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

SUBMITTED AS A BRIEF REPORT

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Abstract

Previous studies report that 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 (time-based prospective memory, TBPM). To disentangle the respective contribution of frequent vs. strategic clock-checking to age-related decrease in TBPM performance, we propose a new, more fine-grained indicator of strategicness. Together, both aspects of clock-checking fully mediated the negative age effect on TBPM performance and explained 54.6% of the variance of TBPM performance in an adult lifespan sample (N=221, age-range = 19-86), thereby providing avenues of intervention for improving older adults' TBPM.

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

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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, forgetting PM tasks occurs frequently in everyday life (Haas et al., 2020) and laboratory studies showed that PM performance typically decreases with age (Henry et al., 2004; Zuber & Kliegel, 2020; but 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).

For many time-based PM tasks (TBPM, i.e., intentions that have to be performed at particular time or after a certain time has elapsed), one of the main factors at play in this regard is clock-checking behavior – that is, assessing how often or when individuals check the time (e.g., Vanneste et al., 2016). So far, studies examined the role of clock-checking with two different, typically separate, approaches (for subsequent illustrations, we will use the example of a TBPM task that has to be performed after 60 seconds).

Some studies examined clock-checking in terms of *absolute frequency*, that is, how often participants check the clock (across the 60-seconds 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 some studies, older adults checked the clock less frequently than younger adults and displayed lower TBPM performance; in other studies 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; McFarland & Glisky, 2009; Mioni & Stablum, 2014; Mioni et al., 2020; Park et al., 1997; Vanneste et al.,

2016; Waldum & McDaniel, 2016; but see Gonneaud et al., 2011; Jäger & Kliegel, 2008). Thus, although absolute frequency of clock-checking seems to play a crucial role in predicting TBPM performance, previous results are inconsistent regarding the direction of age effects on absolute clock-checking and its impact on age-related differences in performance.

Other studies also examined clock-checking behavior in terms of the *distribution* of clock-checks – that is, 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 studies deduced strategicness by comparing the number of clock-checks across multiple time-intervals that precede the TBPM target-time (i.e., by separating the 60-seconds trial into four intervals of 15 seconds and comparing clock-checks across these 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 few studies related the strategicness of clock-checking to TBPM performance. They typically evaluated how the number of clock-checks in the last 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 they performed on the TBPM task (Jäger & Kliegel, 2008; McFarland & Glisky, 2009; Mioni et al., 2020; Mioni & Stablum, 2014). Looking at the trial level, Maylor and colleagues (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, although others found no age-related differences in strategic clock-checking (Einstein et al., 1995; Jäger & Kliegel, 2008; Logie et al., 2004;

Maylor et al., 2002; McFarland & Glisky, 2009; Mioni et al., 2020; Mioni & Stablum, 2014; Vanneste et al., 2016). 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 it remains unknown whether they predict unique aspects of TBPM performance, or whether they are interchangeable, thus redundant in predicting TBPM. In one rare study evaluating the impact of both absolute and strategic clock-checking frequency on TBPM performance, Voigt and colleagues (2014) showed that both aspects predicted TBPM performance in 5- to 14-year-old children. Specifically, checking the clock overall more often, but also increasing checking from the third to the last 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.

Critically, 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 (e.g., very few clock-checks in early intervals and many more in the last 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 – that is, examining the number of clock-checks during the last interval before the target-time – strategicness actually intertwines with absolute frequency.

Therefore, 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 suggest and examine a new, more fine-grained, indicator of strategicness of clock-checking. This indicator, called *relative clock-checking*, reflects participants' tendency to concentrate clock-checks in the last interval before the target-time, while accounting for the absolute number of clock-checks across the trial. Specifically, this indicator is computed as the percentage of clock-checks in the last interval (averaged across multiple trials). Hence, high relative clock-checking 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 few of the clock-checks were made immediately before the target-time, a pattern that reflects a low strategic clock-checking behavior.

Accordingly, the first aim of the present study was to (a) propose a new indicator of strategicness of clock-checking (i.e., relative clock-checking) that partials-out 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.'s (2014) and McFarland and Glisky's (2009) findings, subsequent aims were to (b) investigate the respective and concomitant effect of absolute and relative clock-checking frequency on TBPM performance, (c) test for age-related differences in those indicators, and (d) examine whether

these differences account for (i.e., mediate) age effects on TBPM performance in an adult lifespan sample.

Method

The data presented in this study stem from a larger project assessing TBPM both in the laboratory and online (Haas et al., submitted; Zuber et al., 2021; see Appendix A of supplemental material for additional details).

Participants

Two hundred sixty-two participants took part in this study. We excluded 41 participants (also see Zuber et al., 2021) because of issues with data recording ($n = 10$), outlier values (± 2.5 SD) on crystallized intelligence, fluid intelligence, processing speed or number of clock-checking ($n = 9$); impossibility to recall the TBPM instructions at the end of the task ($n = 7$); and performance below the value for the fifth percentile in the ongoing task (OT, see below; corresponding to an overall accuracy of .62 or lower, $n = 15$). The final sample comprised 221 individuals aged between 19 and 86 years ($M = 45.30$, $SD = 17.30$; 68% female in total). Education ranged from obligatory school to doctorate ($M = 15.73$ years, $SD = 3.48$), and participants showed normal cognitive functioning and vocabulary as indicated by the matrices from the WAIS-IV ($M = 19.08$, $SD = 4.35$, Wechsler, 2008) and the Mill Hill Vocabulary scale ($M = 24.39$, $SD = 4.97$; Deltour, 1993). The study was conducted in accordance with the Declaration of Helsinki, 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

We assessed TBPM performance through a TBPM task embedded in a 2-back picture decision task (OT, e.g., Jäger & Kliegel, 2008). Participants had to remember to push the Enter key every 60 seconds (i.e., TBPM task; to be performed at 60 seconds, 120 seconds,

etc.; six TBPM target-times in total; for similar approaches, see Guo & Huang, 2021; Labelle et al., 2009; Talbot & Kerns, 2014; Vanneste et al., 2016; Voigt et al., 2014; Zuber et al., 2019, 2021), while performing the OT for six minutes (i.e., the OT; 144 trials). 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). We recorded the number and time of clock-checks to compute both indicators of absolute and relative clock-checking frequency. TBPM performance was given by the percentage of TBPM hits (i.e., pressing the ENTER key during a response window of ± 5 seconds of the target-time).

