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Frequency and Strategicness of Clock-Checking Explain Detrimental Age-Effects in Time-Based Prospective Memory

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This first submitted version of the manuscript has been uploaded as a preprint at https://psyarxiv.com/2msk9/ on November 23, 2021 and has been presented in a preliminary version as a poster at the Geneva Aging Series conference in September 2021. The data presented in this study stem from a broader project assessing time-based prospective memory both in the laboratory and online (Haas et al., 2021; Zuber et al., 2021). De-identified data, analytical codes and material are openly available at https://osf.io/zxbpa/ and in the supplemental material, respectively. Task scripts are available for download at https://cigev.unige.ch/openscience/. Please note that the pictures from Snodgrass and Vanderwart (1980) are protected by copyright, and may not be shared freely. Accordingly, the E-Prime file for the task is available online, but without the corresponding pictures.

Researchers that would like to use the task can either buy the rights for the picture set or replace them with equivalent free picture data sets (e.g., Moreno-Martínez & Montoro, 2012; Rossion & Pourtois, 2004). We have no conflict of interest to disclose. We gratefully acknowledge funding from the Swiss National Science Foundation (SNSF) under Grant 100019_165572 and under the Swiss National Center of Competences in Research LIVES – Overcoming vulnerability: life course perspectives (grant number: 51NF40-185901). We thank Estelle Gillioz, Vanessa Garcia, Annick Hottelier, Laurène Kuhn, Clémentine Laboret, Laura Pede for their assistance in study preparation and data collection. Correspondence concerning this article should be addressed to Emilie Joly-Burra, University of Geneva (CIGEV), Boulevard du Pont d'Arve 28, CH- 1205 Genève, SWITZERLAND. Email: Emilie.Joly@unige.ch

Abstract

Previous studies report that monitoring the passing of time by checking a clock either frequently or strategically (immediately before a target-time) improves the likelihood of remembering to perform a planned intention at a specific time (i.e., time-based prospective memory, TBPM). Critically, strategicness of clock-checking is usually measured as the number of clock-checks during the last time interval before the target-time – an operationalization where strategicness actually intertwines with absolute frequency of clock-checking and may not properly account for age-effects in TBPM performance. To disentangle the respective contribution of frequent vs. strategic clock-checking to the age-related decrease in TBPM performance, we propose a new, more fine-grained indicator of strategicness (i.e., *relative clock-checking*), which accounts for interindividual differences in the total frequency of clock-checking (i.e., *absolute clock-checking*). In this study, 223 participants from an adult lifespan sample (age-range = 19-86, M = 45.61, SD =17.24; 70% women) had to remember to push the ENTER key every 60 seconds while performing a 2-back picture decision task. Together, relative and absolute clock-checking fully mediated the negative age-effect on TBPM and explained 53.6% of the variance of TBPM performance. Complementary analyses revealed that both indicators were needed to fully mediate the effect of age on TBPM, but that strategic (i.e., relative) clock-checking was a stronger predictor of TBPM performance than absolute clock-checking. These results stress the importance of considering both aspects of clock-checking to investigate time monitoring in laboratory TBPM tasks and age effects therein, and provide avenues of intervention for improving older adults' TBPM.

Keywords: Prospective Memory; Time-based; Monitoring; Lifespan; Aging

Abstract word count: 249 (Max authorized: 250)

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Public Significance:

By using a new indicator for the strategicness of clock-checking we showed that older adults' tendency to check the time less frequently and less strategically than younger adults fully explained why they were more prone to forgetting to carry out planned intentions. These results suggest simple strategies to improve older adults' time-based prospective memory, such as setting alarms at specific strategic times.

Public Significance word count: 62 words (Max authorized: 70)

Frequency and Strategicness of Clock-Checking Explain Detrimental Age-Effects in Time-Based Prospective Memory

Prospective memory (PM), the ability to carry out a planned intention at a specific moment in the future, is an essential predictor of autonomy throughout the lifespan and represents one of the key indicators of cognitive functioning in older adults (Hering et al., 2018; Woods et al., 2012). Unfortunately, in everyday life people often fail to remember PM tasks (Haas et al., 2020) and laboratory studies show that PM performance typically decreases with age (Henry et al., 2004; Zuber & Kliegel, 2020; but also see Schnitzspahn et al., 2020). Given its fundamental role to manage everyday tasks – particularly for older adults – a key goal of PM research is to identify factors that explain age-related differences in PM performance (Kliegel et al., 2016).

In all PM tasks, one has to form an intention, retain it while performing one or more other tasks, and then initiate and execute the intention when appropriate (Kliegel et al., 2002). In time-based PM (TBPM) tasks, intentions have to be performed at a particular time or after a certain time has elapsed (e.g., taking a cake out of the oven after 45 minutes, or pressing a specific key after 5 minutes in a laboratory task). Detecting the appropriate moment to perform the intention additionally requires actively monitoring the progression of time. For instance, to make sure not to under- or overcook a cake without setting an alarm, one has to check the clock regularly to monitor the passing of time while attending other activities. Indeed, one of the main factors contributing to successful TBPM performance is time monitoring behavior – that is, how often or when one checks the clock (e.g., Mioni & Stablum, 2014; Vanneste et al., 2016). So far, studies have examined the role of clock-checking with two different, typically separate, approaches.

One approach examines clock-checking in terms of *absolute frequency*, that is, how often participants check the clock (across the entire PM trial). Typically, participants who check the clock more often perform better on the TBPM task (Henry et al., 2004; Jäger & Kliegel, 2008; Mioni et al., 2020). In relation to age differences, some studies have shown that older adults checked the clock less frequently than younger adults and displayed lower TBPM performance (Maylor et al., 2002; McFarland & Glisky, 2009; Mioni et al., 2020; Mioni & Stablum, 2014; Park et al., 1997; Vanneste et al., 2016; Waldum & McDaniel, 2016). In other studies, it appears that older adults checked the clock more frequently than younger adults and displayed similar levels of TBPM performance (Logie et al., 2004; Mäntylä et al., 2009; Maylor et al., 2002; Mioni & Stablum, 2014; but see Gonneaud et al., 2011; Jäger & Kliegel, 2008, for no age-related differences). Thus, absolute frequency of clock-checking seems to play a crucial role in predicting TBPM performance, and older adults might compensate the age-related decline in TBPM ability by checking the clock more frequently than younger adults. However, the studies examining absolute frequency have not specifically investigated whether an increased frequency of clock-checking during the task in older adults actually explains why older adults may at times perform equally well as younger adults.

The second approach examines clock-checking behavior in terms of the *distribution*, rather than absolute frequency, of clock-checks – that is, they focus on when those clock-checks occur in relation to the TBPM target-time – a measure that provides insights into the *strategicness* of clock-checking (e.g., Jäger & Kliegel, 2008). So far, most of these studies deduced strategicness by examining how clock-checks are distributed across the TBPM trial (e.g., by counting clock-checks in a 5-minute trial separately for five intervals of 1 minute each, and then comparing clock-checks across these five intervals). Examining the strategic distribution of clock-checking showed that the number of clock-checks typically increases as the target-time approaches (e.g., Mioni & Stablum, 2014; Vanneste et al., 2016). However, while the link between absolute frequency and TBPM performance is rather well established, only a few studies have related the strategicness of clock-checking to TBPM performance.

They typically evaluated how the number of clock-checks in the last time interval (immediately before the TBPM target-time) affected TBPM performance and showed that the more individuals checked the clock during that last interval, the better their performance on the TBPM task (Jäger & Kliegel, 2008; McFarland & Glisky, 2009; Mioni et al., 2020; Mioni & Stablum, 2014). Looking at the trial level, Maylor et al. (2002) showed that the frequency of clock-checking increased as the target-time approached in successful, but not in failed, TBPM trials. Hence, checking the clock strategically enhances TBPM remembering.

In the context of aging, studies generally showed that older adults checked the clock less strategically than younger adults (Einstein et al., 1995; Maylor et al., 2002; McFarland & Glisky, 2009; Mioni et al., 2020; Mioni & Stablum, 2014; Vanneste et al., 2016), although others found no age-related differences in strategic clock-checking (Jäger & Kliegel, 2008; Logie et al., 2004). Most importantly, even though McFarland and Glisky (2009) suggested that interindividual differences in strategicness of clock-checking may explain age-related differences in TBPM performance, the role of such differences is currently unclear.

Examining both aspects of clock-checking has provided important insights into the relationship between clock-checking and TBPM performance and into age-related differences in clock-checking behavior. However, because these approaches have mostly been examined separately, and hardly ever together within a single study, it remains unknown whether they predict unique aspects of TBPM performance or are redundant predictors. In one rare study evaluating the impact of both absolute and strategic clock-checking frequency on TBPM performance, Voigt et al. (2014) showed that both aspects predicted TBPM performance in 5- to 14-year-old children. Specifically, checking the clock overall more often, but also increasingly checking it from the second-to-last to the last time interval, both predicted better TBPM performance in children. Nevertheless, because the authors assessed the contribution of the two aspects of clock-checking in separate analyses, it remains unclear whether they predict

TBPM performance when analyzed together. Moreover, it is yet unknown whether the two aspects of clock-checking differentially and directly explain adult age differences in TBPM – that is whether age-related impairments in TBPM performance are specifically due to age or driven by age-related interindividual differences in absolute frequency and/or strategicness of clock-checking.

