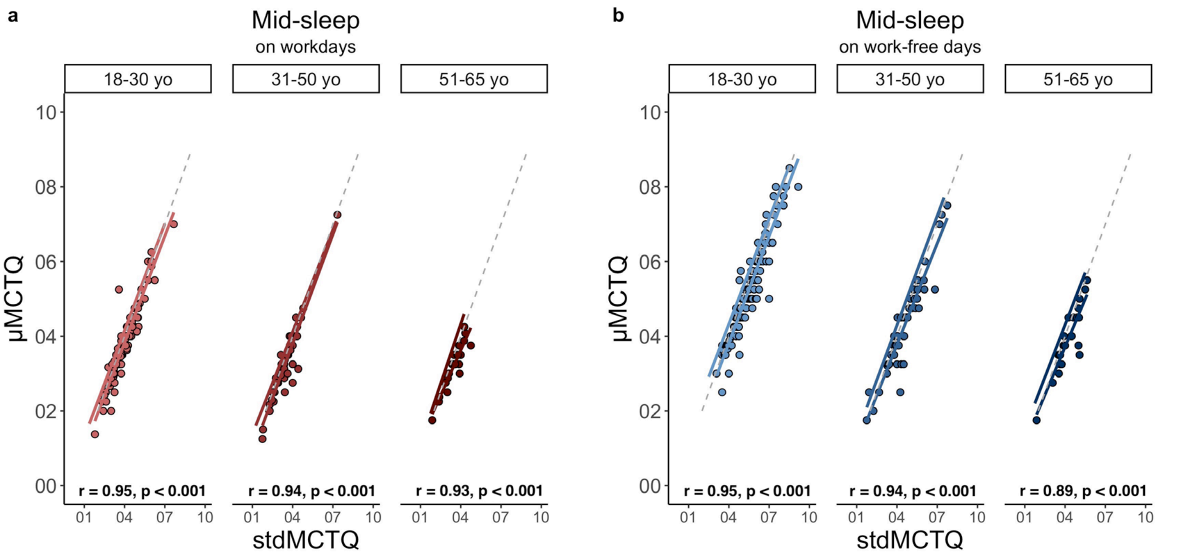


***Figure S3.*** *Associations between stdMCTQ and µMCTQ divided into age categories. Mid- sleep on work- (a) and work-free (b) days. Blue/red lines represent xy and yx regression lines. Pearson. 18-30 yo: N = 132; 31-50 yo: N = 54; 51:65 yo: N =25. Data are expressed in local time (hh), and originated from Study 1: Validation of the µMCTQ against the stdMCTQ.*

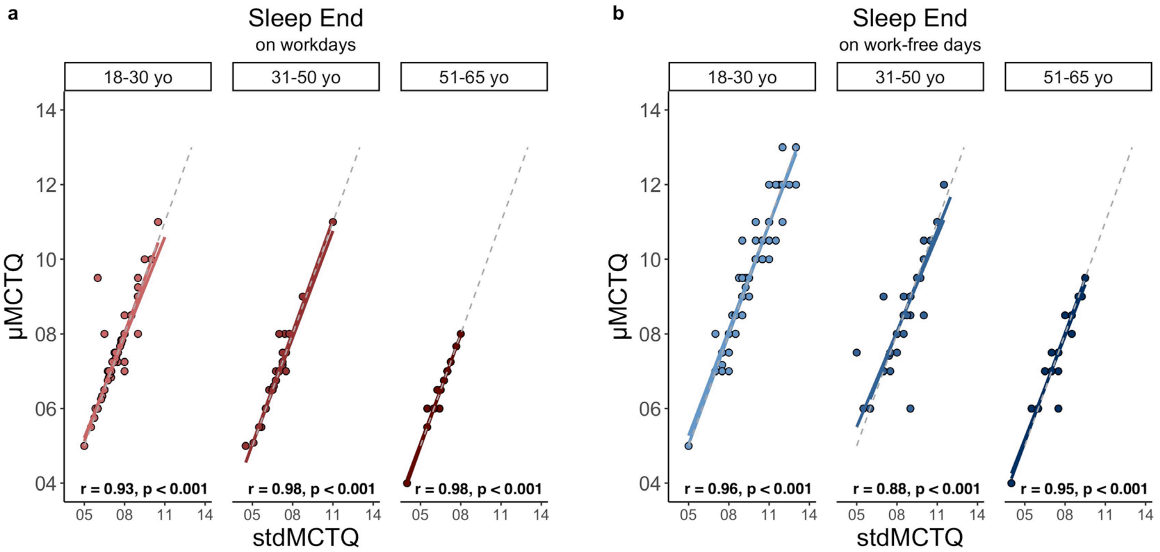


***Figure S4.*** *Associations between stdMCTQ and µMCTQ divided into age categories. Sleep End on work- (a) and work-free (b) days. Blue/red lines represent xy and yx regression lines. Pearson. 18-30 yo: N = 132; 31-50 yo: N = 54; 51:65 yo: N =25. Data are expressed in local time, and originated from Study 1: Validation of the µMCTQ against the stdMCTQ.*

## 3. Study 1: Comparison of subjects who use vs. subjects who do not use alarm clocks

Subjects from study 1 were classified into groups according to use of alarm clock on free days, as reported in the stdMCTQ. In the µMCTQ, individuals are asked to report their wake up times on free days when they do not use alarm clocks, whereas in the stdMCTQ they are asked to report their usual behaviour and if they use alarm clocks. No significant differences were seen between the groups using Student's t-tests. Two-way ANOVA shows a significant main effect of alarm usage in the $MSF_{sc}$ timing variable (and only a tendency in MSF and MSW). No effect of questionnaire (stdMCTQ/µMCTQ) or interaction was seen on any variable.