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 consecutive intervals of 15 seconds each (T1, T2, T3, and T4). We then divided the number of clock-checks during the last interval¹ (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 = $\sum_{i=1}^6 \frac{T4_t}{T1_t + T2_t + T3_t + T4_t} / 6 * 100$, where t = trial). This resulted in one percentage score, where higher scores indicate highly strategic time monitoring behaviors.

Analytical approach

In a structural equation modeling framework, we tested whether age predicted TBPM performance and whether this effect was mediated by absolute and relative clock-checking. To rule out potential confounds, we controlled for the effects of education, sex, and crystallized and fluid intelligence. Hence, years of education, sex, WAIS-IV matrices and Mill-Hill vocabulary were set to predict TBPM performance directly and indirectly through absolute and relative clock-checking (see Figure S1 of supplemental material for a diagram of the model). We further conducted additional analyses (reported in supplemental material): a) to test whether accounting for only one of the clock-checking indicators was sufficient to fully mediate the effect of age, or whether both indicators were needed (Appendix B), and b) to

compare the predictive power of the classical indicator of strategicness (i.e., number of clock-checks in the last sub-interval before the target-time, further called *T4 clock-checking*) and the new indicator we propose (Appendix C). Models were estimated using Maximum Likelihood estimation in the package jAMM in Jamovi version 1.6.23 (2021). We estimated 95% confidence intervals for the direct, indirect, and total effects using bias corrected bootstrap. The indirect effects are reported as indexes of mediation (Preacher & Kelley, 2011).

Transparency and Openness

The dataset analyzed in this study is not publicly available because participant consent forms did not include authorization for public data sharing. However, data are available from the corresponding author [EJB] upon reasonable request. Syntaxes for the mediation models and links to the materials are available in the Supplemental Material. The study and analytic plans were not preregistered.

Results

Accuracy for the OT was high ($M = 88.8$, $SD = 6.86$, range = 62.90-98.60), while accuracy for the TBPM task was close to 50% ($M = 51.70$, $SD = 35.5$, range = 0-100). There were important between-person variations for absolute ($M = 9.85$, $SD = 7.76$, range = 0-38) and relative clock-checking frequency ($M = 29.60$, $SD = 21.70$, range = 0-100). The two clock-checking indicators correlated positively and moderately ($r = .57$, $p < .001$).

Correlations between variables of interest are reported in Table S1 of supplemental material.

Age negatively predicted TBPM performance ($\beta = -0.31$, $Z = -3.90$, $p < .001$, as indicated by the total effect), absolute clock-checking ($\beta = -0.28$, $Z = -3.71$, $p < .001$), and relative clock-checking ($\beta = -0.22$, $Z = -2.67$, $p < .01$). In turn, both absolute ($\beta = 0.36$, $Z = 7.16$, $p < .001$) and relative clock-checking ($\beta = 0.62$, $Z = 12.37$, $p < .001$) positively predicted TBPM performance. Importantly, relative clock-checking predicted TBPM almost twice as

strongly as absolute clock-checking, as indicated by differences in standardized estimates ($\beta = 0.62$ vs. $\beta = 0.36$).

The direct effect of age on TBPM performance was not significant when accounting for absolute and relative clock-checking ($\beta = -0.10$, $Z = -1.77$, $p = .08$), while the indirect effects through absolute ($\beta = -0.10$, $Z = -3.42$, $p < .001$) and relative clock-checking ($\beta = -0.14$, $Z = 2.63$, $p < .01$) were significant. Hence, the two clock-checking indicators together fully mediated the effect of age on TBPM performance. No indicator of clock-checking alone was sufficient to fully mediate the effect of age on TBPM performance (see Appendix B of supplementary material).

Regarding the control variables, the matrices had a positive indirect effect on TBPM performance ($\beta = 0.10$, $Z = 2.27$, $p = .02$) through relative clock-checking ($\beta = 0.17$, $Z = 2.25$, $p = .03$). Sex had a direct effect on TBPM performance ($\beta = 0.10$, $Z = 2.17$, $p = .03$) such that men performed better than women. All other effects were non-significant. We report estimates for the direct, indirect, and total effects in Table 1.

All predictors accounted for 10.1% of absolute clock-checking, 12.1% of relative clock-checking, and 68.0% of TBPM performance. Age alone explained 11 % of the variance in TBPM performance, and the control variables added 2.4%. Finally, the two clock-checking indicators together explained 54.6% of additional variance in TBPM performance. Relative clock-checking explained a greater portion of TBPM variance than absolute clock-checking (47.7% vs. 34.0%, respectively, when examined separately, see Appendix B of supplemental material).

To test whether the indicator of relative clock-checking is a better indicator of strategicness than the mere number of clock-checks in the last sub-interval before the TBPM target, we compared results reported above with results from a model in which strategicness was instead indicated by T4 clock-checking (see Appendix C of supplemental material).