Previous operationalization of the two aspects of clock-checking behavior prevents a proper evaluation of their respective contribution to TBPM performance. As illustrated in Figure 1, it is possible that certain individuals check the clock quite rarely (i.e., low absolute frequency), but that these few clock-checks are used very strategically (i.e., very few clock-checks in early intervals and many more in the last time interval). In contrast, other individuals may check the clock much more frequently (i.e., high absolute frequency), but may check at a similar rate across all time intervals, thus reflecting a less strategic clock-checking behavior. Hence, in the classical indicator of strategicness – that is, examining the number of clock-checks during the last time interval before the target-time – strategicness actually intertwines with absolute frequency.

To properly *distinguish between the two aspects of clock-checking* and to capture interindividual differences in time monitoring behavior more accurately, we set out to develop a new, more fine-grained, indicator of strategicness of clock-checking. This indicator, which we will label *relative clock-checking,* reflects the number of clock-checks in the last time interval before the target-time relative to the total number of clock-checks across the PM trial. Specifically, this indicator is computed as the percentage of clock-checks occurring in the last time interval (averaged across multiple TBPM trials). Hence, high scores indicate that relative to the total number of clock-checks, a participant mostly checks the clock immediately before the target-time, a pattern that reflects a high strategic clock-checking behavior. In contrast, low scores would indicate that only few of the clock-checks occurred immediately before the target-time, a pattern that reflects a low strategic clock-checking behavior.

Accordingly, the first aim of the present study was (a) to propose a new indicator of strategicness of clock-checking (i.e., relative clock-checking) that accounts for the effect of absolute clock-checking frequency in the relationship between strategicness of clock-checking and age-related differences in TBPM performance. Further, extending Voigt et al. (2014) and McFarland and Glisky (2009), subsequent aims were (b) to investigate the respective and concomitant effect of absolute and relative clock-checking frequency on TBPM performance, (c) to test for age-related differences in these indicators, and (d) to examine whether these differences account for (i.e., mediate) age effects in TBPM performance in an adult lifespan sample. The final aim of the present study was to compare the relative clock-checking indicator with the classical indicator of strategicness of clock-checking in predicting TBPM performance and age effects therein.

Method

Transparency and Openness

We report how we determined our sample size, and describe all data exclusions, manipulations, and all measures in the study. The data presented in this study stem from a broader project assessing different cognitive abilities both in the laboratory and online (Haas et al., 2021; Zuber et al., 2021). This project primarily aimed to examine the online administration of two newly developed tools, one assessing TBPM in a serious-game like environment (i.e., the Geneva Space Cruiser, Zuber et al., 2021) and the other assessing general cognitive abilities (i.e., eCOGTEL, Haas et al., 2021). Data collection was split into three assessment sessions. For all participants, the first session was administered in the laboratory and included a series of cognitive measures, such as the classical laboratory TBPM task, which will be the specific focus of the present study. Thus, all data and variables investigated in the present paper were collected during the first session only (see Supplemental Material A for additional details regarding the full study protocol, including all manipulations and measures). De-identified data are openly available at the Open Science Framework (OSF), https://osf.io/zxbpa/. Links to the materials and analytical codes for the mediation models are available in the Supplemental Material A and B, respectively. The E-Prime2 script for the TBPM task is openly available online at https://cigev.unige.ch/openscience/. The study design, hypotheses, and analytic plans were not preregistered.

Participants

Because the aims of the broader project were to assess whether the two online assessment tools had satisfactory data distribution and sensitivity across the adult lifespan, and represented comparable alternatives to more traditional laboratory tasks, we set out to recruit an age-stratified adult lifespan sample. We therefore aimed to recruit between 40 and 50 participants in each age stratum (five 10-year strata from 19 to 69 years, plus a stratum for participants aged 70 and above), for a total of 240 to 300 participants. Participants were recruited via experimenters' networks, networks of former participants, and flyers distributed in public places. Young participants were also recruited from an undergraduate course in psychology (they were required to be unacquainted with prospective memory tasks). In exchange for participation, students received eligibility to take the course exam (but were not awarded any course credits). Students refusing could of course gain eligibility by an alternative activity. Importantly, data collection was impacted by the COVID-19 outbreak before we could complete recruitment for middle-aged (30-39 and 40-49 strata) and older participants (> 70 stratum). Given the sanitary conditions, we decided to stop recruitment at 262 participants, a number that was within the range of our initial sample size goal.

We excluded 39 participants because of issues with data recording (*n* = 10), outlier (± 2.5 SD) or missing values on crystallized intelligence or fluid intelligence (details below, *n* = 7); an inability to recall the TBPM instructions at the end of the task (*n* = 8); and in case performance was below the value for the fifth percentile in the ongoing task (OT, see the TBPM task section below; corresponding to an overall accuracy of 53.53% or lower, *n* = 14).

The final sample comprised 223 individuals aged between 19 and 86 years (*M* = 45.61, *SD* =17.24; 70% women, see Table 1 for number of participants, mean and standard deviation of age and percentage of women in each age stratum). Education ranged from compulsory education to doctorate (*M* = 15.87 years, *SD* = 3.36), and participants did not show major impairment in fluid and crystalized intelligence as indicated by the Matrices subtest of the WAIS-IV (*M* = 19.10, *SD* = 4.42, Wechsler, 2008) and the Mill Hill Vocabulary scale (*M* = 24.74, *SD* = 4.60; Deltour, 1993). Additional information on participants' race/ethnicity was not collected, as this is not common practice in the country of data collection (Switzerland). The study was conducted in accordance with the Declaration of Helsinki and with APA ethical standards, and the protocol was approved by the Ethical Committee of the Faculty of Psychology and Educational Sciences at the University of Geneva (decision protocol: PSE.20180803.02).

Material and Procedure

Participants first gave their informed consent and filled out a socio-demographic questionnaire (see Supplemental Material A). They then completed the TBPM task (details below). Participants filled out the Mill Hill Vocabulary Scale (Deltour, 1993) as delay phase between the TBPM instructions and the actual PM task (see Time-Based Prospective Memory task subsection below). Finally, participants completed the Matrices subtest of the WAIS-IV as a measure of fluid intelligence (Wechsler, 2008). No experimental manipulation was involved regarding the data analyzed in the present study.

TBPM Task

The TBPM task was embedded in a typical n-back picture decision task (for studies using similar paradigms, see e.g., Altgassen et al., 2010; Ballhausen et al., 2017; Chen et al., 2017; Cona et al., 2015; Einstein et al., 1992; Einstein & McDaniel, 1990; Jäger & Kliegel, 2008; Oksanen et al., 2014). In this n-back task, referred further as the ongoing task (OT), participants had to decide whether the picture presented at each trial was the same as the picture presented two trials before (2-back picture decision task). If the pictures were identical (i.e., hit trials), participants had to push the green button (i.e., right arrow on the keyboard), whereas they had to push the red button (i.e., left arrow on the keyboard) if the pictures were different (i.e., no-hit trials). Each picture was presented during 1000ms preceded by a 1500ms fixation cross. Pictures were selected from the Snodgrass and Vanderwart (1980) picture set. Participants first completed a practice block, in which they had to provide correct responses for at least 10 out of 14 practice trials. In case participants responded correctly to fewer than 10 trials, they repeated the practice block until successful completion. After the practice block, participants completed an OT-only block of 48 trials (not analyzed in the present study).

Then, the experimenter gave the instructions for the TBPM task. Specifically, participants were instructed that, in addition to performing the OT (i.e., 144 trials, of which 103 no-hit and 41 hit trials, lasting for six minutes in total), they had to remember to push the ENTER key every 60 seconds (i.e., the TBPM task; to be performed at 60 seconds, 120 seconds, etc.; six TBPM target-times in total). To check the time, participants could press the spacebar, which displayed a clock at the bottom of the screen during 3 seconds (format: mm:ss). Participants completed the Mill-Hill vocabulary Scale to introduce a delay between the TBPM instructions and the task, and they were not reminded of the TBPM instructions before beginning the task. Finally, at the end of the task, participants were asked to summarize task instructions to ensure that they understood and remembered the TBPM instructions. The task was programmed and run on Eprime 2.0 (Psychology Software Tools, Inc., 2012).

TBPM performance was operationalized as the percentage of correctly performed TBPM trials (i.e., pressing the ENTER key during a response window of ± 5 seconds of the target-time), and OT performance was assessed as the percentage of correct responses on all OT trials. We recorded the number and time of clock-checks to compute both indicators of absolute and relative clock-checking frequency. Specifically, to compute the relative clock-checking frequency, we first separated each trial (i.e., 60s) of the task (i.e., the six TBPM trials) into four consecutives intervals of 15 seconds each (T1, T2, T3, and T4). We then divided the number of clock-checks during the last time interval[i] (T4) by the total number of clock-checks during each trial (T1 to T4) and averaged these values across the six trials for each participant (relative clock-checking = $\left(\frac{\sum_{i=1}^{6} \frac{T4_t}{T1_t + T2_t + T3_t + T4_t}}{6} \right)$, where t = trial).

This resulted in a single percentage score, where higher scores indicate highly strategic time monitoring behaviors.

