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RESEARCH

Factors influencing passage of time judgment in individuals' daily lives: evidence from the experience sampling and diary methods

Yanci Liu[1] · Siyu Ma[1] · Jiayu Li[3] · Xi Song[2,4] · Feng Du[2,4] · Meihong Zheng[1]

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Abstract

People often express feeling that time passes quickly or slowly in their daily lives, which is termed passage of time judgment (PoTJ). Past studies have shown that PoTJ is affected by emotional valence and arousal; however, few studies have verified the effects of alertness, attention to time, and time expectation on PoTJ and whether the effects are stable over different time periods. Using the experience sampling method (ESM) and diary method, the present study collected data from 105 participants and examined for the first time whether alertness, attention to time, and time expectation affect PoTJ based on daily life data, as well as whether above factors, emotional valence, and arousal are stable over different time periods. All participants answered a questionnaire five times a day on their in-the-day PoTJ and related factors regarding the last 30 min, and answered the same questionnaire once a day at 23:00 regarding the of-the-day PoTJ. The results showed that alertness and time expectation, as well as emotional valence and arousal, predicted an individual's in-the-day PoTJ over a shorter period (i.e., the last 30 min); in contrast, only time expectation and emotional arousal predicted of-the-day PoTJ over a longer period (i.e., the past day). These results suggest that, alertness and time expectation are important factors influencing PoTJ, in addition to emotional state. Of-the-day PoTJ correlates most strongly with the mean and latest in-the-day PoTJ, implying that overall perception of time passage is influenced by both cumulative temporal experience and recent temporal experience.

Introduction

The perception of the speed at which time passes is termed passage of time judgment (PoTJ), and it plays a critical role in daily life (Cahoon & Edmonds, 1980; Wearden, 2015). Modulatory factors of PoTJ have attracted many psychologists' attention (Droit-Volet & Dambrun, 2019; Martinelli & Droit-Volet, 2022; Tanaka & Yotsumoto, 2017; Wittmann et al., 2015). Among these factors, emotional valence and emotional arousal are suggested to be related to PoTJ (Droit-Volet & Wearden, 2016; Droit-Volet et al., 2017; Martinelli & Droit-Volet, 2022), but few investigations have focused on the impact of alertness, time expectation, or attention to time on PoTJ in everyday settings. The relationships between these identified and potential factors and PoTJ are discussed next.

Previous investigations have shown that PoTJ is related to emotional valence (Droit-Volet & Wearden, 2016; Droit-Volet et al., 2017; Wittmann et al., 2015). Specifically, the level of positive emotion (e.g., happiness) is positively correlated with fast sense of passage of time, which means that time passes quickly when participants are experiencing positive emotions, while the level of negative emotion (e.g., sadness) is negatively correlated with PoTJ, meaning that time is judged to pass more slowly when participants' level of negative emotions is higher (Droit-Volet & Wearden, 2015, 2016). Meanwhile, these self-reported emotional states impact PoTJ without affecting individuals' duration perceptions (Droit-Volet et al., 2017).

Arousal, as another important dimension of emotion, has also been found to be correlated with PoTJ in daily life (Droit-Volet & Wearden, 2015, 2016; Droit-Volet et al.,

✉ Feng Du
duf@psych.ac.cn

✉ Meihong Zheng
zhengmh@mail.tsinghua.edu.cn

[1] Department of Psychology, Tsinghua University, Beijing 100084, China

[2] Key Laboratory of Behavioral Science, Institute of Psychology, Chinese Academy of Sciences, Beijing 100101, China

[3] Department of Computer Science and Technology, Tsinghua University, Beijing 100084, China

[4] Psychology Department, University of Chinese Academy of Sciences, Beijing 100049, China