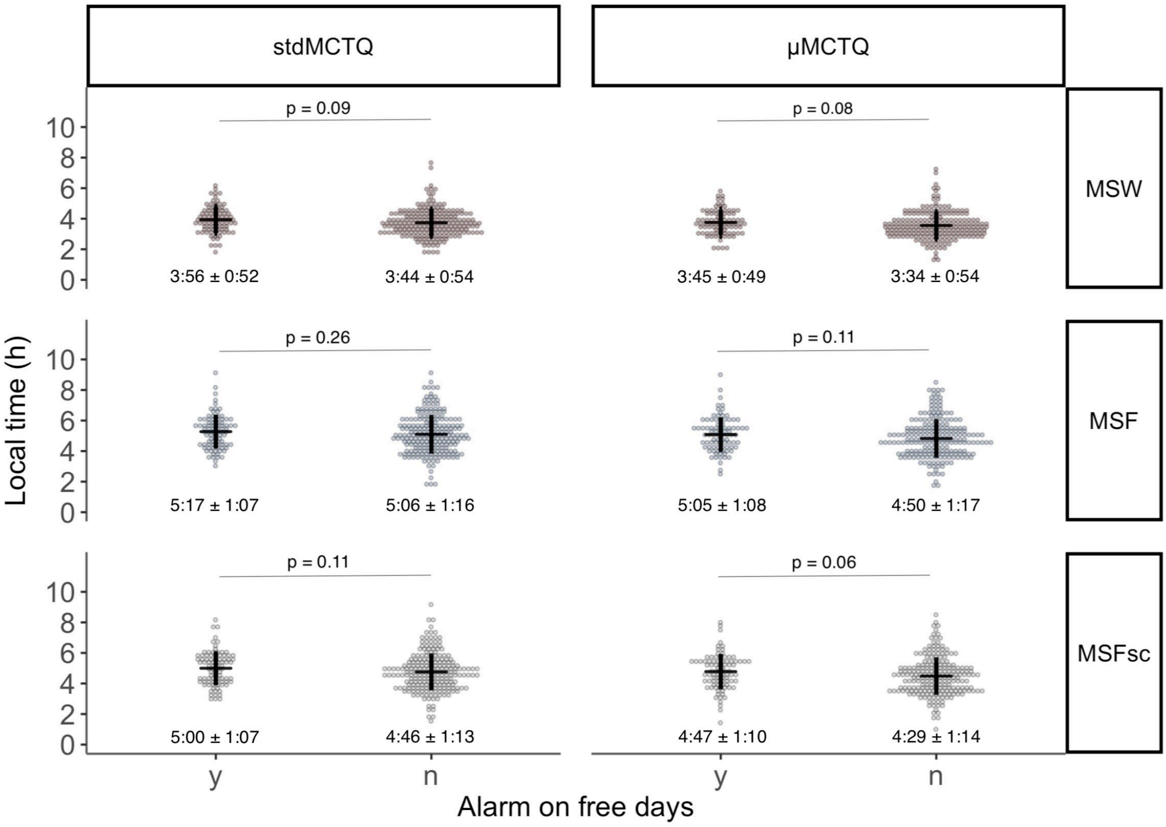


***Figure S5.*** *Comparison of groups according to use of alarm clock on work-free days. Results from Student's t-tests are shown in the graphs (p not corrected for multiple comparisons). Data are expressed in local time for all variables. Mean ± standard deviation. N = 300, out of each 87 use alarm clocks on free days (Study 1: Validation of the µMCTQ against the stdMCTQ).*