Analytical Approach

In a structural equation modeling framework, to address our main research questions, we first tested whether age predicted TBPM performance and whether this effect was mediated by absolute and relative clock-checking (Model 1). Second, in two subsequent models, we tested whether accounting for each of the clock-checking indicators separately was sufficient to fully mediate the effect of age (Models 2 and 3), or whether both indicators were needed. Finally, to compare the predictive power of the two alternative strategicness indicators, we replaced relative clock-checking in Model 1 with the number of clock-checks in the last time interval before the target-time (further called *T4 clock-checking;* see Model 4). To rule out potential confounds, we controlled for the effects of education, sex, and crystallized and fluid intelligence in all models. Hence, the number of years of education, sex, and the score on the WAIS-IV matrices and Mill-Hill vocabulary scale were set to predict TBPM performance directly and indirectly through clock-checking indicators in all models (see Figure 2 for a diagram of the model). In Models 1 and 4, residual variances of the clock-checking indicators were allowed to covary. All four models were saturated, and thus fitted the data perfectly, and for this reason we do not report fit indices. Indeed, the purpose was not to propose models that reproduce the structure of the data, but in comparing predictive power (β-weights and R^2) across models with different strategicness indicators. Models were estimated using Maximum Likelihood estimation using the package lavaan (version 0.6-9; Rosseel, 2012) in RStudio (version 1.4.1717; Rstudio Team, 2021; using R version 4.1.2; R Core Team, 2020). We estimated 95% confidence intervals (CI) for the direct, indirect, and total effects using bias corrected bootstraps. The indirect effects are reported as indexes of mediation (Preacher & Kelley, 2011).

Additional exploratory analyses were conducted to follow-up on our main results. First, we computed an alternative model to Model 1 (Model 1a) to test whether relative clock-checking predicted TBPM performance more strongly than absolute clock-checking. Therefore, we constrained the two regression weights to be equal in Model 1a and performed a likelihood ratio test to compare model fit with Model 1. Second, because age, sex and performance on the matrices predicted PM performance and/or clock-checking indicators, we computed partial correlations between OT performance, PM performance, and absolute and relative clock-checking controlling for age, sex and matrices, to assess potential trade-off effects between the OT and time-monitoring behavior.

Results

Accuracy for the OT was high (*M* = 85.32%, *SD* = 9.22, range = 54.93-97.89), while accuracy for the TBPM task was close to 50% (*M* = 51.27%, *SD* = 35.37, range = 0-100). There was a small but significant positive correlation between OT and TBPM performance ($r(222) = .13$, $p = .048$), meaning that participants with better OT performance also had better TBPM performance. Age was associated with worse performance on the OT and TBPM task ($r(222) = -.35$, $p < .001$ and $r(222) = -.38$, $p < .001$ respectively). Regarding clock-checking behavior, there were important between-person variations for absolute (*M* = 9.86, *SD* = 7.92, range = 0-38) and relative clock-checking frequency (*M* = 29.22%, *SD* = 21.94, range = 0-100). The two indicators correlated positively and moderately ($r(222) = .57$, $p < .001$), indicating that participants who checked the clock frequently also tended to check the clock strategically. Absolute and relative clock-checking correlated positively and strongly with TBPM performance ($r(222) = .67$, $p < .001$ and $r(222) = .76$, $p < .001$, respectively). We report descriptive statistics and correlations between variables of interest in Table 2.

Do Absolute and Relative Clock-Checking Mediate the Association Between Age and TBPM Performance?

In Model 1, age negatively predicted TBPM performance ($\beta = -0.32$, $z = -3.95$, $p < .001$, as indicated by the total effect), absolute clock-checking ($\beta = -0.32$, $z = -4.14$, $p < .001$), and relative clock-checking ($\beta = -0.24$, $z = -2.78$, $p = .006$). In turn, both absolute ($\beta = 0.32$, $z = 7.26$, $p < .001$) and relative clock-checking ($\beta = 0.56$, $z = 13.28$, $p < .001$) positively predicted TBPM performance. Importantly, as indicated by standardized estimates, relative clock-checking predicted TBPM almost twice as strongly as absolute clock-checking ($\beta = 0.56$ vs. $\beta = 0.32$). To test the difference between the two coefficients, we examined an alternative model (Model 1a), in which the two corresponding regression weights were constrained to be equal. As indicated by the likelihood ratio test between Models 1 and 1a

($\Delta\chi^2(1, N = 223) = 4.19, p = .041$), this constraint significantly worsened model fit, thereby confirming that there is a significant difference between the weights of the two parameters. Consequently, checking the clock more strategically contributed more strongly to TBPM performance than checking the clock frequently.

The direct effect of age on TBPM performance was not significant when accounting for absolute and relative clock-checking ($\beta = -0.09, z = -1.80, p = .071$), while the indirect effects through absolute ($\beta = -0.10, z = -3.72, p <.001$) and relative clock-checking ($\beta = -0.13$, $z = 2.66, p =.008$) were significant. Hence, the two clock-checking indicators together fully mediated the association between age and TBPM performance.

Regarding the control variables, sex had a direct effect on TBPM performance ($\beta = 0.09, z = 2.08, p = .037$). Men's performance was on average 7.08% higher than women's. Higher scores on fluid intelligence predicted more strategic clock-checking behaviors ($\beta = 0.15, z = 1.97, p = .049$). Although the p-value for the indirect effect was just below significance, we rely on the robust CI to conclude that higher fluid intelligence lead to better TBPM performance through its positive effect on relative clock-checking ($\beta = 0.08, z = 1.95$, $p = .051$, 95% CI [0.01, 1.34]). All other effects were non-significant. We report estimates for the direct, indirect, and total effects of Model 1 in Table 3.

All predictors in Model 1 accounted for 11.3% of absolute clock-checking, 12.3% of relative clock-checking, and 67.8% of TBPM performance. Age alone explained 12.1 % of the variance in TBPM performance, and the control variables added 2.1%[ii]. Finally, the two clock-checking indicators together explained 53.6% of additional variance in TBPM performance.

Are Both Indicators of Clock-Checking Needed to Fully Mediate the Relationship Between Age and TBPM Performance?

Keeping all other covariates in the model, we tested whether absolute (Model 2) or relative clock-checking (Model 3) separately mediated the association between age and TBPM performance. We report estimates for the direct, indirect, and total effects of Models 2 and 3 in Tables 4 and 5, respectively.

Results revealed that neither absolute nor relative clock-checking fully mediated the effect of age on TBPM when they are considered alone. In both models, the direct effect of age was still significant when controlling for either absolute ($\beta = -0.13$, $z = -1.99$, $p = .046$, see Table 4) or relative clock-checking ($\beta = -0.15$, $z = -2.73$, $p = .006$, see Table 5). Relative clock-checking explained a greater portion of TBPM variance (46.9%) than absolute clock-checking (33.7%) when accounted for separately.

Strategicness of Clock-Checking: Comparing our Relative Indicator to the Classical Indicator

To test whether the indicator of relative clock-checking is a better operationalization of strategicness of clock-checking than the classical indicator, we compared results from Models 1 and 4, in which relative clock-checking was replaced by T4 clock-checking. Given that absolute clock-checking and T4 clock-checking correlated very strongly ($r(222) = .90$, $p < .001$), we also conducted redundancy analyses to test for potential multicollinearity using ordinary least square multiple linear regressions. We report estimates for the direct, indirect, and total effects of Model 4 in Table 6 and redundancy analyses in Table 7.

As in Model 1, the strategic clock-checking indicator, operationalized as T4 clock-checking, strongly and positively predicted TBPM performance in Model 4 ($\beta = 0.94$, $z = 10.48$, $p < .001$). Absolute and T4 clock-checking also fully mediated the association between age and TBPM ($\beta = -0.10$, $z = -1.92$, $p = .056$). However, differences between Models 1 and 4 emerged when considering the effect of absolute clock-checking on TBPM performance.

Contrary to Model 1, where absolute clock-checking had a positive impact on TBPM performance, absolute clock-checking had a negative impact on TBPM performance in Model 4 (β = -0.21, z = -2.32, p = .02). In other words, when controlling for the number of clock checks that occurred in the last time-interval before the TBPM target, higher absolute clock-checking predicted worse TBPM performance. This negative effect of absolute clock-checking on TBPM performance when controlling for T4 clock-checking is most probably an artefact due to multicollinearity between absolute and T4 clock-checking indicators (r(222)= .90, p < .001, VIF = 5.32 and 5.42, respectively). In contrast, absolute and relative clock-checking positively correlated but were not subject to multicollinearity (r(222) = .57, p < .001, VIF = 1.56 and 1.58, respectively), resulting in positive effects of both clock-checking indicators on TBPM performance in Model 1.

Finally, a modest difference in explaining TBPM variance has been achieved in favor of the model using the relative clock-checking indicator (67.8%) compared to T4 clock-checking (64.2%).

Does Clock-Checking Behavior Involve a Cost to OT Performance?

We conducted additional analyses to further examine the relationship between OT and PM performance on the one hand, and between OT performance and clock-checking behavior on the other hand. Because age, sex and performance on the matrices predicted PM performance and/or clock-checking indicators, we computed partial correlations between OT performance, PM performance, absolute and relative clock-checking controlling for age, sex and fluid intelligence. Results showed that there was no significant association between OT and TBPM performance beyond the effects of age, sex, and fluid intelligence (r(218) = -.06, p = .417). In contrast, when controlling for the effects of age, sex and fluid intelligence, absolute clock-checking significantly correlated with OT performance (r(218) = -.16, p = .014) indicating a trade-off between performing the OT and checking the clock. Finally, the partial correlation between strategic clock-checking and OT performance was not significant ($r(218) = -.07$, $p = .331$).

Discussion

The first aim of this paper was to propose *relative clock-checking* as a new indicator of strategicness of clock-checking in TBPM tasks that accounts for the effect of absolute clock-checking frequency in the relationship between strategicness of clock-checking and age-related differences in TBPM performance. Further aims were to test whether the two complementary aspects of clock-checking behavior concomitantly predicted TBPM performance across the adult lifespan, and whether age-related differences in clock-checking behavior accounted for age-related differences in TBPM performance.