Given that absolute clock-checking and T4 clock-checking correlated very strongly ($r = .90$, $p < .001$), there was multicollinearity between the two variables ($VIF = 5.18$ and 5.33 , respectively)². Because of the collinearity issue, higher absolute clock-checking predicted lower TBPM performance when controlling for T4 clock-checking.

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 partials-out 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 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. In contrast, because our new indicator accounts for interindividual differences in absolute clock-checking, there was no issue with 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 for each aspect of monitoring 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 47.7% of the variance of TBPM performance in our sample, and together the two clock-checking indicators explained almost 55% 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 even more important.

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's study (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, divergences in age-related clock-checking and TBPM performance patterns may come from varying 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 low cognitive load OTs (i.e., watching a movie or listening to a story), in which participants had more available attentional resources to both carry the OT out and check the clock. However, in more challenging tasks (e.g., flanker or n-back tasks), such as the one used in the present study, older participants with lower attentional resources may have difficulties performing both the OT and TBPM tasks, thereby resulting in lower TBPM performance (Logie et al., 2004; Mäntylä et al., 2009). Hence, older adults in our sample may have operated a trade-off and directed their limited resources preferentially towards the OT rather than towards clock-checking for the TBPM task (Mäntylä & Carelli, 2006).

To conclude, 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 than 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. 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. Thus, the present study provides valuable insights into efficient strategies to improve daily-life TBPM performance, especially for older adults. It might

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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

¹ Corresponding to the classical indicator of strategicness of clock-checking.

² This was not the case with relative clock-checking ($VIF = 1.52$ and 1.56 respectively).

AGE AND TIME MONITORING EFFECTS IN TIME-BASED PM

Table 1

Estimates for the Direct, Indirect, and Total Effects for the Mediation of the Effect of Age on TBPM Performance Through Absolute and Relative Clock-Checking Indicators, Controlling for Education, Sex, Matrices, and Mill-Hill Scores.

Effect	Estimate	S.E.	95 % C.I.		β	Z	<i>p</i>
			Lower	Upper			
Indirect effects							
Age → Absolute clock-checking → TBPM	-0.19	0.06	-0.31	-0.09	-0.10	-3.42	< .001
Age → Relative clock-checking → TBPM	-0.26	0.10	-0.47	-0.07	-0.14	-2.63	0.009
Education → Absolute clock-checking → TBPM	0.03	0.22	-0.34	0.48	0.01	0.13	0.898
Education → Relative clock-checking → TBPM	-0.06	0.40	-0.81	0.79	-0.01	-0.14	0.890
Sex → Absolute clock-checking → TBPM	1.34	1.75	-1.82	5.18	0.02	0.77	0.441
Sex → Relative clock-checking → TBPM	-0.76	2.86	-6.22	5.14	-0.01	-0.26	0.791
Matrices → Absolute clock-checking → TBPM	0.12	0.20	-0.32	0.49	0.02	0.59	0.554
Matrices → Relative clock-checking → TBPM	0.78	0.34	0.10	1.50	0.10	2.27	0.023
Mill-Hill → Absolute clock-checking → TBPM	-0.09	0.17	-0.45	0.25	-0.01	-0.51	0.613
Mill-Hill → Relative clock-checking → TBPM	-0.28	0.30	-0.90	0.29	-0.04	-0.95	0.345
Components of the indirect effects							
Age → Absolute clock-checking	-0.13	0.03	-0.19	-0.06	-0.28	-3.71	< .001
Absolute clock-checking → TBPM	1.49	0.21	1.09	1.87	0.36	7.16	< .001
Age → Relative clock-checking	-0.28	0.10	-0.50	-0.07	-0.22	-2.67	0.008
Relative clock-checking → TBPM	0.93	0.07	0.77	1.08	0.62	12.37	< .001
Education → Absolute clock-checking	0.02	0.15	-0.24	0.32	0.01	0.13	0.896

AGE AND TIME MONITORING EFFECTS IN TIME-BASED PM

Education → Relative clock-checking	-0.06	0.43	-0.85	0.84	-0.01	-0.14	0.889
Sex → Absolute clock-checking	0.90	1.16	-1.23	3.41	0.05	0.78	0.437
Sex → Relative clock-checking	-0.82	3.08	-6.50	5.55	-0.02	-0.27	0.790
Matrices → Absolute clock-checking	0.08	0.13	-0.20	0.33	0.04	0.60	0.546
Matrices → Relative clock-checking	0.84	0.37	0.11	1.64	0.17	2.25	0.025
Mill-Hill → Absolute clock-checking	-0.06	0.11	-0.28	0.16	-0.04	-0.52	0.604
Mill-Hill → Relative clock-checking	-0.30	0.32	-0.94	0.34	-0.07	-0.96	0.340
Direct effects							
Age → TBPM	-0.18	0.10	-0.38	0.02	-0.10	-1.77	0.076
Education → TBPM	-0.40	0.60	-1.55	0.72	-0.04	-0.66	0.507
Sex → TBPM	7.04	3.24	0.88	13.97	0.10	2.17	0.030
Matrices → TBPM	0.06	0.35	-0.71	0.72	0.01	0.16	0.873
Mill-Hill → TBPM	0.61	0.34	-0.06	1.30	0.09	1.82	0.068
Total effects							
Age → TBPM	-0.63	0.16	-0.95	-0.31	-0.31	-3.90	< .001
Education → TBPM	-0.43	0.70	-1.80	0.95	-0.04	-0.61	0.544
Sex → TBPM	7.63	4.82	-1.82	17.08	0.10	1.58	0.113
Matrices → TBPM	0.95	0.59	-0.22	2.11	0.12	1.60	0.110
Mill-Hill → TBPM	0.24	0.53	-0.80	1.29	0.03	0.46	0.649

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.