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2017; Schelhorn et al., 2022; Tanaka & Yotsumoto, 2017). In a series of studies conducted by Droit-Volet and colleagues (Droit-Volet & Wearden, 2015; Droit-Volet et al., 2017, 2018), arousal was assessed using a seven-point scale ranging from "not at all" to "a lot", emphasizing the degree of excitement and general arousal. These studies suggest that higher arousal is associated with a faster PoTJ. However, some investigations indicate that arousal is negatively correlated with fast PoTJ. Schelhorn et al. (2022) measured individuals' emotional arousal levels by plotting orthogonal tables of arousal and valence, and found that higher arousal predicted slower PoTJ. Similarly, a study by Tanaka and Yotsumoto (2017) assessed arousal was related to an individual's level of wakefulness, as the asked question was "During the task, how aroused/awake were you?" and found that higher arousal predicted slower PoTJ. The above results suggest an unclear effect of arousal on PoTJ. It is noteworthy that participants in previous studies were given words such as excited, stimulated, and awake to aid their understanding of arousal. However, the understanding of arousal varies across researchers and participants. Arousal and alertness, in particular, have been confused in previous empirical studies. Therefore, the inconsistent results of previous studies on the effect of arousal on PoTJ may be due to different understandings among participants and different researchers. In the present study, we focused on emotional arousal, which refers to the intensity of emotions, and participants were questioned as "Please rate the average arousal/intensity of your emotions" with 9-point from almost none to extremely strong.

Alertness refers to a cognitive but not physiological or emotional state (Brown & Bowman, 2002; Posner, 2008), however, it has been confused with arousal in previous studies (Tanaka & Yotsumoto, 2017). High levels of alertness are associated with an attentive state; in contrast, high physiological or emotional arousal levels may or may not be associated with an attentive state (Brown & Bowman, 2002). Many previous experience sampling method (ESM) studies on PoTJ have focused on emotion and attention (Droit-Volet & Wearden, 2016; Droit-Volet et al., 2017, 2018; Larson & Eye, 2006), with few studies focusing on alertness. Alpha power is strongly negatively correlated with alertness (Cajochen et al., 1997; Klimesch et al., 1998), which has also been found to correlate with time perception (Glicksohn et al., 2009; Wacker, 1996): individuals tend to overestimate time when they have stronger alpha power (Mioni et al., 2020). Thus, alertness may correlate with duration perception, as they show similar neuro oscillation. Moreover, in the range of several minutes, when the passage of time was experienced as faster, the interval durations were judged to be shorter (Droit-Volet et al., 2017). These findings indicate that in the range of several minutes, low alertness may lead to time overestimation and thus a slower subjective passage of time. What is the situation for longer durations? The present study hypothesizes that alertness is positively correlated with PoTJ, i.e., the higher the alertness, the faster the PoTJ. In order not to confuse the meaning of arousal and alertness, the question used to measure alertness in the present study was "What was your level of alertness?" the level of alertness covered 9 scales ranging from extremely dozy to extremely alert.

In everyday life, one sometimes expects time to pass quickly or slowly, but things turn out to be the opposite of what is expected. Time expectation (expectation of time length) has been first verified to affect individuals' PoTJ in the laboratory (Tanaka & Yotsumoto, 2017). As in daily life, people always utilize the words "fast" or "slow" to describe their expectations of time. We, therefore, define an individual's expectation of the speed at which time passes as "time expectation" in this study. There are numerous instances of time expectation influencing PoTJ in everyday life. People often feel that time is passing slowly when they expect it to go faster, for example, when waiting for a traffic light to change from red to green, or sitting through a tedious lecture. Conversely, when one expects time to pass more slowly, such as when spending time with loved ones or attending a joyful party, one often feels that time passes quickly (Wearden et al., 2014). There is still a dearth of studies validating time expectations on PoTJ, but there is some side evidence of a negative correlation between the two. When individuals are presented with stimuli or states that they like, they tend to feel that time passes quickly (Conti, 2001; Gable & Poole, 2012; Gable et al., 2016, 2022). Conversely, time gets slowly (Gable et al., 2022; see a review). All these phenomena could be explained by time expectation, meaning that when individuals want time to pass quickly, time slows down instead. In summary, there is a need for more direct evidence of the impact of time expectations on PoTJ in daily life.