Regarding our first aim, results indeed confirmed the added value of our new indicator as they suggest that relative clock-checking may represent a purer indicator of clock-checking strategicness than the mere number of clock-checks in the last time interval before target-time. Critically, when this classical indicator was examined together with absolute clock-checking as predictors of TBPM, absolute clock-checking had a *negative* effect on TBPM performance. This counter-intuitive, negative effect on TBPM resulted from the important overlap (i.e., multicollinearity) between the two clock-checking indicators. Therefore, because the two variables are not statistically independent, using the classical indicator of strategicness of clock-checking is not adequate if one wishes to assess the respective and concomitant effect of both absolute and strategic clock-checking on TBPM performance. In contrast, because our proposed indicator accounts for interindividual differences in absolute clock-checking, there was no multicollinearity when including both absolute and relative clock-checking as predictors of TBPM. Finally, as indicated by the positive and moderate correlation between the two indicators, absolute and relative clock-checking reflect distinct, yet related, aspects of time monitoring behavior.

As so far suggested, when analyzed separately, absolute frequency and strategicness of clock-checking concomitantly predicted TBPM in our study (e.g., Jäger & Kliegel, 2008; Maylor et al., 2002; McFarland & Glisky, 2009; Mioni et al., 2020; Voigt et al., 2014). Checking the clock more often and strategically both led to better TBPM performance. Strategicness of clock-checking alone explained a substantial 46.9% of the variance of TBPM performance in our sample, and together the two clock-checking indicators explained 53.6% of TBPM variance. These results therefore reveal that even if checking the clock often is key to remember to perform a TBPM intention, checking for it strategically (i.e., close to TBPM target-time) is a more successful strategy.

Regarding age effects, in line with previous studies, older participants had poorer performance on the TBPM task and checked the clock less frequently and strategically than younger participants (Einstein et al., 1995; Maylor et al., 2002; McFarland & Glisky, 2009; Mioni et al., 2020; Mioni & Stablum, 2014; Park et al., 1997; Vanneste et al., 2016; Waldum & McDaniel, 2016). Unlike in Jäger and Kliegel (2008), we did not observe a negative effect of age on TBPM after considering the effects of clock-checking. Interestingly, and in line with Jäger and Kliegel, considering either one or the other clock-checking indicator resulted in a partial mediation only of the effect of age on TBPM in our data. Therefore, while these authors suggested that age-related impairments in time processing explained the unique association between age and TBPM performance, we instead argue that considering both absolute frequency and strategicness of clock-checking behavior captures more accurately how participants monitor for the passage of time than each one separately. In that respect, future studies should investigate how both clock-checking indicators differentially relate to time-estimation abilities (see Block & Zakay, 2006; Harris & Wilkins, 1982).

Finally, our results may appear to contradict studies reporting increased clock-checks but similar TBPM performance in older as compared to younger participants (Logie et al., 2004; Mäntylä et al., 2009; Maylor et al., 2002; Mioni & Stablum, 2014). However, different patterns in age-related clock-checking and TBPM performance may originate from variations in OT requirements across studies (Ballhausen et al., 2017; d'Ydewalle et al., 2001; Martin & Schumann-Hengsteler, 2001). Studies that found similar TBPM performance and increased clock-checks in older as compared to younger adults used OTs with low cognitive load (i.e., watching a movie or listening to a story on which they will have to answer questions later on), in which participants had more attentional resources available to check the clock while carrying out the OT (Mioni & Stablum, 2014). However, in more demanding OTs (e.g., flanker or n-back tasks), such as the one used in the present study, demands of the OT and of the PM task may compete more strongly for cognitive resources, which are generally scarcer in older participants (d'Ydewalle et al., 2001). In order to also focus on the OT, older adults may therefore have to reduce clock-checking, resulting in lower TBPM performance. This hypothesis is supported by results from previous studies showing that when cognitive load of the OT is low, older adults check the clock more frequently than younger participants, and thereby are able to perform the PM task equally well as younger adults (Mäntylä et al., 2009; also see Logie et al., 2004). By contrast, when cognitive load of the OT is high, older participants check the clock less frequently and thus show worse PM performance than younger participants. This is further supported by our data: after controlling for the effect of age, sex and fluid intelligence, there was a negative association between absolute clock-checking and OT performance, indicating that the more participants checked the clock, the worse they performed on the OT and vice versa (also see Mäntylä & Carelli, 2006). Together, these findings suggest a direct trade-off between OT and PM demands. In this regard, it would be interesting to further explore to which extent participants are aware of the competing demands of the two tasks and whether they apply particular strategies to manage both tasks simultaneously. We therefore encourage future work to directly ask participants to rate how difficult it was to juggle both the OT and TBPM tasks at the same time, and to ask participants which strategies they used to do so (see for instance Reese-Melancon et al., 2019, in event-based PM). This approach might reveal individual and age-related differences in the type and number of strategies participants use, but also whether they are aware of using these strategies. Furthermore, coupling self-reported strategies with a refined analysis of accuracy and RTs in both tasks across trials might clarify the dynamic interplay between clock-checking behavior and OT and TBPM performances, as well as age effects therein.

The main goals of the present study were to examine a new indicator of strategicness of clock-checking, and to investigate how absolute frequency and strategicness of clock-checking together explain age-related decrease in TBPM performance typically observed in laboratory studies. Thereby, one key limitation of the present study, as well as for similar laboratory studies, is the issue of whether findings generalize to participants' TBPM performance in their daily life. We used a TBPM task requiring participants to perform an action every minute, a PM interval that is on the shorter side of the PM delays (many experimental TBPM tasks use 2, 3, or 5-minute intervals, e.g., Jäger & Kliegel, 2008; Maylor et al., 2002; McFarland & Glisky, 2009; Mioni & Stablum, 2014; Gonneaud et al., 2011). Previous research on the "age-PM paradox" suggested that older adults often perform worse than younger adults on laboratory TBPM tasks, but that they may perform equally well, or even better than younger adults in daily-life tasks (Rendell & Thomson, 1999; Haines et al., 2020; Henry et al., 2004). Results from Haines et al. (2020) emphasize that age effects also vary according to the exact TBPM requirements (i.e., a time that has to be performed at a particular time of day versus after a certain time has elapsed). The question remains thus open as to how often and how strategically older adults check the clock in various daily-life TBPM tasks, and whether clock-checking is equally important to remembering to perform real-life intentions with varying requirements. Therefore, future studies ought to replicate the present findings, using longer TBPM intervals (e.g., 5-minute intervals or longer), and – maybe even more importantly – compare observed age-effects with TBPM performance in daily life. One could expect that checking the clock strategically is even more important in predicting TBPM success when the intention has to be maintained for longer periods of time and while the individual is immersed in other activities that are more personally relevant or cognitively more demanding.

Conclusion

The present study offers some important methodological and conceptual advances for research on TBPM in general and on age effects in this cognitive task in particular. We first established that our relative clock-checking indicator was a more specific indicator of strategic time-monitoring compared to the mere number of times participants checked the clock in the last sub-interval before the target-time. We therefore strongly encourage future studies to use relative clock-checking as an indicator of time monitoring strategicness in both experimental and daily life TBPM tasks. Second, in order to understand time monitoring processes more properly, it is essential to measure both absolute frequency and strategicness of clock-checking as they jointly explain more than half of the variance in TBPM performance. Third, and most importantly, we showed that decreased TBPM performance in older adults is not related to age *per se*, but rather to age-related differences in clock-checking behavior. We believe that the present study provides valuable insights into efficient strategies that might improve daily-life TBPM performance, especially for older adults. It might constitute an effective intervention to train older adults to increase clock-checking as the target-time approaches, or to set up "strategic" (i.e., close to target-time), rather than just "frequent" reminders on their phone, in order to remember and complete their intentions on time.

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Footnotes

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[i] Corresponding to the classical indicator of strategicness of clock-checking.

[ii] In order to estimate the variable specific effect sizes, two models with (1) age as an only predictor of TBPM, and (2) age and control variables were estimated but not reported in the manuscript.

Table 1

Mean Age and Gender Distribution for Each Age Stratum

Age Strata	*N*	*Mean* Age	*SD* Age	Sex *Women*
19-29	56	23.62	2.19	77%
30-39	36	34.08	3.13	56%
40-49	31	45.80	2.98	74%
50-59	40	54.90	2.94	78%
60-69	44	63.39	2.57	68%
>70	16	76.06	5.27	56%
Total	223	45.61	17.24	70%

Table 2

Descriptive Statistics and Correlations of Study Variables

Variables	*M*	*SD*	1	2	3	4	5	6	7	8	9
1. Age	45.61	17.24	—								
2. Education	15.87	3.36	-.14*	—							
3. Matrices	19.10	4.42	-.45***	.18**	—						
4. Mill-Hill	24.74	4.60	.33***	.27***	.03	—					
5. Absolute clock-checking	9.86	7.92	-.33***	.08	.16*	-.11	—				
6. Relative clock-checking	29.22	21.94	-.32***	.06	.25***	-.13	.57***	—			
7. T4 clock-checking	4.14	3.56	-.34***	.08	.21**	-.13	.90***	.81***	—		
8. TBPM	51.27	35.37	-.35***	.04	.25***	-.09	.67***	.76***	.79***	—	
9. OT	85.32	9.22	-.38***	.08	.43***	-.02	.01	.10	.06	.13*	—

Note. $N = 223$. TBPM = Time-Based Prospective Memory accuracy (in percent). OT = Ongoing-Task accuracy (in percent).