AGE AND TIME MONITORING EFFECTS IN TIME-BASED PM

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).

Supplemental Material for Online Publication

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

Supplemental Figure S1

Visual Representation of the Model in Which Age, Education, Sex, Matrices and Mill-Hill Directly and Indirectly Predict TBPM Performance Through Absolute and Relative Clock-Checking (i.e. the Initial Model that was Reported in the Manuscript)

Note. Covariances between the predictors and residual variances for the outcome variables are estimated but not shown.

Corresponding R/Jamovi Computer Code

Main model (absolute and Relative clock-checking as mediators)

```
jamm::jammGLM(  
  formula = list( Absoluteclockchecking ~ Age + Education + Sex +  
Matrices + MillHill,  
  Relativedclockchecking ~ Age + Education + Sex + Matrices +  
MillHill,  
  TBPM ~ Absoluteclockchecking + Relativedclockchecking + Age +  
Education + Sex + Matrices + MillHill ),  
  data = data,  
  ciType = "bca",  
  tableOptions = c("beta", "component"),  
  moderatorsTerms = list(  
    list(),  
    list()),  
  duplicate = 2)
```

Supplemental Table S1.

Correlations among the Variables of Interest

		Age	Education	Mill-Hill	Matrices	Absolute clock-checking	Relative clock-checking	T4 clock-checking	TBPM
Age	Pearson's r	—							
	<i>p</i>	—							
Education	Pearson's r	-0.136 *	—						
	<i>p</i>	0.044	—						
Mill-Hill	Pearson's r	0.341 ***	0.285 ***	—					
	<i>p</i>	< .001	< .001	—					
Matrices	Pearson's r	-0.416 ***	0.190 **	0.104	—				
	<i>p</i>	< .001	0.005	0.122	—				
Absolute clock-checking	Pearson's r	-0.310 ***	0.044	-0.129	0.160 *	—			
	<i>p</i>	< .001	0.511	0.056	0.017	—			
Relative clock-checking	Pearson's r	-0.317 ***	0.032	-0.131	0.250 ***	0.565 ***	—		
	<i>p</i>	< .001	0.641	0.052	< .001	< .001	—		
T4 clock-checking	Pearson's r	-0.334 ***	0.049	-0.135 *	0.215 **	0.897 ***	0.803 ***	—	
	<i>p</i>	< .001	0.467	0.045	0.001	< .001	< .001	—	
TBPM	Pearson's r	-0.330 ***	0.036	-0.071	0.243 ***	0.664 ***	0.764 ***	0.789 ***	—
	<i>p</i>	< .001	0.590	0.290	< .001	< .001	< .001	< .001	—

Note. * $p < .05$, ** $p < .01$, *** $p < .001$. T4 clock-checking represents the classical operationalization of strategicness of clock-checking (i.e., the number of times participants checked the clock in the last time-interval before the TBPM target-time).

APPENDIX A: Additional Information on Study Material and Procedure

The data presented in this study stem from a larger 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. Below, we provide complementary information on the study sample and detail all the tasks and questionnaires used in this larger project. We also provide additional details for the tasks that are relevant for the present study.

Study Sample

Because the primary aim of the project was 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-years 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, advertising of former participants, and flyers distributed in public places. Young participants were also recruited from a Bachelor course in Psychology. In exchange for participation, students received eligibility to take the course exam (but were not awarded any course credits). 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 and because we were close ($N = 262$) to our sample size goal, we decided to stop recruitment at that point.

Supplemental Table A1

Final Sample Size, Mean and Standard Deviation of Age, and Percentages of Woman as a Function of Age Strata in both Zuber et al. (2021) and the Present Paper

Age Strata	Final Sample in Zuber et al. (2021)				Final Sample in the Present Paper			
	<i>N</i>	<i>Mean Age</i>	<i>SD Age</i>	<i>Gender Women</i>	<i>N</i>	<i>Mean Age</i>	<i>SD Age</i>	<i>Gender Women</i>
19-29	56	23.64	2.29	79%	58	23.74	2.25	78%
30-39	39	34.01	2.98	54%	35	34.05	3.16	51%
40-49	37	45.67	3.00	68%	31	45.63	2.84	68%
50-59	46	54.60	3.04	72%	38	54.57	2.90	74%
60-69	50	63.47	2.55	67%	43	63.42	2.60	67%
>70	24	76.56	4.55	58%	16	76.34	5.07	56%

Reasons for participants exclusions are reported in Zuber et al. (2021) and in the main body of this paper. The final number and proportion of female participant in the final samples for

Zuber et al. (2021) and for the present study are reported in Supplemental Table A1 above. Of importance, racial distribution of the sample as a function of age is not available given that it is not customary to record this information in research conducted in Switzerland, unless it is relevant to the research hypotheses.

Tasks and Questionnaires

Supplemental Table A2 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 tasks were administered.

In the present study, we focused on analyzing data of a TBPM task that was embedded in a typical n-back picture decision task working memory paradigm (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). This task is labelled below as the 2-back picture decision task (OT + TBPM). In this task, participants had to decide whether the picture presented at a given trial was the same as the picture presented two trials before. If the pictures were identical, they had to push the “green button” (i.e., right arrow on the keyboard), whereas they had to push the “red key” (i.e., left arrow on the keyboard) if the pictures were different. 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. Upon successful completion of the practice block, participants completed an OT only block of 48 trials (i.e., 2-back picture decision task). Next, the experimenter explained the TBPM task. Participants were instructed that, in addition to the OT, they had to remember to push the “Enter” button at every full minute (i.e., at 60 seconds, 120 seconds, etc.). They could check the progression of time by pushing the spacebar, which displayed a timer at the bottom of the screen for 3 seconds (format: mm:ss). During a delay phase, participants then completed the Mill Hill Vocabulary Scale as filler task. They were not reminded of the TBPM instructions before beginning the next task block (OT + TBPM). The OT + TBPM block lasted six minutes (i.e., 144 OT trials, six TBPM target times). Afterwards, participants were asked to describe summarize task instructions to ensure that they remembered the TBPM task. Participants that could not recall the instructions after the task were excluded from analyses. The task was run on Eprime2, and is available for download at <https://cigev.unige.ch/openscience/>. Please note that the pictures from Snodgrass and Vanderwart (1980) are protected by copyrights, and may not be used for free. Accordingly, the Eprime 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).