More attention to time may predict a slower perception of the passage of time. In the internal clock model (Gibbon, 1977; Gibbon et al., 1984; Lui et al., 2011), attention is a crucial factor, and some investigators have found that allocating attention to or away from time changes our experience of it (Conti, 2001; Larson & Eye, 2006). Allocating attention to time usually results in overestimation (usually interpreted as time passing slowly), whereas taking attention away from time usually results in underestimation (usually seen as time passing fast) (Gibbon, 1977; Gibbon et al., 1984; Lui et al., 2011). For instance, after finishing a meditation (during which individuals pay less attention to time or forget time), participants mostly reported that time passed quickly (Droit-Volet et al., 2019; Wearden, 2015). Previous ESM studies suggest that attention to the current activity is positively correlated with PoTJ (Conti, 2001; Droit-Volet & Wearden, 2016; Droit-Volet et al., 2017). Although it could be explained by the fact that time passes quickly when less attention is allocated to time, direct evidence is needed.

Furthermore, based on daily experiences, it appears that underlying mechanism behind the influence of time expectation on PoTJ may be attributed to the allocation of attention toward time (Conti, 2001). For example, when a person expects the end of a lecture or a red traffic light goes out, he or she may pay close attention to temporal information, such as checking his or her watch more frequently, resulting in the perception that time passes more slowly. Conversely, during enjoyable experiences such as spending time with loved ones or attending enjoyable parties, individuals may pay less attention to time, leading to the sensation that time passes more quickly. However, there are instances that contradict this notion, indicating that time expectation and attention allocation to time may not necessarily affect PoTJ in the same way. For instance, imagine a scenario where a person is taking an exam and has only one question left to complete as time is running out, one may anticipate time to slow down due to his/her expectation of finishing the exam, but upon frequently checking the time, he/she may actually feel time is passing faster. Therefore, it is essential to identify and examine the similarities and differences between these two factors' effects on PoTJ. Furthermore, given the scarcity of such studies in the literature, research is needed to differentiate the impacts of time expectation and attention allocation to time on PoTJ.

In terms of perception of the passage of time, two types of judgments are included, namely, "the passing judgment of looking back over the course of life" and "the passing judgment of the present" (Droit-Volet & Dambrun, 2019; Droit-Volet & Wearden, 2016; Wittmann et al., 2015). For the first type, participants in previous studies judged the passage of time on a long scale of several years, such as 1 or 10 years (Droit-Volet & Wearden, 2015; Wittmann et al., 2015). The second type of judgment concerns the experience of the passage of time in the present moment (Droit-Volet & Wearden, 2016). Few studies have focused on a fixed, suitable period of time, such as half an hour, and how the average state of this time affects PoTJ. An extremely long period (e.g., several years) is not suitable for examining the relationship between individuals' emotional states and PoTJ, because these states (e.g., alertness, emotional states) change dynamically during this period. A short duration (e.g., several milliseconds) may not be sufficient to generate PoTJ (Droit-Volet & Dambrun, 2019). A half hour and a day are familiar time scales for individuals, and they facilitate the reporting of emotional states and related mental processes, which are often used in ESM studies (Han et al., 2019).

Some studies have examined PoTJ using the ESM and diary methods, which makes it possible to assess PoTJ in everyday life (Droit-Volet & Wearden, 2016; Droit-Volet et al., 2017; Larson & Eye, 2006). In these studies, in addition to a series of background questions that may be correlated to PoTJ, participants also report the perceived rate of time passage for a week, a day, or the present moment (Droit-Volet & Wearden, 2015, 2016; Martinelli & Droit-Volet, 2022; Wittmann et al., 2015). In one of the studies, both ESM and diary methods were used to detect the individual's sense of passage of time at the moment eight times in the day, as well as, PoTJ of the day at the end of each day (Droit-Volet & Wearden, 2015), and indicate that average PoTJ in the day is positively correlated to the of day PoTJ. For convenience, we call that describing PoTJ for a short term within a day as in-the-day PoTJ, and that describing PoTJ for a whole day as of-the-day PoTJ. The present study uses half an hour to acquire ESM data, and 1 day to acquire diary data, respectively, to explore the relationships between emotional valence, emotional arousal, attention to time, alertness, time expectation, and PoTJ. Furthermore, the ESM and the diary method help to explore how in-the-day PoTJ and of-the-day PoTJ are influenced by different factors and how they are related.