* $p < .05$, ** $p < .01$, *** $p < .001$

Table 3

Estimates for the Direct, Indirect, and Total Effects for Model 1

Effect	Estimate	S.E.	95 % C.I. Lower	95 % C.I. Upper	β	Z	*p*
Indirect effects							
Age → Absolute clock-checking → TBPM	-0.21	0.06	-0.33	-0.12	-0.10	-3.72	< .001
Age → Relative clock-checking → TBPM	-0.27	0.10	-0.47	-0.09	-0.13	-2.66	.008
Education → Absolute clock-checking → TBPM	0.14	0.24	-0.23	0.71	0.01	0.59	.558
Education → Relative clock-checking → TBPM	0.08	0.41	-0.60	1.01	0.01	0.20	.839
Sex → Absolute clock-checking → TBPM	1.31	1.72	-2.06	4.75	0.02	0.76	.448
Sex → Relative clock-checking → TBPM	-0.72	2.90	-6.55	4.66	-0.01	-0.25	.803
Matrices → Absolute clock-checking → TBPM	0.02	0.19	-0.39	0.40	0.01	0.09	.931
Matrices → Relative clock-checking → TBPM	0.66	0.34	0.01	1.34	0.08	1.95	.051
Mill-Hill → Absolute clock-checking → TBPM	-0.05	0.17	-0.38	0.76	-0.01	-0.31	.760
Mill-Hill → Relative clock-checking → TBPM	-0.26	0.29	-0.86	0.31	-0.03	-0.89	.373
Components of the indirect effects							
Age → Absolute clock-checking	-0.15	0.04	-0.22	-0.08	-0.32	-4. 14	< .001
Absolute clock-checking → TBPM	1.44	0.20	1.07	1.86	0.32	7.26	< .001
Age → Relative clock-checking	-0.30	0.11	-0.50	-0.09	-0.24	-2.78	.006
Relative clock-checking → TBPM	0.90	0.07	0.76	1.03	0.56	13.28	< .001
Education → Absolute clock-checking	0.10	0.16	-0.17	0.48	0.04	0.60	.550
Education → Relative clock-checking	0.09	0.45	-0.67	1.09	0.01	0.21	.837

Sex → Absolute clock-checking	0.91	1.18	-1.42	3.19	0.05	0.77	.443
Sex → Relative clock-checking	-0.80	3.21	-7.23	5.20	-0.02	-0.25	.803
Matrices → Absolute clock-checking	0.01	0.13	-0.27	0.28	0.01	0.09	.931
Matrices → Relative clock-checking	0.74	0.37	0.02	1.48	0.15	1.97	.049
Mill-Hill → Absolute clock-checking	-0.04	0.12	-0.26	0.20	-0.02	-0.31	.756
Mill-Hill → Relative clock-checking	-0.29	0.32	-0.92	0.35	-0.06	-0.90	.368
Direct effects							
Age → TBPM	-0.18	0.10	-0.38	0.03	-0.09	-1.80	.071
Education → TBPM	-0.59	0.64	-1.81	0.64	-0.06	-0.92	.357
Sex → TBPM	7.08	3.40	0.59	14.00	0.09	2.08	.037
Matrices → TBPM	0.11	0.33	-0.52	0.75	0.01	0.33	.745
Mill-Hill → TBPM	0.52	0.39	-0.32	1.20	0.07	1.35	.178
Total effects							
Age → TBPM	-0.66	0.17	-0.97	-0.33	-0.32	-3.95	< .001
Education → TBPM	-0.37	0.73	-1.81	1.08	-0.04	-0.51	.614
Sex → TBPM	7.67	4.70	-1.32	16.66	0.10	1.63	.103
Matrices → TBPM	0.79	0.57	-0.30	1.94	0.10	1.38	.169
Mill-Hill → TBPM	0.21	0.55	-0.95	1.12	0.03	0.37	.709

Note. S.E. = standard error of estimate. C.I. = Confidence intervals, computed using bias corrected bootstrap. Betas are standardized estimates and correspond to indexes of mediation for the indirect effects.

Table 4

Estimates for the Direct, Indirect and Total Effects for Model 2

Effect	Estimate	S.E.	95 % C.I. Lower	95 % C.I. Upper	β	Z	*p*
Indirect effects							
Age → Absolute clock-checking → TBPM	-0.40	0.10	-0.60	-0.20	-0.20	-3.91	< .001
Education → Absolute clock-checking → TBPM	0.27	0.43	-0.46	1.20	0.03	0.61	.540
Sex → Absolute clock-checking → TBPM	2.49	3.44	-4.54	9.41	0.03	0.73	.468
Matrices → Absolute clock-checking → TBPM	0.03	0.36	-0.69	0.74	0.01	0.09	.931
Mill-Hill → Absolute clock-checking → TBPM	-0.10	0.34	-0.76	0.59	-0.01	-0.29	.772
Components of the indirect effects							
Age → Absolute clock-checking	-0.15	0.04	-0.22	-0.07	-0.32	-3.91	< .001
Absolute clock-checking → TBPM	2.75	0.26	2.24	3.26	0.62	10.70	< .001
Education → Absolute clock-checking	0.10	0.16	-0.16	0.44	0.04	0.62	.536
Sex → Absolute clock-checking	0.91	1.24	-1.50	3.48	0.05	0.73	.465
Matrices → Absolute clock-checking	0.01	0.13	-0.23	0.26	0.01	0.09	.930
Mill-Hill → Absolute clock-checking	-0.04	0.12	-0.28	0.20	-0.02	-0.29	.770
Direct effects							
Age → TBPM	-0.26	0.13	-0.53	-0.01	-0.13	-1.99	.046
Education → TBPM	-0.63	0.71	-1.99	0.67	-0.06	-0.89	.374
Sex → TBPM	5.17	3.86	-2.24	12.75	0.07	1.34	.180
Matrices → TBPM	0.76	0.42	-0.06	1.58	0.09	1.82	.069

Mill-Hill → TBPM	0.31	0.47	-0.66	1.18	0.04	0.66	.513
Total effects							
Age → TBPM	-0.66	0.17	-0.97	-0.31	-0.32	-3.94	< .001
Education → TBPM	-0.37	0.73	-1.76	1.10	-0.04	-0.50	.615
Sex → TBPM	7.67	5.00	-1.93	17.46	0.10	1.53	.125
Matrices → TBPM	0.79	0.57	-0.28	1.94	0.10	1.38	.167
Mill-Hill → TBPM	0.21	0.56	-0.87	1.32	0.03	0.37	.713

Note. S.E. = standard error of estimate. C.I. = Confidence intervals, computed using bias corrected bootstrap. Betas are standardized estimates, and correspond to indexes of mediation for the indirect effects.

Table 5

Estimates for the Direct, Indirect and Total Effects for Model 3

Effect	Estimate	S.E.	95 % C.I. Lower	95 % C.I. Upper	β	Z	*p*
Indirect effects							
Age → Relative clock-checking → TBPM	-0.35	0.13	-0.62	-0.10	-0.17	-2.77	.006
Education → Relative clock-checking → TBPM	0.11	0.52	-0.76	1.19	0.01	0.21	.834
Sex → Relative clock-checking → TBPM	-0.94	3.59	-7.79	6.13	-0.01	-0.26	.793
Matrices → Relative clock-checking → TBPM	0.87	0.43	0.01	1.68	0.11	2.00	.045
Mill-Hill → Relative clock-checking → TBPM	-0.34	0.42	-1.09	0.52	-0.04	-0.82	.412
Components of the indirect effects							
Age → Relative clock-checking	-0.30	0.11	-0.52	-0.08	-0.24	-2.79	.005
Relative clock-checking → TBPM	1.18	0.08	1.03	1.34	0.73	15.29	< .001
Education → Relative clock-checking	0.09	0.44	-0.64	1.01	0.01	-0.21	.833
Sex → Relative clock-checking	-0.80	3.05	-6.77	5.14	-0.02	-0.26	.793
Matrices → Relative clock-checking	0.74	0.37	-0.025	1.46	0.15	1.98	.048
Mill-Hill → Relative clock-checking	-0.29	0.35	-0.91	0.47	-0.06	-0.827	.408
Direct effects							
Age → TBPM	-0.31	0.11	-0.53	-0.08	-0.15	-2.73	.006
Education → TBPM	-0.48	0.62	-1.66	0.66	-0.05	-0.77	.442
Sex → TBPM	8.61	3.36	1.53	15.93	0.11	2.39	.017
Matrices → TBPM	-0.08	0.37	-0.80	0.69	-0.01	-0.22	.828

Mill-Hill → TBPM	0.55	0.39	-0.25	1.32	0.07	1.39	.163
			Total effects				
Age → TBPM	-0.66	0.17	-0.99	-0.31	-0.32	-3.94	< .001
Education → TBPM	-0.37	0.75	-1.93	1.01	-0.04	-0.49	.625
Sex → TBPM	7.67	4.91	-1.88	16.89	0.10	1.56	.118
Matrices → TBPM	0.79	0.59	-0.33	2.00	0.10	1.33	.183
Mill-Hill → TBPM	0.21	0.59	-1.05	1.29	0.03	0.35	.727

Note. S.E. = standard error of estimate. C.I. = Confidence intervals, computed using bias corrected bootstrap. Betas are standardized estimates, and correspond to indexes of mediation for the indirect effects.