#### 4. Study 2: Correlation between µMCTQ- MSW and MSF and Activity- & Melatonin- phase (DLMO)

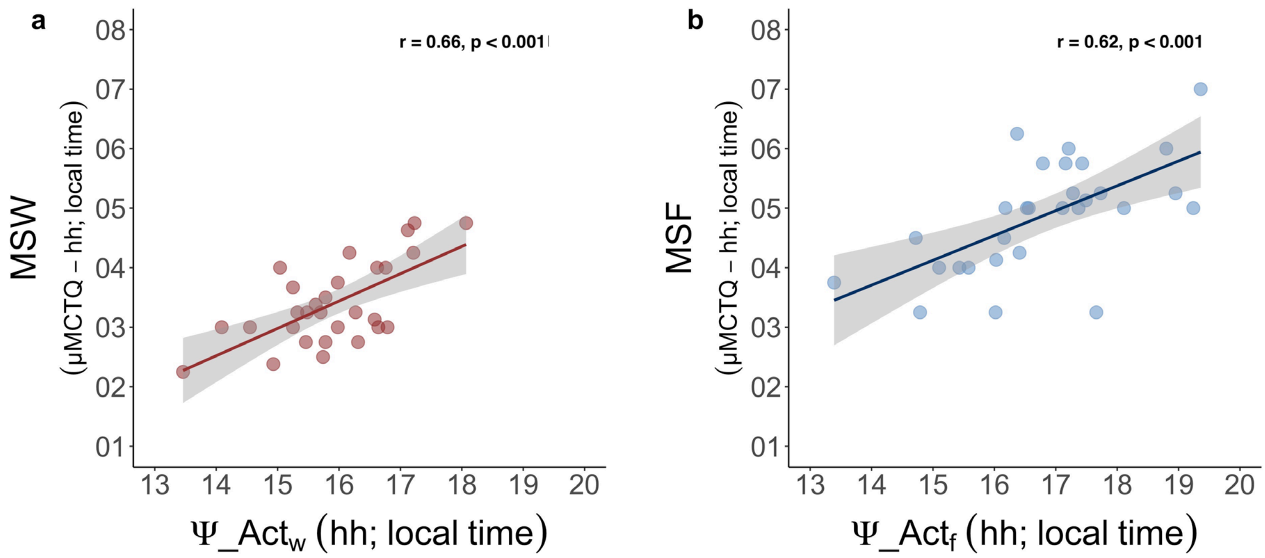


***Figure S6.*** *Associations between variables from the µMCTQ (MSW and MSF) and actimetry (activity acrophase, Ψ_Act). Mid-sleep on workdays correlates with Ψ_Act$_w$ (a), as does mid-sleep on work-free days (MSF) with Ψ_Act$_f$ (b). The grey shaded area around the regression line represents the 95% confidence interval. Results of Pearson correlations are provided in each graph. Data are expressed in local time for both variables. N = 29 (Study 2: Validation of the µMCTQ against actimetry).*

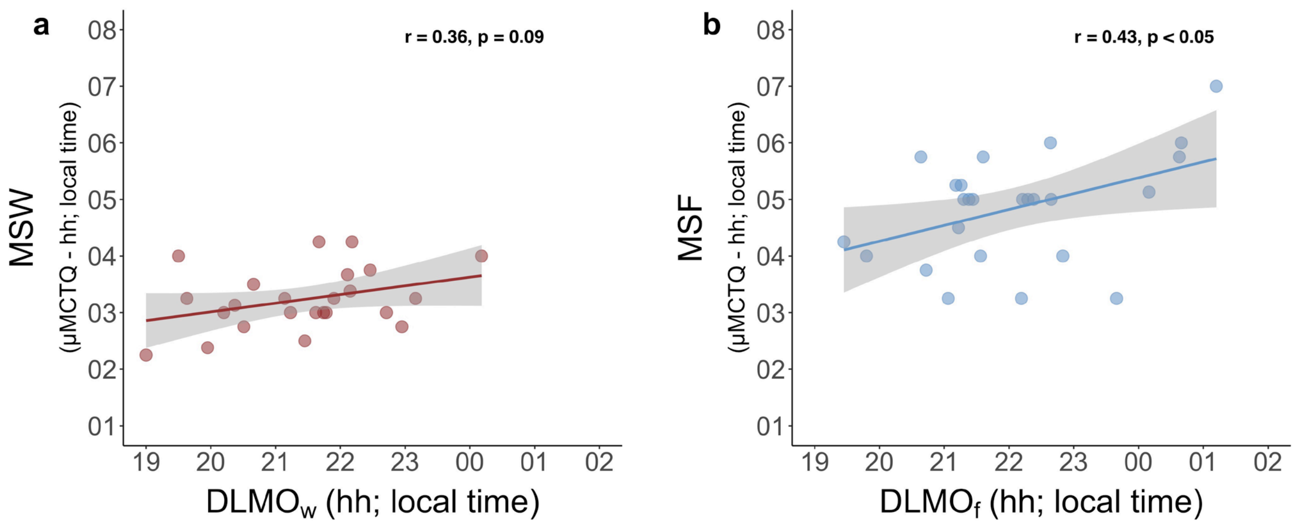


***Figure S7.*** *Association between variables from the µMCTQ (MSW and MSF) and dim light melatonin onset (DLMO). Mid-sleep on workdays (MSW) shows a tendency to correlate with DLMO$_w$ (a), while MSF correlates significantly with DLMO$_f$ (b). The grey shaded area around the regression lines represent the 95% confidence intervals. Results of Pearson correlations are provided in each graph. Data are expressed in local time for both variables. N = 24-25 (Study 2: Validation of the µMCTQ against DLMO). DLMO, collected at home with no objective measures of compliance.*