Supplemental Table A2

Questionnaires/Tasks	Used in this paper	Reference	Where to find
Socio-demographic questionnaire	Yes		See pages 9-10 of this document
Mill-Hill vocabulary test	Yes	Deltour, J. J. (1993). <i>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)</i> . Editions L'Application des Techniques Modernes.	
WAIS-IV Matrices subtest	Yes	Wechsler, D. (2008). <i>Wechsler adult intelligence scale—Fourth edition</i> . 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: <i>Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)</i>	http://www.computer-literacy.net/
2-back picture decision task (OT only)	No		
2-back picture decision task (OT + TBPM)	Yes		https://cigev.unige.ch/openscience/
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. <i>Memory</i> , 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) <i>Online Assessment of Cognitive Functioning Across the Adult Lifespan Using the eCOGTEL: A Reliable Alternative to Laboratory Testing</i> Manuscript submitted for publication.	https://cigev.unige.ch/openscience/

Note. OT = ongoing task. TBPM = Prospective Memory. WAIS-IV = Wechsler Adult Intelligence Scale - Fourth edition

Supplemental Figure A1*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:

INFORMATIONS GÉNÉRALES

1. Veuillez noter le code du participant : _____

2. Quelle est la date de naissance du participant ? _____

3. Le participant est :

Femme	
Homme	

4. Le participant est :

Droitier	
Gaucher	

5. Quel est votre état civil ?

Célibataire	
Marié(e), remarié(e), Pacsé(e)	
En couple	
Divorcé(e), séparé(e)	
Veuf (veuve)	

6. Quel est le plus haut niveau de formation que vous avez accompli ?

Primaire	
Secondaire inférieur (cycle orientation)	
Formation professionnelle (apprentissage)	
Secondaire supérieur (collège, école de commerce, gymnase, etc.)	
École technique ou professionnelle supérieure (infirmières, assistants sociaux, maîtres d'école, ingénieurs, etc.)	
Université, école polytechnique fédérale	
Autre (à préciser)	

7. Combien d'années avez-vous consacrées à... l'école obligatoire (CH : fin Cycle d'orientation | FR : fin collège, 3^e)

... l'école secondaire (CH : Maturité | FR : Baccalauréat) _____

... l'université ou équivalent _____

... d'autres formations _____

8. Laquelle des options suivantes décrit au mieux vos activités et/ou responsabilités quotidiennes en ce moment ?

Retraité(e)	
Emploi à temps plein	
Emploi à temps partiel	
Étudiant(e)	
Femme (homme) au foyer	
Maladie / invalidité	
Chômage	
Autre (à préciser)	

9. Quel est le métier que vous exercez (avez exercé en dernier) ?**10. Quel est (était) votre taux de travail ?****11. Ce travail est (était) - il pénible physiquement, demandait-il de gros efforts physiques ?**

Non		Oui	
-----	--	-----	--

12. Sur une échelle de 0 « pire état de santé imaginable » à 100 « meilleur état de santé imaginable » où situez-vous votre santé AUJOURD'HUI : _____

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APPENDIX B: Are the Two Clock-Checking Indicators Necessary to Fully Mediate the Effect of Age on TBPM?

In order to establish whether accounting for the two indicators of clock-checking was really necessary to fully mediate the effect of age on TBPM performance, we estimated two additional models in which each of the indicator separately predicted TBPM performance, keeping all other covariates. The model in which absolute clock-checking alone predicted TBPM is depicted in Figure S2 and results are reported in Table S2. The model in which relative clock-checking alone predicted TBPM is depicted in Figure S3 and results are reported in Table S3.

Results from the two models revealed that neither absolute nor relative clock-checking fully mediated the effect of age on TBPM alone. The direct effect of age was still significant when controlling for either absolute ($\beta = -0.13$, $Z = -1.97$, $p = .049$, see Table S2) or relative clock-checking ($\beta = -0.14$, $Z = -2.59$, $p = .010$, see Table S3). In contrast, as reported in Table 1 from the manuscript, accounting for the two clock-checking indicators fully mediated the effect of age on TBPM performance as indicated by the non-significant direct effect ($\beta = -0.10$, $Z = -1.77$, $p = .076$).

Based on these additional results, we can conclude that we need both indicators of clock-checking to fully explain the age-related differences in TBPM performance in our sample.

Finally, to compute effect sizes, a model with and without each of the predictors of interest was estimated. Differences in R^2 are used to assess specific contribution of each predictor of interest. Accounting for all predictors, the full model reported in the paper explained 68.0% of TBPM variance. Of importance, TBPM performance was better explained by relative clock-checking (47.7 % of TBPM variance) than by absolute clock-checking (34.0 % of TBPM variance), when accounted for separately. Together, the two indicators explain 54.6 % of TBPM variance.

Supplemental Figure S2

Visual Representation of the Model in Which Age, Education, Sex, Matrices and Mill-Hill Directly and Indirectly Predict TBPM Performance Through Absolute Clock-Checking Only

Note. Covariances between the predictors and residual variances for the outcome variables are estimated but not shown.