Table 6

Estimates for the Direct, Indirect and Total Effects for Model 4

Effect	Estimate	S.E.	95 % C.I. Lower	95 % C.I. Upper	β	Z	*p*
Indirect effects							
Age → Absolute clock-checking → TBPM	0.14	0.07	0.03	0.29	0.07	1.98	.048
Age → T4 clock-checking → TBPM	-0.59	0.16	-0.91	-0.29	-0.29	-3.68	< .001
Education → Absolute clock-checking → TBPM	-0.09	0.15	-0.49	0.13	-0.01	-0.59	.555
Education → T4 clock-checking → TBPM	0.29	0.63	-0.73	1.64	0.03	0.45	.651
Sex → Absolute clock-checking → TBPM	-0.85	1.26	-4.07	1.12	-0.01	-0.68	.500
Sex → T4 clock-checking → TBPM	5.38	4.99	-4.35	14.99	0.07	1.08	.281
Matrices → Absolute clock-checking → TBPM	-0.01	0.14	-0.34	0.21	-0.01	-0.08	.937
Matrices → T4 clock-checking → TBPM	0.45	0.56	-0.59	1.60	0.06	0.81	.415
Mill-Hill → Absolute clock-checking → TBPM	0.03	0.12	-0.16	0.34	0.01	0.28	.781
Mill-Hill → T4 clock-checking → TBPM	-0.27	0.49	-1.18	0.68	-0.04	-0.56	.577
Components of the indirect effects							
Age → Absolute clock-checking	-0.15	0.04	-0.22	-0.08	-0.32	-4.04	< .001
Absolute clock-checking → TBPM	-0.94	0.41	-1.76	-0.14	-0.21	-2.32	.020
Age → T4 clock-checking	-0.06	0.02	-0.10	-0.03	-0.30	-3.83	< .001
T4 clock-checking → TBPM	9.35	0.89	7.62	11.21	0.94	10.48	< .001
Education → Absolute clock-checking	0.10	0.16	-0.15	0.46	0.04	0.61	.539
Education → T4 clock-checking	0.03	0.07	-0.08	0.18	0.03	0.45	.655

Sex → Absolute clock-checking	0.91	1.17	-1.48	3.19	0.05	0.78	.438
Sex → T4 clock-checking	0.58	0.53	-0.45	1.56	0.07	1.09	.278
Matrices → Absolute clock-checking	0.01	0.13	-0.23	0.27	0.01	0.09	.931
Matrices → T4 clock-checking	0.05	0.06	-0.06	0.17	0.06	0.82	.413
Mill-Hill → Absolute clock-checking	-0.04	0.12	-0.27	0.22	-0.02	-0.30	.761
Mill-Hill → T4 clock-checking	-0.03	0.05	-0.13	0.08	-0.04	-0.56	.578
Direct effects							
Age → TBPM	-0.21	0.11	-0.43	0.01	-0.10	-1.92	.056
Education → TBPM	-0.56	0.59	-1.76	0.49	-0.05	-0.95	.341
Sex → TBPM	3.14	3.40	-3.63	10.31	0.04	0.92	.356
Matrices → TBPM	0.34	0.36	-0.39	0.99	0.04	0.95	.342
Mill-Hill → TBPM	0.44	0.39	-0.35	1.13	0.06	1.15	.252
Total effects							
Age → TBPM	-0.66	0.17	-0.97	-0.29	-0.32	-3.91	< .001
Education → TBPM	-0.37	0.71	-1.87	1.01	-0.04	-0.52	.607
Sex → TBPM	7.67	4.94	-2.22	17.09	0.10	1.55	.121
Matrices → TBPM	0.79	0.59	-0.38	1.88	0.10	1.33	.183
Mill-Hill → TBPM	0.21	0.55	-0.98	1.24	0.03	0.38	.707

Note. S.E. = standard error of estimate. C.I. = Confidence intervals, computed using bias corrected bootstrap. Betas are standardized estimates, and correspond to indexes of mediation for the indirect effects. T4 clock-checking corresponds to the classical measure of clock-checking strategicness (i.e., the number of times the participants checked the clock in the last time-interval before the target-time).

Table 7

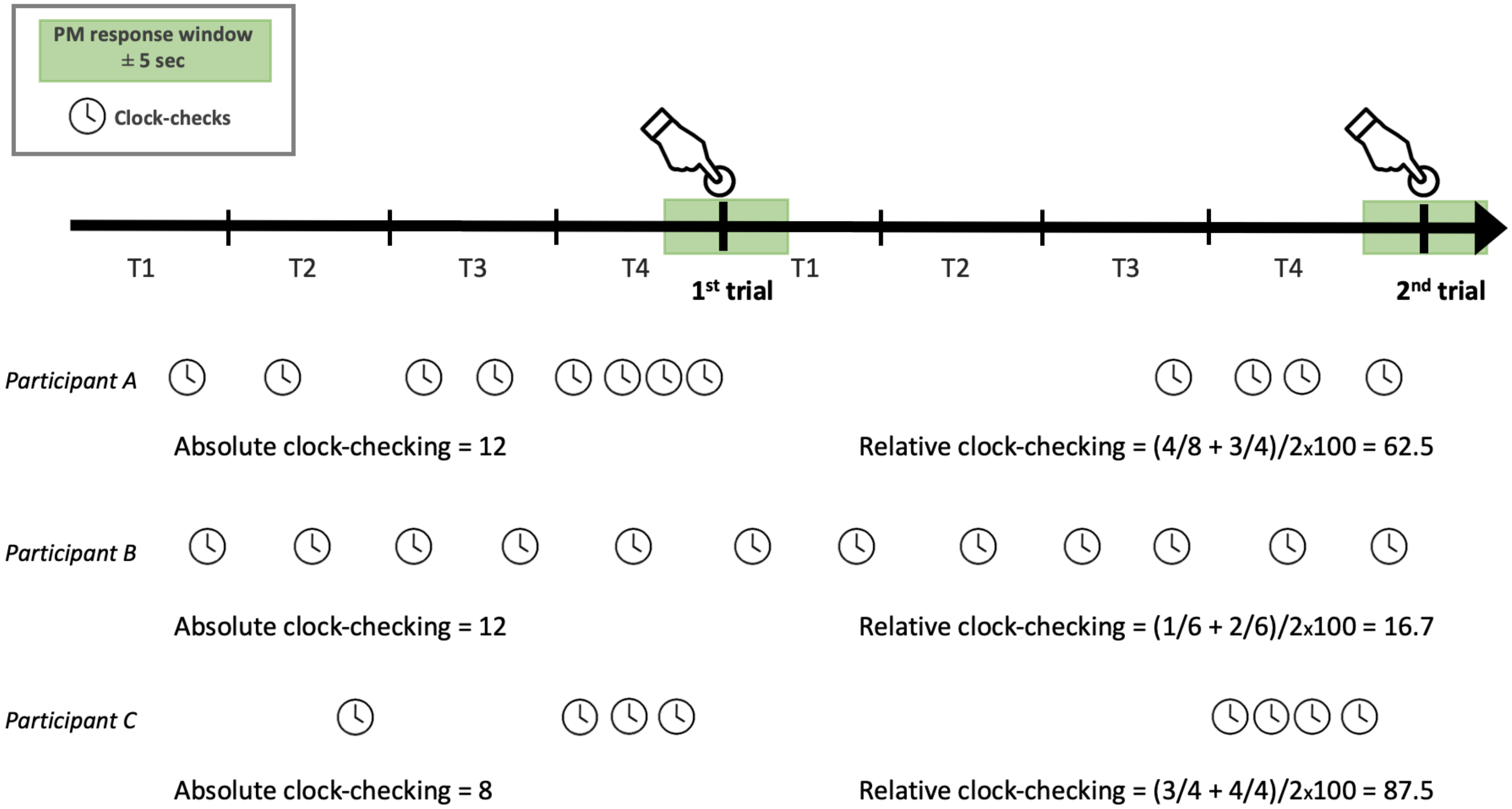
VIF and Tolerance Values Coming From the Redundancy Analysis for Initial (Relative Clock-checking) and Alternative (T4 Clock-checking) Models

	Model 1		Model 4	
	VIF	Tolerance	VIF	Tolerance
Age	1.67	.60	1.67	.60
Education	1.16	.86	1.16	.86
Sex	1.03	.97	1.03	.97
Matrices	1.37	.73	1.35	.74
Mill-Hill	1.32	.76	1.32	.76
Absolute clock-checking	1.56	.64	5.32	.19
Relative clock-checking	1.58	.63	-	-
T4 clock-checking	-	-	5.42	.18

Note. Different cut-off values for the VIF value exists. A more relaxed criterion considers that there is a multicollinearity issue when the VIF value exceeds 10 (Vittinghoff et al., 2011), while more conservative criteria consider values exceeding 5 (Menard, 2001) or even 2.5 (Johnston et al., 2018) to already be problematic