**5. Study 2: µMCTQ against DLMO using dynamic threshold (2 standard deviations above mean of the baseline)**

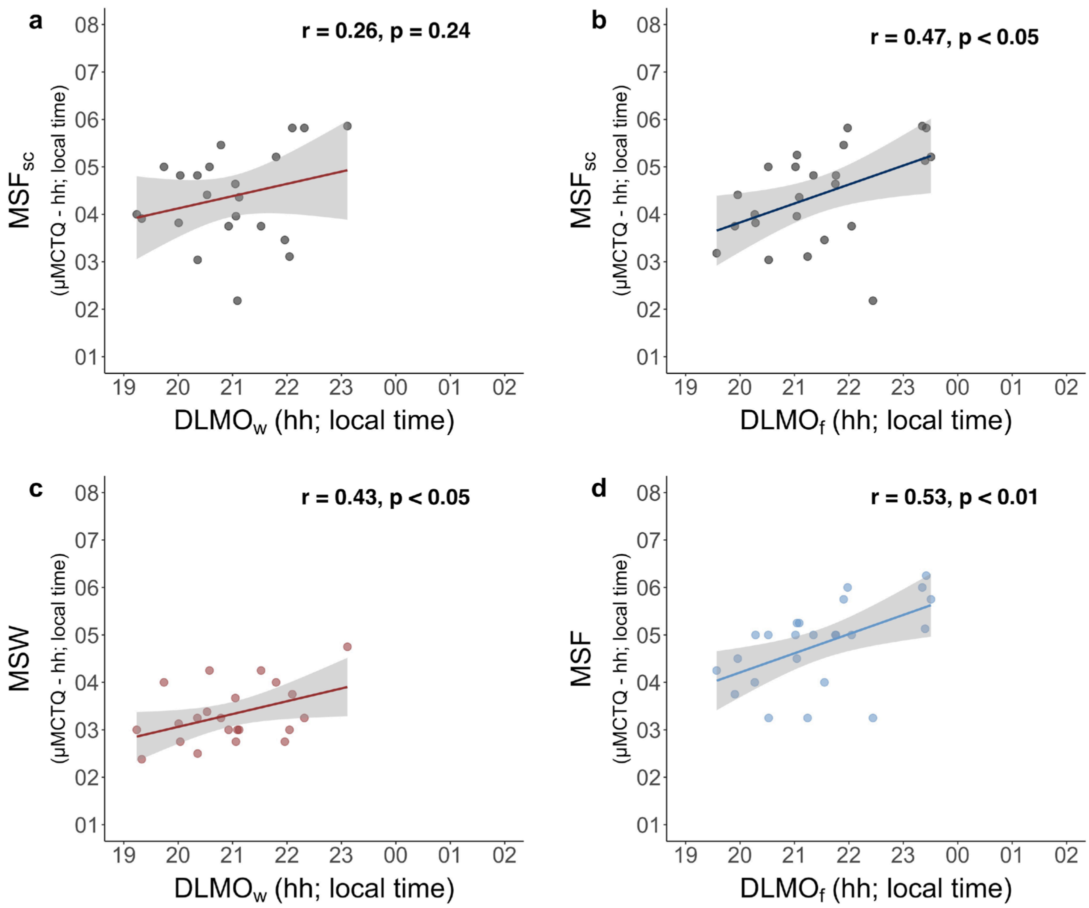


***Figure S8.*** *Association between variables from the µMCTQ and dim light melatonin onset (DLMO) calculated using dynamic thresholds. $MSF_{sc}$ correlates significantly with DLMO measured on work-free days ($DLMO_f$, b), but not with that measured on workdays ($DLMO_w$, a). Mid-sleep on workdays (MSW) correlates with $DLMO_w$ (c), while MSF correlates significantly with $DLMO_f$ (d). The grey shaded areas around the regression lines represent the 95% confidence intervals. Results of Pearson correlations are provided in each graph. Data are expressed in local time for both variables. N = 22-24 (Study 2: Validation of the µMCTQ against DLMO).*