Supplemental Figure S3

Visual Representation of the Model in Which Age, Education, Sex, Matrices and Mill-Hill Directly and Indirectly Predict TBPM Performance Through Relative Clock-Checking Only

Note. Covariances between the predictors and residual variances for the outcome variables are estimated but not shown.

Corresponding R/Jamovi Computer Code

Model with only relative clock checking as a mediator

```
jamm::jammGLM(  
  formula = list( Relativeclockchecking ~ Age + Education + Sex +  
Matrices + MillHill,  
  TBPM ~ Relativeclockchecking + Age + Education + Sex + Matrices  
+ MillHill ),  
  data = data,  
  ciType = "bca",  
  tableOptions = c("beta", "component"),  
  duplicate = 2)
```

Model with only absolute clock checking as a mediator

```
jamm::jammGLM(  
  formula = list( Absoluteclockchecking ~ Age + Education + Sex +  
Matrices + MillHill,  
  TBPM ~ Absoluteclockchecking + Age + Education + Sex + Matrices  
+ MillHill ),  
  data = data,  
  ciType = "bca",  
  tableOptions = c("beta", "component"),  
  duplicate = 2)
```

Supplemental Table S2

Estimates for the Direct, Indirect and Total Effects for the Mediation of the Effect of Age on TBPM Performance Through Absolute Clock-Checking Alone, Controlling for Education, Sex, Matrices and Mill-Hill Scores

Effect	Estimate	S.E.	95 % C.I.		β	Z	p
			Lower	Upper			
Indirect effects							
Age $\rightarrow$ Absolute clock-checking $\rightarrow$ TBPM	-0.35	0.09	-0.55	-0.18	-0.17	-3.79	< .001
Education $\rightarrow$ Absolute clock-checking $\rightarrow$ TBPM	0.05	0.41	-0.63	0.96	0.01	0.13	0.896
Sex $\rightarrow$ Absolute clock-checking $\rightarrow$ TBPM	2.55	3.33	-3.40	9.16	0.03	0.76	0.444
Matrices $\rightarrow$ Absolute clock-checking $\rightarrow$ TBPM	0.22	0.38	-0.50	0.99	0.03	0.58	0.563
Mill-Hill $\rightarrow$ Absolute clock-checking $\rightarrow$ TBPM	-0.17	0.33	-0.86	0.49	-0.02	-0.50	0.615
Components of the indirect effects							
Age $\rightarrow$ Absolute clock-checking	-0.13	0.03	-0.19	-0.06	-0.28	-3.67	< .001
Absolute clock-checking $\rightarrow$ TBPM	2.82	0.27	2.30	3.36	0.62	10.60	< .001
Education $\rightarrow$ Absolute clock-checking	0.02	0.15	-0.22	0.32	0.01	0.13	0.895
Sex $\rightarrow$ Absolute clock-checking	0.90	1.19	-1.18	3.45	0.05	0.76	0.448
Matrices $\rightarrow$ Absolute clock-checking	0.08	0.14	-0.18	0.34	0.04	0.58	0.559
Mill-Hill $\rightarrow$ Absolute clock-checking	-0.06	0.12	-0.28	0.17	-0.04	-0.51	0.612
Direct effects							
Age $\rightarrow$ TBPM	-0.27	0.14	-0.56	-0.00	-0.13	-1.97	0.049
Education $\rightarrow$ TBPM	-0.48	0.68	-1.82	0.85	-0.05	-0.71	0.479
Sex $\rightarrow$ TBPM	5.08	3.91	-2.65	12.91	0.07	1.30	0.193

Matrices → TBPM	0.73	0.45	-0.17	1.61	0.09	1.63	0.104
Mill-Hill → TBPM	0.41	0.43	-0.48	1.26	0.06	0.94	0.346
Total effects							
Age → TBPM	-0.63	0.16	-0.94	-0.31	-0.31	-3.90	< .001
Education → TBPM	-0.43	0.70	-1.80	0.95	-0.04	-0.61	0.544
Sex → TBPM	7.63	4.82	-1.82	17.07	0.10	1.58	0.113
Matrices → TBPM	0.95	0.59	-0.22	2.11	0.12	1.60	0.110
Mill-Hill → TBPM	0.24	0.53	-0.80	1.29	0.03	0.46	0.649

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.

Supplemental Table S3

Estimates for the Direct, Indirect and Total Effects for the Mediation of the Effect of Age on TBPM Performance Through Relative Clock-Checking Alone, Controlling for Education, Sex, Matrices and Mill-Hill Scores

Effect	Estimate	S.E.	95 % C.I.		β	Z	p
			Lower	Upper			
Indirect effects							
Age → Relative clock-checking → TBPM	-0.34	0.13	-0.59	-0.11	-0.16	-2.69	0.007
Education → Relative clock-checking → TBPM	-0.07	0.52	-0.94	1.09	-0.01	-0.14	0.890
Sex → Relative clock-checking → TBPM	-0.98	3.83	-8.61	6.61	-0.01	-0.26	0.797
Matrices → Relative clock-checking → TBPM	1.01	0.44	0.18	1.90	0.12	2.27	0.023
Mill-Hill → Relative clock-checking → TBPM	-0.37	0.36	-1.02	0.39	-0.05	-1.01	0.314
Components of the indirect effects							
Age → Relative clock-checking	-0.28	0.10	-0.48	-0.09	-0.22	-2.72	0.006
Relative clock-checking → TBPM	1.21	0.08	1.06	1.38	0.74	14.74	<.001
Education → Relative clock-checking	-0.06	0.43	-0.78	0.91	-0.01	-0.14	0.890
Sex → Relative clock-checking	-0.82	3.18	-7.18	5.32	-0.02	-0.26	0.797
Matrices → Relative clock-checking	0.84	0.37	0.15	1.59	0.17	2.24	0.025
Mill-Hill → Relative clock-checking	-0.30	0.30	-0.85	0.31	-0.07	-1.01	0.310
Direct effects							
Age → TBPM	-0.29	0.11	-0.52	-0.08	-0.14	-2.59	0.010
Education → TBPM	-0.35	0.57	-1.44	0.75	-0.03	-0.62	0.538
Sex → TBPM	8.61	3.45	2.06	15.52	0.11	2.49	0.013