Figure 1

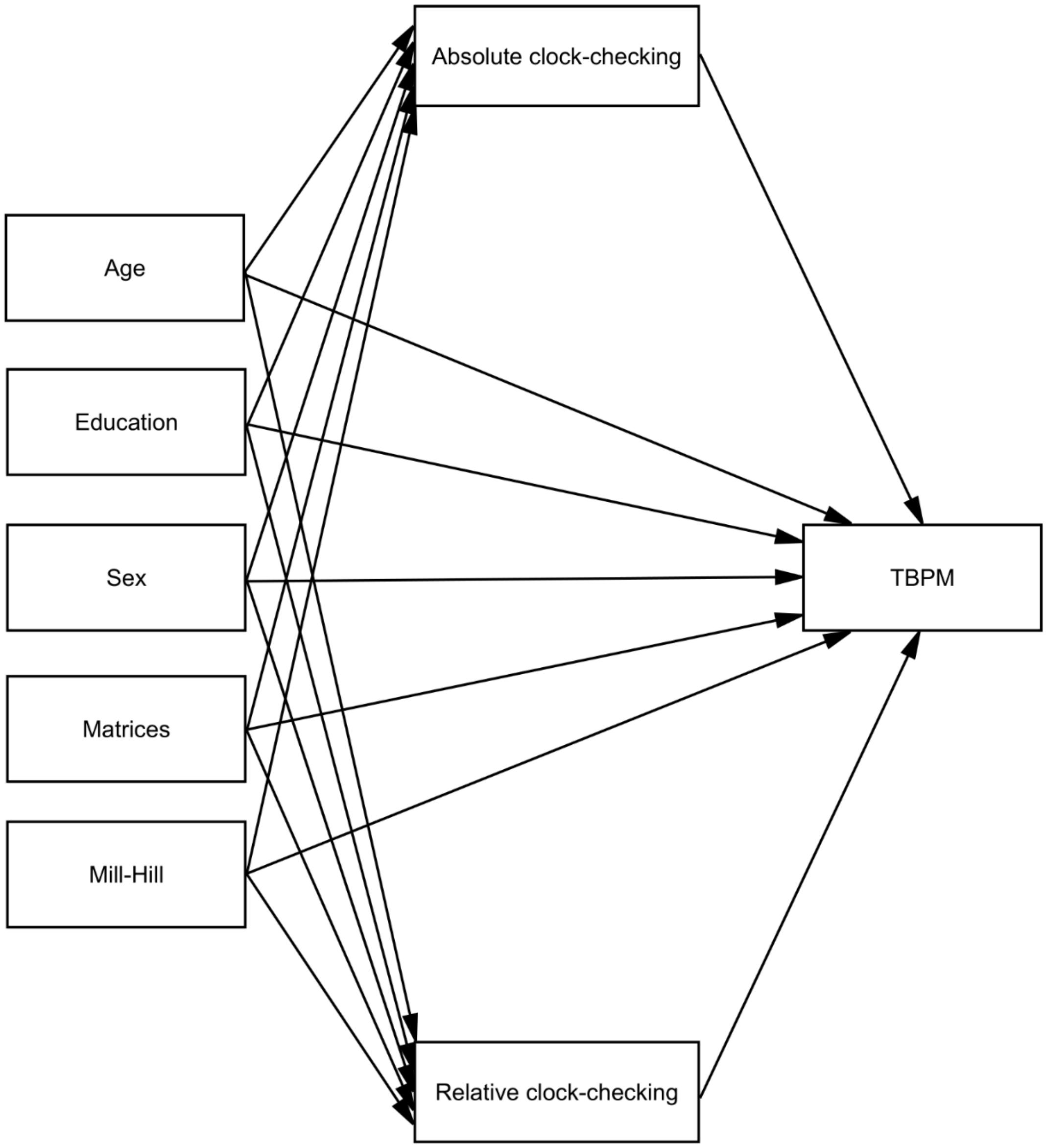
Examples of Different Patterns of Clock-Checking Behavior



Note. Each clocks line (Participants A, B, and C) illustrates a different clock-checking strategy. For clarity, the present example only depicts two TBPM trials (of 60 seconds each)

Figure 2

Visual Representation of Model 1



Note. Covariances between the predictors and residual variances between the two clock-checking indicators were estimated but are not depicted for clarity of presentation.

Supplemental Material for Online Publication

Frequency and Strategicness of Clock-Checking Explain Detrimental Age-Effects in Time-Based Prospective Memory

Supplemental Material A: Additional Information on Study Material and Procedure
The data presented in this study stem from a broader project assessing different cognitive abilities both in the laboratory and in an online setting. This project primarily aimed to validate two online tools to assess time-based prospective memory (TBPM; the Geneva Space Cruiser, Zuber et al., 2021) and general cognitive abilities (the eCOGTEL, Haas et al., 2021). The full procedure is described in detail in Zuber et al. (2021) and Haas et al. (2021). In the present study, we specifically focused on investigating the role of clock-checking when performing a classical laboratory TBPM task, which for all participants was administered in the very first session of the study and was therefore not affected by the broader study design or any of its manipulations. Below, we provide complementary information on the study design and full material.

Tasks and Questionnaires

Supplemental Table S1 summarizes all the tasks that were administered in the larger study project (i.e., also those not examined in the present paper), and where to find the corresponding material (when available). Supplemental Figure A1 details in which order these tasks and questionnaires were administered. Data used in the present paper were all collected during the first (in-person) session only, before any experimental manipulation occurred.

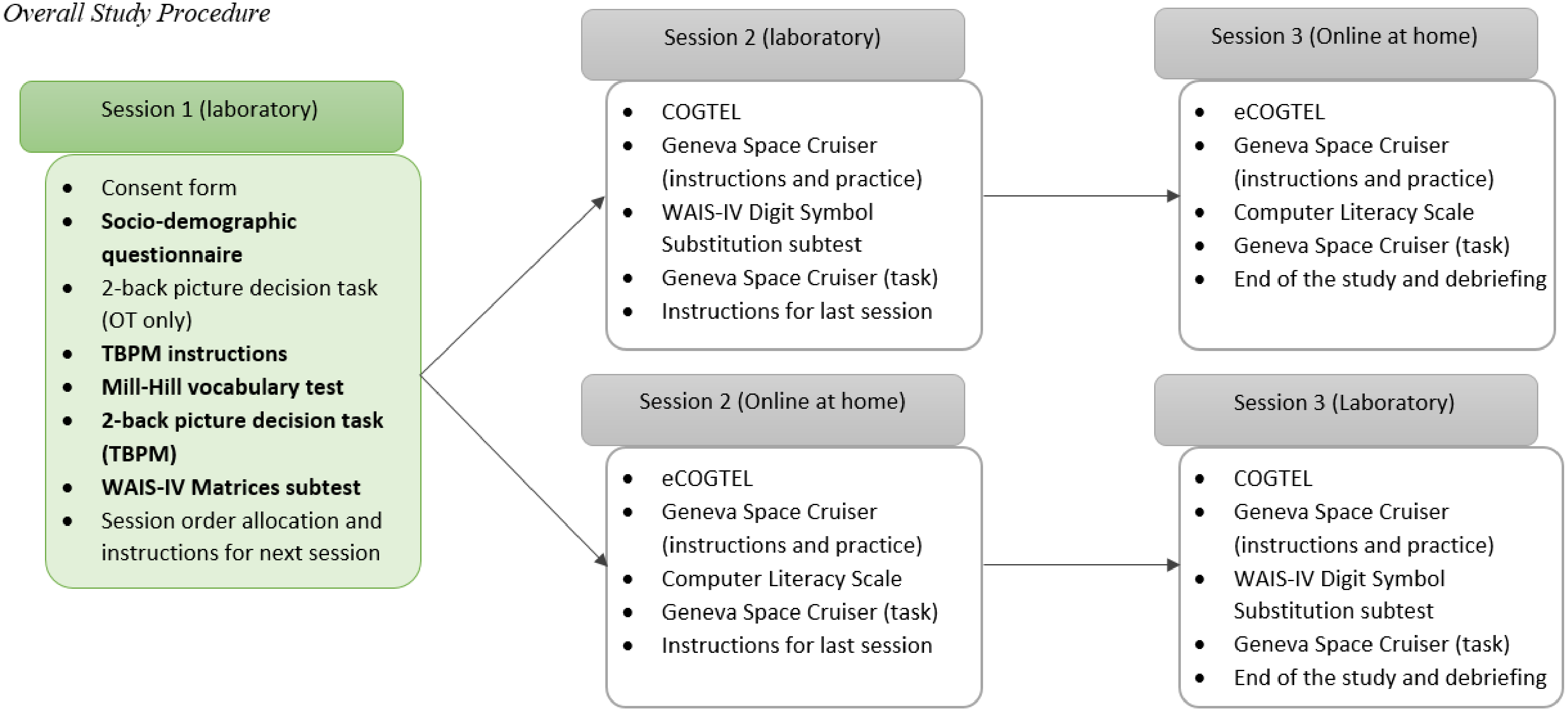
Supplemental Table S1

Questionnaires/Tasks	Used in this paper	Reference	Where to find
Socio-demographic questionnaire	Yes		See pages 5-6 of this document
Mill-Hill vocabulary test	Yes	Deltour, J. J. (1993). *Echelle de vocabulaire de Mill Hill de JC Raven : Adaptation française et normes européennes du Mill Hill et du Standard Progressive Matrices de Raven (TBPM38)*. Editions L'Application des Techniques Modernes.	
WAIS-IV Matrices subtest	Yes	Wechsler, D. (2008). *Wechsler adult intelligence scale—Fourth edition*. Pearson Assessment.	
WAIS-IV Digit Symbol Substitution subtest	No		
Computer Literacy Scale (CLS)	No	Sengpiel M, Jochems N (2015) Validation of the computer literacy scale (Cls). In: *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*	http://www.computer-literacy.net/
2-back picture decision task (OT only)	No		https://cigev.unige.ch/openscience/
2-back picture decision task (TBPM)	Yes		
Geneva Space Cruiser	No	Zuber, S., Haas, M., Framorando, D., Ballhausen, N., Gillioz, E., Künzi, M., & Kliegel, M. (2021) The Geneva Space Cruiser: A Fully Self-Administered Online Tool to Assess Prospective Memory across the Adult Lifespan. *Memory, 0*(0), 1-16.	https://cigev.unige.ch/openscience/
COGTEL / eCOGTEL	No	Haas, M., Scheibe, S., El Khawli, E., Künzi, M., Ihle, A., Ballhausen, N., Framorando, D., Kliegel, M., & Zuber, S. (2021). *Online assessment of cognitive functioning across the adult lifespan using the eCOGTEL*: A reliable alternative to laboratory testing. European Journal of Ageing.	https://cigev.unige.ch/openscience/

Note. OT only = participants only performed the ongoing task (no TBPM instructions). TBPM = participants perform the ongoing task plus the Time-Based Prospective Memory task. WAIS-IV = Wechsler Adult Intelligence Scale - Fourth edition

Supplemental Figure S1

Overall Study Procedure



Note. Text in bold indicates the tasks and/or questionnaires used in the present paper. All participants participated in a laboratory session (session 1), in which the used in the present paper were collected. All measures used in the present study were thus collected before any condition allocation in the study (i.e., order of the last two sessions). In counter-balanced order, half of the participants then participated in another laboratory (session 2) and finally in an online session (session 3), whereas the other half then participated in the online (session 2) and finally in another laboratory session (session 3). Tasks and/or questionnaires are reported in exact order of administration. Adapted from Zuber et al. (2021).