## 6. µMCTQ test-retest reliability

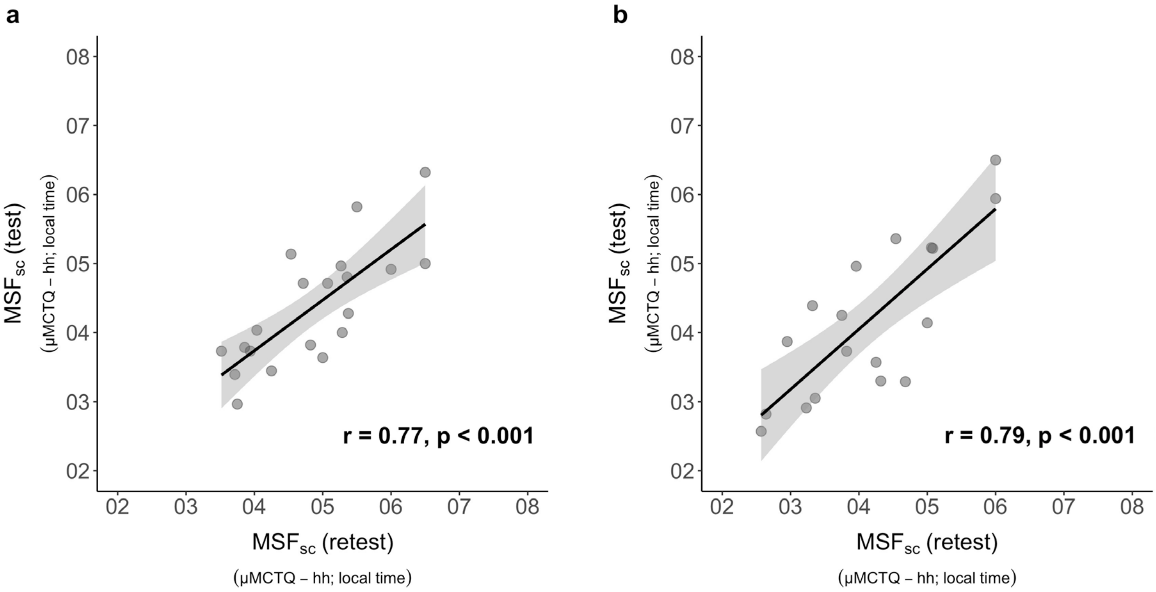


***Figure S9.*** *Test-retest reliability of the µMCTQ within ~60 days (a) and ~14 days (b). Data are expressed in local time for both variables. N = 20 (a) / N = 18 (b).*

## 7. Study 3: Correspondence of the standard MCTQ-MSF$_{sc}$ with activity phase (Ψ_Act)

**Methods**

To systematically validate chronotype assessment by the standard MCTQ (stdMCTQ) against activity phase, we combined data sets from several different studies in which the stdMCTQ had been used in combination with actimetry.

Participants: 117 individuals were selected from our growing actimetry study database. Inclusion criteria were 18 years or older, a minimum of 14 days of actimetry with at least 5 workdays/work-free days. Three outliers were excluded (Ψ_Act, 3 IQR below Q1 or above Q3). The resulting cohort consisted of 69 women (61%), with a mean age of 33.5 years (±12.25, range: 18-81).

Study Design: We compared the average Ψ_Act across all days, as well as Ψ_Act$_w$ and Ψ_Act$_f$ with MSF$_{sc}$ calculated from the stdMCTQ, which was usually applied at the beginning of the studies.

Actimetry: Activity was recorded at 1 Hz and average activity counts stored at a 30s-resolution. Data were averaged into 10min-bins for analyses and are expressed in local time. Ψ_Act, Ψ_Act$_w$ and Ψ_Act$_f$ were calculated as described in the Actimetry section of the main text (Study 2). For the calculation of Ψ_Act,, days that were not specified as workdays or work-free days were also included. In order to achieve a value of Ψ_Act accurately reflecting activity phase before sleep onset, we set a threshold for Ψ_Act occurring before 6am. The threshold was determined since less than 1% of Ψ_Act data occurred between midnight and 6 am and we therefore propose that the correction does not have a large effect on the results. However when not correcting by using the threshold, similar results were obtained. The following number of days went into the analyses: (1) Ψ_Act range: 14 – 52, mean: 28. (2) Ψ_Act$_w$ range: 6 – 37, mean: 17. (3) Ψ_Act$_f$ range: 5 – 23, mean: 10.

Test-retest reliability: Additionally, we used data from 19 subjects (11 women, mean age 34.2 ± 18.9, range 18 – 56 years old) to test the stdMCTQ-MSF$_{sc}$ reliability by correlating two assessments, which were taken in autumn and in the following spring.

Statistical analysis: Normal distribution was checked by visual inspection of the histograms. The correlations between MSF$_{sc}$ and Ψ_Act, Ψ_Act$_w$ and Ψ_Act$_f$ were tested using Pearson and Spearman correlations. SPSS 24 and GraphPad Prism 6 were used for statistical analysis. Graphs were plotted using the R package ggplot2.

**Results**

Chronotype as estimated by the stdMCTQ (MSF$_{sc}$) correlates with Ψ_Act (Fig. S9a), Ψ_Act$_w$ (Fig. S9b) and Ψ_Act$_f$ (Fig. S9c).