Matrices → TBPM	-0.06	0.38	-0.81	0.69	-0.01	-0.16	0.875
Mill-Hill → TBPM	0.61	0.35	-0.16	1.25	0.08	1.72	0.086
Total effects							
Age → TBPM	-0.63	0.16	-0.94	-0.31	-0.31	-3.90	< .001
Education → TBPM	-0.43	0.70	-1.80	0.95	-0.04	-0.61	0.544
Sex → TBPM	7.63	4.82	-1.82	17.07	0.10	1.58	0.113
Matrices → TBPM	0.95	0.59	-0.22	2.11	0.12	1.60	0.110
Mill-Hill → TBPM	0.24	0.53	-0.80	1.29	0.03	0.46	0.649

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.

APPENDIX C: Comparing our New Indicator to the Classical Indicator of Strategicness of Clock-Checking

The aim of this appendix was to test whether the indicator of strategicness of clock-checking we proposed (i.e., relative clock-checking) was a better operationalization of strategicness of clock-checking than the classical indicator, that is the number of clock checks during the last time-interval before the TBPM target-time (i.e., T4 clock-checking). In this regard, we first estimated an alternative model in which we replaced relative clock-checking by T4 clock-checking, keeping all other covariates (see Figure S4). Second, given that there was a strong correlation between T4 and absolute clock-checking ($r = .90$, $p < .001$, see Table S1), we conducted redundancy analyses to test for multicollinearity issues using ordinary least square multiple linear regressions (see Table S5).

Results from the alternative model are reported in Table S4, and compared below with results from the initial model (Table 1 in the manuscript).

In both models the strategicness of clock-checking indicator (i.e. T4 clock-checking or relative clock-checking) strongly and positively predicted TBPM performance ($\beta = 0.83$, $Z = 22.28$, $p < .001$ and $\beta = 0.62$, $Z = 12.37$, $p < .001$ respectively). In addition, both indicators of clock-checking fully mediated the effect of age on TBPM, irrespective of the indicator of strategicness of clock-checking used ($\beta = -0.09$, $Z = -1.89$, $p = .06$ and respectively $\beta = -0.10$, $Z = -1.77$, $p = .08$). However, differences between the models emerged when considering the effect of absolute clock-checking on TBPM performance.

In the alternative model, using the classical T4 clock-checking indicator, absolute clock-checking had a *negative* impact on TBPM performance ($\beta = -0.19$, $Z = -5.20$, $p < .001$). 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.

In contrast, in the initial model (see Table 1 in the manuscript), using the indicator of relative clock-checking we proposed, absolute clock-checking had a *positive* impact on TBPM performance ($\beta = 0.36$, $Z = 7.16$, $p < .001$). In other words, when controlling for the percentage of clock checks that occurred during the last time-interval before the TBPM target-time, higher absolute clock-checking predicted *better* TBPM performance. Hence, when partialling-out the effect of absolute clock-checking in the indicator of strategicness of monitoring, we conclude that both checking the clock often and strategically had a positive impact on TBPM performance.

Therefore, the negative effect of absolute clock-checking on TBPM performance when controlling for T4 clock-checking is an artefact coming from the overlap between the two indicators, as indicated by the high values for both correlation and VIF ($r = .90$ and a $VIF_{\text{Absolute clock-checking}} = 5.18$ and $VIF_{\text{T4 clock-checking}} = 5.33$ respectively). Such a strong correlation is to be expected since T4 clock-checking is not independent from absolute clock-checking. Therefore, 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 strategicness of clock-checking on TBPM performance. In contrast, because we partialled-out the effect of absolute clock-checking in relative clock-checking (see the method section in the

manuscript to see how this indicator is computed), the two indicators positively correlated but were not subject to multicollinearity issues ($r = .57$, $VIF_{\text{Absolute clock-checking}} = 1.52$ and $VIF_{\text{Relative clock-checking}} = 1.56$ respectively).

Furthermore, contrary to T4 clock-checking, the relative clock-checking indicator was sensitive to interindividual differences in fluid intelligence, as indicated by a significant regression weight from matrices to relative clock-checking ($\beta = 0.17$, $Z = 2.25$, $p = .03$) but a non-significant regression weight from matrices to T4 clock-checking ($\beta = 0.10$, $Z = 1.38$, $p = .17$).

Finally, using relative as compared to T4 clock-checking yielded a modest difference in explained TBPM variance in favor of the relative clock-checking indicator. Indeed, in the alternative model, all predictors explained 64.6% of variance in TBPM performance, while they explained 68.0% of variance in the initial model.

These results provide evidence for our claim that the indicator we proposed is a more informative, and potentially purer, indicator of strategicness of clock-checking than the mere number of times participants checked the clock during the last time-interval before the TBPM target-time. We hence, strongly encourage future studies to use this indicator of relative clock-checking frequency, as a measure of strategicness in time monitoring.

Supplemental Figure S4

Visual Representation of the Model in Which Age, Education, Sex, Matrices and Mill-Hill Directly and Indirectly Predict TBPM Performance Through Relative Clock-Checking Only

Note. Covariances between the predictors and residual variances for the dependent variables are estimated but not shown.