Socio-demographic questionnaire:

GENERAL INFORMATION

1. **Participant's Code (to be filled in by the experimenter): ______________________**

2. **Date of birth : _________________________**

3. **The participant is :**

Female	
Male	

4. **The participant is :**

Right-handed	
Left-handed	

5. **What is the participant's marital status?**

Single	
Married, remarried, civil partnership	
Cohabiting couple	
Divorced, separated	
Widowed	

6. **What is the participant's highest degree of education achieved?**

Elementary school	
Middle school	
Professional training	
High school	
Community college, Junior college, or Technical college	
University	
Other (please describe)	

7. **How many years did the participant spend in**

   … compulsory education ___________________

   … High school (CH : Maturité | FR : Baccalauréat) _________________________

   … university (or equivalent) ___________________________

   … other training(s) ____________________________

8. **Which one of these options best describes the participant's daily activities/obligations at the moment?**

Retired	
Full-time job	
Part-time job	
Student	
House-wife/husband	
Illness / invalitidy	
Unemployed	
Other (please describe)	

9. **What does the participant currently do for a living (or what was his/her last job)?**

10. **What is/was the participant's employment rate (i.e., does/did he/she work part-time)?**

11. **Is/was that job physically demanding?**

No		yes	

12. **On a scale from 0 « worst possible health status » to 100 « best possible health status », how does the participant rates his/her health TODAY?** ____________________

Supplemental Material B: R Codes for Models 1, 1a, 2, 3, and 4

All models were computed using the package Lavaan (version 0.6-9; Rosseel, 2012) in RStudio (version 1.4.1717; Rstudio Team, 2021; using R version 4.1.2; R Core Team, 2020)

Model 1 (absolute and relative clock-checking as mediators of the effect of age on TBPM performance)

```
[import database from your computer, database in this script
will be called DB]
library(lavaan)
DB$Sex <- factor(DB$Sex)

Model1 <-'
Absolute_clockchecking ~ a*Age + f*Education + i*Sex +
l*Matrices + o*Mill_Hill
Relative_clockchecking ~ b*Age + g*Education + j*Sex +
m*Matrices + p*Mill_Hill
TBPM ~ c*Absolute_clockchecking + d*Relative_clockchecking +
e*Age + h*Education + k*Sex + n*Matrices + q*Mill_Hill

# indirect effects
Age_AbsoluteCC_indirect := a*c
Age_RelativeCC_indirect := b*d
Educ_AbsoluteCC_indirect := f*c
Educ_RelativeCC_indirect := g*d
Sex_AbsoluteCC_indirect := i*c
Sex_RelativeCC_indirect := j*d
Mat_AbsoluteCC_indirect := l*c
Mat_RelativeCC_indirect := m*d
MH_AbsoluteCC_indirect := o*c
MH_RelativeCC_indirect := p*d

# total effects
Agetotal := e + (a*c)+ (b*d)
Eductotal:= h + (f*c)+ (g*d)
Sextotal:= k + (i*c)+ (j*d)
Mattotal:= n + (l*c)+ (m*d)
MHtotal:= q + (o*c)+ (p*d)

Absolute_clockchecking~~Relative_clockchecking
'

fit1 <- sem(Model1, data = DB, se = "bootstrap")
summary(fit1, standardized = TRUE, fit.measures =TRUE, rsquare
= TRUE)
parameterEstimates(fit1, boot.ci.type = "bca.simple")
```

Model 1a (testing the equality constraint on regression weights from absolute and relative onto TBPM)

```
Model1a <-'
Absolute_clockchecking ~ a*Age + f*Education + i*Sex +
l*Matrices + o*Mill_Hill
Relative_clockchecking ~ b*Age + g*Education + j*Sex +
m*Matrices + p*Mill_Hill
TBPM ~ c*Absolute_clockchecking + c*Relative_clockchecking +
e*Age + h*Education + k*Sex + n*Matrices + q*Mill_Hill

# indirect effects
Age_AbsoluteCC_indirect := a*c
Age_RelativeCC_indirect := b*c
Educ_AbsoluteCC_indirect := f*c
Educ_RelativeCC_indirect := g*c
Sex_AbsoluteCC_indirect := i*c
Sex_RelativeCC_indirect := j*c
Mat_AbsoluteCC_indirect := l*c
Mat_RelativeCC_indirect := m*c
MH_AbsoluteCC_indirect := o*c
MH_RelativeCC_indirect := p*c

# total effects
Agetotal := e + (a*c)+ (b*c)
Eductotal:= h + (f*c)+ (g*c)
Sextotal:= k + (i*c)+ (j*c)
Mattotal:= n + (l*c)+ (m*c)
MHtotal:= q + (o*c)+ (p*c)

Absolute_clockchecking~~Relative_clockchecking
'

fit1a <- sem(Model1a, data = DB, se = "bootstrap")
summary(fit1a, standardized = TRUE, fit.measures =TRUE,
rsquare = TRUE)
parameterEstimates(fit1a, boot.ci.type = "bca.simple")
```

Model 2 (absolute clock-checking as the only mediator of the effect of age on TBPM performance)

```
Model2 <-'
Absolute_clockchecking ~ a*Age + f*Education + i*Sex +
l*Matrices + o*Mill_Hill
TBPM ~ c*Absolute_clockchecking + e*Age + h*Education + k*Sex
+ n*Matrices + q*Mill_Hill

# indirect effects
Age_AbsoluteCC_indirect := a*c
Educ_AbsoluteCC_indirect := f*c
Sex_AbsoluteCC_indirect := i*c
Mat_AbsoluteCC_indirect := l*c
MH_AbsoluteCC_indirect := o*c

# total effects
Agetotal := e + (a*c)
Eductotal:= h + (f*c)
Sextotal:= k + (i*c)
Mattotal:= n + (l*c)
MHtotal:= q + (o*c)
'

fit2 <- sem(Model2, data = DB, se = "bootstrap")
summary(fit2, standardized = TRUE, fit.measures =TRUE, rsquare
= TRUE)
parameterEstimates(fit2, boot.ci.type = "bca.simple")
```

Model 3 (relative clock-checking as the only mediator of the effect of age on TBPM performance)

```
Model3 <-'
Relative_clockchecking ~ b*Age + g*Education + j*Sex +
m*Matrices + p*Mill_Hill
TBPM ~ d*Relative_clockchecking + e*Age + h*Education + k*Sex
+ n*Matrices + q*Mill_Hill

# indirect effects
Age_RelativeCC_indirect := b*d
Educ_RelativeCC_indirect := g*d
Sex_RelativeCC_indirect := j*d
Mat_RelativeCC_indirect := m*d
MH_RelativeCC_indirect := p*d

# total effects
Agetotal := e + (b*d)
Eductotal:= h + (g*d)
Sextotal:= k + (j*d)
Mattotal:= n + (m*d)
MHtotal:= q + (p*d)
'

fit3 <- sem(Model3, data = DB, se = "bootstrap")
summary(fit3, standardized = TRUE, fit.measures =TRUE, rsquare
= TRUE)
parameterEstimates(fit3, boot.ci.type = "bca.simple")
```

Model 4 (absolute and T4 clock-checking as mediators of the effect of age on TBPM performance)

```
Model4 <-'
Absolute_clockchecking ~ a*Age + f*Education + i*Sex +
l*Matrices + o*Mill_Hill
T4_clockchecking ~ b*Age + g*Education + j*Sex + m*Matrices +
p*Mill_Hill
TBPM ~ c*Absolute_clockchecking + d*T4_clockchecking + e*Age +
h*Education + k*Sex + n*Matrices + q*Mill_Hill

# indirect effects
Age_AbsoluteCC_indirect := a*c
Age_T4CC_indirect := b*d
Educ_AbsoluteCC_indirect := f*c
Educ_T4CC_indirect := g*d
Sex_AbsoluteCC_indirect := i*c
Sex_T4CC_indirect := j*d
Mat_AbsoluteCC_indirect := l*c
Mat_T4CC_indirect := m*d
MH_AbsoluteCC_indirect := o*c
MH_T4CC_indirect := p*d

# total effects
Agetotal := e + (a*c)+ (b*d)
Eductotal:= h + (f*c)+ (g*d)
Sextotal:= k + (i*c)+ (j*d)
Mattotal:= n + (l*c)+ (m*d)
MHtotal:= q + (o*c)+ (p*d)

Absolute_clockchecking~~T4_clockchecking
'

fit4 <- sem(Model4, data = DB,se = "bootstrap")
summary(fit4, standardized = TRUE, fit.measures =TRUE, rsquare
= TRUE)
parameterEstimates(fit4, boot.ci.type = "bca.simple")
```