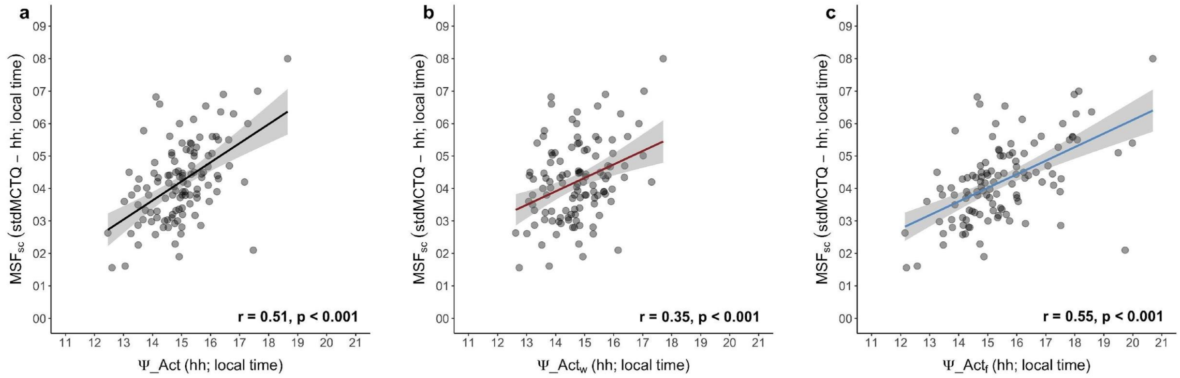


***Figure S10**. Pearson correlations between chronotype- indicator ($MSF_{sc}$) from the stdMCTQ and Ψ_Act from actimetry for all days (a) and separately for workdays (b) and work-free days (c). The grey shaded area around the regression line represents the 95% confidence interval. Pearson. N = 114, (Study 3: Validation of the stdMCTQ against actimetry).*

Correlations between stdMCTQ and Ψ_Act according to age categories can be seen in Figure S10.

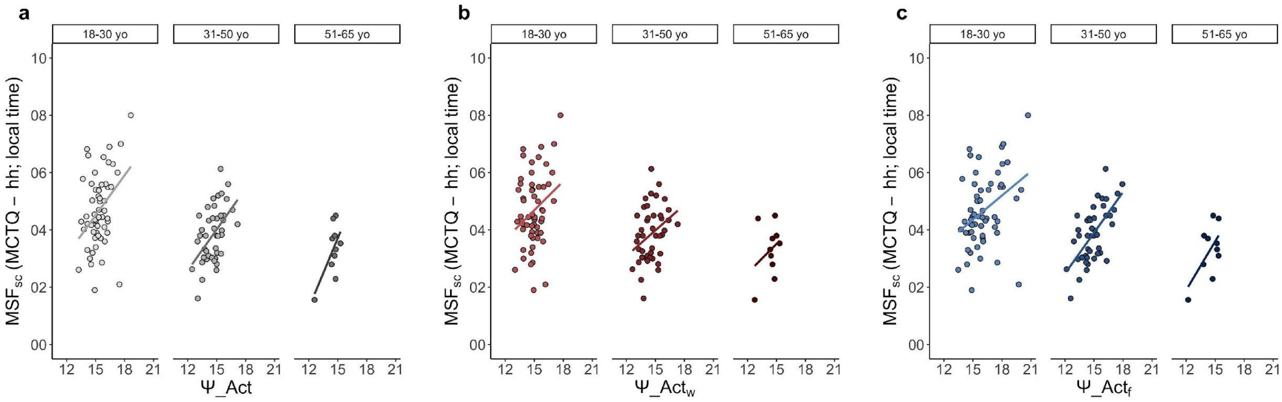


***Figure S11.** Association between stdMCTQ $MSF_{sc}$ and Ψ_Act (a) $Ψ\_Act_w$ (b) and $Ψ\_Act_f$ (c) across age categories. (a) <u>18-30 yo</u>: $r = 0.38$, $p < 0.01$; <u>31-50 yo</u>: $r = 0.51$, $p < 0.001$; <u>51-65 yo</u>: $r = 0.35$, $p = 0.33$. (b) <u>18-30 yo</u>: $r = 0.27$, $p < 0.05$; <u>31-50 yo</u>: $r = 0.32$, $p < 0.05$; <u>51-65 yo</u>: $r = 0.32$, $p = 0.37$. (c) <u>18-30 yo</u>: $r = 0.37$, $p < 0.01$; <u>31-50 yo</u>: $r = 0.64$, $p < 0.001$; <u>51-65 yo</u>: $r = 0.42$, $p = 0.23$. Pearson for age categories 18- 30 (n = 59) & 31 – 50 (n = 43). Spearman for age category 51 – 65 (n = 10), since small sample size and not normal distribution. Data from Study 3: correspondence of the stdMCTQ-$MSF_{sc}$ with activity phase (Ψ_Act).*

Figure S11 shows $MSF_{sc}$ test-retest reliability. Additionally, the correspondence between Ψ_Act is shown.