Corresponding R/Jamovi computer code**Alternative model (replacing Relative clock-checking by T4 clock-checking, the classical indicator of strategicness of clock-checking)**

```
jamm::jammGLM(  
  formula = list( Absoluteclockchecking ~ Age + Education + Sex +  
Matrices + MillHill,  
  Relativclockchecking ~ Age + Education + Sex + Matrices +  
MillHill,  
  TBPM ~ Absoluteclockchecking + Relativclockchecking + Age +  
Education + Sex + Matrices + MillHill ),  
  data = data,  
  ciType = "bca",  
  tableOptions = c("beta", "component"),  
  moderatorsTerms = list(  
    list(),  
    list()),  
  duplicate = 2)
```

Supplemental Table S4

Estimates for the Direct, Indirect and Total Effects for the Mediation of the Effect of Age on TBPM Performance Through Absolute and T4 Clock-checking Indicators, Controlling for Education, Sex, Matrices and Mill-Hill Scores

Effect	Estimate	S.E.	95 % C.I.		β	Z	<i>p</i>
			Lower	Upper			
Indirect effects							
Age → Absolute clock-checking → TBPM	0.13	0.04	0.04	0.21	0.05	2.91	0.004
Age → T4 clock-checking → TBPM	-0.55	0.16	-0.86	-0.24	-0.23	-3.51	< .001
Education → Absolute clock-checking → TBPM	-0.02	0.16	-0.33	0.29	-0.01	-0.12	0.901
Education → T4 clock-checking → TBPM	0.04	0.67	-1.27	1.35	0.01	0.06	0.953
Sex → Absolute clock-checking → TBPM	-0.91	1.09	-3.05	1.23	-0.01	-0.83	0.404
Sex → T4 clock-checking → TBPM	5.46	4.62	-3.60	14.52	0.06	1.18	0.238
Matrices → Absolute clock-checking → TBPM	-0.08	0.13	-0.34	0.18	-0.01	-0.59	0.552
Matrices → T4 clock-checking → TBPM	0.78	0.57	-0.33	1.90	0.08	1.37	0.170
Mill-Hill → Absolute clock-checking → TBPM	0.06	0.12	-0.17	0.29	0.01	0.50	0.620
Mill-Hill → T4 clock-checking → TBPM	-0.33	0.51	-1.33	0.66	-0.04	-0.66	0.512
Components of the indirect effects							
Age → Absolute clock-checking	-0.13	0.04	-0.20	-0.06	-0.28	-3.51	< .001
Absolute clock-checking → TBPM	-1.01	0.19	-1.39	-0.63	-0.19	-5.20	< .001
Age → T4 clock-checking	-0.06	0.02	-0.09	-0.03	-0.28	-3.56	< .001
T4 clock-checking → TBPM	9.71	0.44	8.86	10.57	0.83	22.28	< .001
Education → Absolute clock-checking	0.02	0.16	-0.29	0.32	0.01	0.12	0.901

Education → T4 clock-checking	0.01	0.07	-0.13	0.14	0.01	0.06	0.953
Sex → Absolute clock-checking	0.90	1.07	-1.19	3.00	0.05	0.84	0.398
Sex → T4 clock-checking	0.56	0.48	-0.37	1.49	0.08	1.18	0.237
Matrices → Absolute clock-checking	0.08	0.13	-0.18	0.34	0.04	0.60	0.549
Matrices → T4 clock-checking	0.08	0.06	-0.03	0.20	0.10	1.38	0.169
Mill-Hill → Absolute clock-checking	-0.06	0.12	-0.29	0.17	-0.04	-0.50	0.618
Mill-Hill → T4 clock-checking	-0.03	0.05	-0.14	0.07	-0.05	-0.66	0.511
Direct effects							
Age → TBPM	-0.21	0.11	-0.42	0.01	-0.09	-1.89	0.058
Education → TBPM	-0.45	0.45	-1.32	0.43	-0.04	-1.00	0.318
Sex → TBPM	3.08	3.09	-2.98	9.13	0.04	1.00	0.319
Matrices → TBPM	0.25	0.38	-0.50	0.99	0.03	0.64	0.519
Mill-Hill → TBPM	0.52	0.34	-0.15	1.18	0.06	1.52	0.128
Total effects							
Age → TBPM	-0.63	0.16	-0.95	-0.31	-0.31	-3.90	< .001
Education → TBPM	-0.43	0.70	-1.80	0.95	-0.04	-0.61	0.544
Sex → TBPM	7.63	4.82	-1.82	17.08	0.10	1.58	0.113
Matrices → TBPM	0.95	0.59	-0.22	2.11	0.12	1.60	0.110
Mill-Hill → TBPM	0.24	0.53	-0.80	1.29	0.03	0.46	0.649

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).

Supplemental Table S5

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

	Initial Model		Alternative Model	
	VIF	Tolerance	VIF	Tolerance
Age	1.65	0.61	1.65	0.61
Education	1.17	0.86	1.17	0.86
Sex	1.02	0.98	1.02	0.98
Mill-Hill	1.39	0.72	1.39	0.72
Matrices	1.36	0.73	1.35	0.74
Absolute clock-checking	1.52	0.66	5.18	0.19
Relative clock-checking	1.56	0.64	-	-
T4 clock-checking	-	-	5.33	0.19

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.

References

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- Menard S. (2001) *Applied Logistic Regression Analysis*. 2nd edition. SAGE Publications.
- Vittinghoff, E., Glidden, D.V., Shiboski, S.C., McCulloch, C.E. (2012) *Regression Methods in Biostatistics: Linear, Logistic, Survival, and Repeated Measures Models*. 2nd edition. Springer.