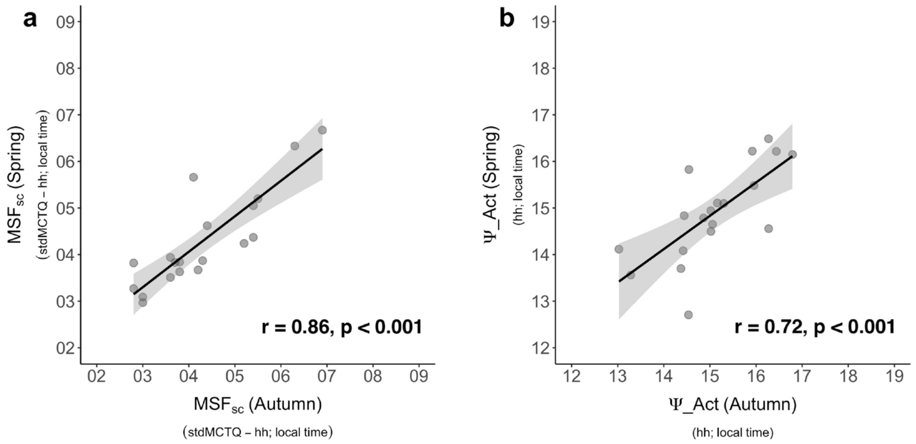


***Figure S12.** Correspondence of stdMCTQ $MSF_{sc}$ (a) and Ψ_Act (b) measured at two different time points (in spring and autumn). Pearson. N = 19. Data from Study 3: Validation of the stdMCTQ against activity phase**.***

**Discussion**

To complete the picture, in addition to the first validation of the µMCTQ, which is presented in the main text, data that support the validity of the standard MCTQ is presented in this supplementary material.

The stdMCTQ-derived chronotype- indicator ($MSF_{sc}$) corresponded well with Ψ_Act calculated from actimetry data in a relatively large and heterogeneous sample. This is in agreement with previous work that showed a good correspondence of sleep timing derived from the stdMCTQ and results from actimetry (using commercial algorithms to detect sleep timing, Santisteban et al., 2018). Sleep variables derived from actimetry and from the stdMCTQ also corresponded in rural populations who have a clear concept of clock time but not always use clocks to organise their daily activities (Pilz et al., 2018). $MSF_{sc}$ also showed good correlation with weighted mid-sleep times calculated from sleep-logs in young healthy volunteers ($r = 0.80$, Blautzik et al., 2013). In our study, statistically significant associations between the stdMCTQ-$MSF_{sc}$ and Ψ_Act, Ψ_$Act_w$, and Ψ_$Act_f$ were also detectable across age categories. These results support the validity of the stdMCTQ-$MSF_{sc}$ as an indicator of chronotype, Furthermore, the stdMCTQ-based chronotype has also been shown to correlate with timing of melatonin onset in varying samples (Facer-Childs et al., 2019; Kantermann et al., 2015; Kitamura et al., 2014; Wright et al., 2013) and an increasing number of studies report that it correlates with the timing of other physiological functions (Nováková et al., 2013; Peres et al., 2011).

In conclusion, the data gathered by these studies suggest that the stdMCTQ offers a reliable alternative to the continuous and objective assessment of subjects through actimetry, as it delivers valuable information on the individuals' phase of entrainment.

**Limitations:**

- The stdMCTQ was applied at the beginning in most studies of our actimetry database. This results in different periods assessed by the stdMCTQ (the weeks before the study) and actimetry (during the study).
- The differences of age ranges in the cohorts should also be taken into account. Participants were between 18-81 years of age in study 3 (correspondence between stdMCTQ and actimetry). The age range of subjects in study 1 (validation of µMCTQ vs. stdMCTQ) was <20 to 75 years and finally subjects of study 2 (µMCTQ vs. actimetry/DLMO) were between 19 and 35 years (see Table S1).

## References:


Blautzik, J., Vetter, C., Peres, I., Gutyrchik, E., Keeser, D., Berman, A., Kirsch, V., Mueller, S., Pöppel, E., Reiser, M., et al. (2013). Classifying fMRI-derived resting-state connectivity patterns according to their daily rhythmicity. NeuroImage *71*, 298–306.

Facer-Childs, E.R., Campos, B.M., Middleton, B., Skene, D.J., and Bagshaw, A.P. (2019). Circadian phenotype impacts the brain's resting-state functional connectivity, attentional performance, and sleepiness. Sleep.

Kantermann, T., Sung, H., and Burgess, H.J. (2015). Comparing the Morningness-Eveningness Questionnaire and Munich ChronoType Questionnaire to the Dim Light Melatonin Onset. J. Biol. Rhythms *30*, 449–453.

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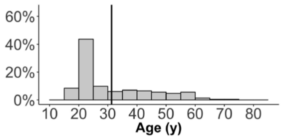
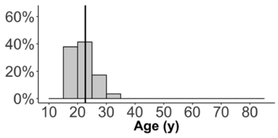
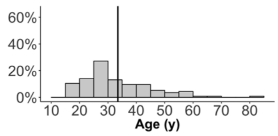
Pilz, L.K., Levandovski, R., Oliveira, M.A.B., Hidalgo, M.P., and Roenneberg, T. (2018). Sleep and light exposure across different levels of urbanisation in Brazilian communities. Sci. Rep. *8*, 11389.

Santisteban, J.A., Brown, T.G., and Gruber, R. (2018). Association between the Munich Chronotype Questionnaire and Wrist Actigraphy. Sleep Disord. *2018*, 5646848.

Wright, K.P., McHill, A.W., Birks, B.R., Griffin, B.R., Rusterholz, T., and Chinoy, E.D. (2013). Entrainment of the Human Circadian Clock to the Natural Light-Dark Cycle. Curr. Biol. *23*, 1554–1558.

## 8. Dataset Characteristics

TABLE S1 - Datasets Characteristics

| | **µMCTQ vs. stdMCTQ (Study 1)** | **µMCTQ vs. DLMO/Ψ_Act (Study 2)** | **stdMCTQ vs Ψ_Act (Study 3)** |
|---|---|---|---|
| | N = 213 | N = 29 | N = 114 |
| Sex - female: n (%) | 129 (61) | 13 (45) | 69 (61) |
| Age (years): mean ± SD | 31.3 ± 13.0<br>(range: 18-75) | 22.7 ± 3.6<br>(range: 19-33) | 33.5 ± 12.25<br>(range: 18-81) |
| Age distribution of sample: |  |  |  |
| <u>Validation study variables</u> | | | |
| $MSF_{sc}$ (h) mean ± SD | **stdMCTQ:** 4:45 ± 1:13<br>**µMCTQ:** 4:29 ± 1:14 | 4:27 ± 1:01 | 4:13 ± 1:13 |
| DLMO (h) mean ± SD | | **WD:** 21:25 ± 1:16<br>**FD:** 22:05 ± 1:28 | - |
| Ψ_Act (h) mean ± SD | | 16:12 ± 1:05<br>**WD:** 15:54 ± 0:59<br>**FD:** 16:47 ± 1:24 | 14:59 ± 1:04<br>**WD:** 14:44 ± 1:02<br>**FD:** 15:28 ± 1:36 |

Three datasets were used in this study for validating the µMCTQ against the stdMCTQ (column 1), for validating the µMCTQ against DLMO and Ψ_Act (column 2) and for assessing the correspondence between the stdMCTQ-$MSF_{sc}$ and Ψ_Act (column 3). *MCTQ*: Munich ChronoType Questionna fire; *µMCTQ*: ultra-short version of the stdMCTQ; *$MSF_{sc}$*: midpoint between sleep on- and offset on free days corrected for potential oversleep on free days to compensate for the sleep debt accumulated over the workweek; DLMO: dim light melatonin onset; *Ψ_Act*: centre of gravity of activity.

**6. MCTQ and µMCTQ variables computation**

TABLE S2 – MCTQ and µMCTQ variables computation

| | Abbreviation | MCTQ | µMCTQ |
|---|---|---|---|
| Number of work-/work-free days per week | WD/FD | From the question: I have a regular work schedule and work ___ days a week. | From the question: Normally, I work ___ days/week. |
| Local time of going to bed WD/FD | $BT_w$ / $BT_f$ | From the question: I go to bed at __:__ o'clock (on workdays / free days) | - |
| Sleep Latency WD/FD | $SLat_w$ / $SLat_f$ | From the question: I need ___ minutes to fall asleep (on workdays / free days) | - |
| Sleep Onset WD/FD | $SO_w$ / $SO_f$ | Local time of preparing to sleep + Latency (on workdays / free days) | From the question: I normally fall asleep at __:__ AM/PM (on workdays / on work-free days when I DON'T use an alarm clock). |
| Sleep End WD/FD | $SE_w$ / $SE_f$ | From the question: I wake up at __:__ o'clock (on workdays / free days) | From the question: I normally wake up at __:__ AM/PM (on workdays / on work-free days when I DON`T use an alarm clock). |
| Alarm clock use (y/n) WD/FD | $Alarm_w$/ $Alarm_f$ | From the question: I use an alarm clock on workdays/ My wake up time is due to the use of an alarm clock. (free days) | - |
| Sleep inertia WD/FD | $SI_w$ / $SI_f$ | From the question: After ___ minutes, I get up. (on workdays / on free days) | - |
| Sleep Duration WD/FD | $SD_w$ / $SD_f$ | $SE_w - SO_w$<br>$SE_f - SO_f$ | $SE_w - SO_w$<br>$SE_f - SO_f$ |
| Midpoint of Sleep WD/FD | MSW / MSF | $SO_w + (SE_w - SO_w)/2$<br>$SO_f + (SE_f - SO_f)/2$ | $SO_w + (SE_w - SO_w)/2$<br>$SO_f + (SE_f - SO_f)/2$ |
| Average weekly sleep duration | $SD_{week}$ | $(SD_w \times WD + SD_f \times FD)/7$ | $(SD_w \times WD + SD_f \times FD)/7$ |
| Chronotype (MSF corrected for oversleep) | $MSF_{sc}$ | If $SD_f \leq SD_w$. $MSF_{sc} = MSF$;<br>If $SD_f > SD_w$,<br>$MSF_{sc} = MSF - (SD_f - SD_{week})/2$ | If $SD_f \leq SD_w$. $MSF_{sc} = MSF$;<br>If $SD_f > SD_w$,<br>$MSF_{sc} = MSF - (SD_f - SD_{week})/2$ |

*MSF and $MSF_{sc}$ can only be used as a proxy for chronotype- indication if alarm clock is not used on work-free days.