Materials and methods

Participants

A total of 105 participants took part in this experiment (45 males, 60 females, $M_{age} = 22.15$, $SD_{age} = 2.62$). All participants had senior high school or higher education, and majority of them are current students (91.43%). This study was conducted in accordance with the Declaration of Helsinki. The protocol was approved by the local ethics committee of the Department of Psychology, Tsinghua University. All participants provided written informed consent. Given the specific nature of the methodology, participants were required to have a stable working environment and minimal business trips during the data collection period. Upon completion of this study, each participant was paid 40–70 RMB, depending on the effective response rate of the questionnaire.

Procedure

Before providing ESM and diary data, each participant installed the Psychorus application (HuiXin, China) on their cell phones to collect PoTJ data during the experiment (Han et al., 2019). The experiment lasted five days, and Psychorus automatically sent each participant five ESM questionnaires and one diary questionnaire each day. Participants were asked to fill out the questionnaire as soon as they received it, and all reported data were automatically uploaded to the server.

Participants received five cell phone notifications a day during the periods of 10:30–11:30 (T1), 13:30–14:30 (T2), 15:30–16:30 (T3), 18:30–19:30 (T4), and 21:30–22:30 (T5), to complete the questionnaire, reporting their PoTJ

and answering other relevant questions regarding the last 30 min. Each push notification remained in the cell phone's notification bar until the participant opened and completed the questionnaire. If a participant did not start filling out the questionnaire after receiving the notification, he/she would be reminded every 5 min for 1 h, after which the push notification would disappear, and the process would be terminated. Participants were notified to fill out the questionnaire at 23:00 every night during the survey period to evaluate their PoTJ and answer related questions regarding their perceptions of the whole day.

Participants were asked to assess the mean value of sense of passage of time, emotional valence, emotional arousal, alertness, attention to time, and time expectation in the last 30 min or the past day based on a nine-point scale. The PoTJ and its potential factors with the main content of measurement titles are shown in Table 1. For example, as for ESM, the question "In the last 30 min, how did you feel about the speed of time passing?" was used to assess PoTJ in the day, and participants were asked to rate this on a scale of 1–9 points (1: Extremely slow to 9: Extremely fast). For the daily questionnaire, the question changes to "Overall, how do you feel about the speed of time passing today?" As previous studies have shown that PoTJ is associated with some discrete emotions (Droit-Volet & Wearden, 2016; Droit-Volet et al., 2017; Wittmann et al., 2015), the present study also required individuals to report their main emotions during the above-mentioned period (see Appendix Fig. 1).

Statistical analysis

Data from participants with ESM or daily response rates below 40% were excluded. ESM data were obtained from 99 valid participants with 2067 valid data points, and the average response rate was 83.52%. Diary data were obtained from 90 valid participants with 407 valid data points, and the average response rate was 90.44%. The ESM and diary data were analyzed by R4.0.5 in the following manner.

(1) The relationships between PoTJ and potential factors were explored at a single measurement level by pooling participants' data and ignoring the nested structure (i.e., stacked data). The corrplot package in R was adopted to analyze the correlation between potential factors and PoTJ, as R package corrplot provides *r*-values, *p*-values, and confidence intervals (CI) to help users determine the statistical significance of the correlations (Wei et al., 2017).

(2) To account for the nested structure of the collected data, which includes multiple reports per participant, this study used a hierarchical linear model (HLM) with two levels of data: observed values (level 1) and data values for each participant (level 2). A baseline model without any predictors was first constructed to calculate the intraclass correlation coefficient (ICC) values, which were found to be 0.338 and 0.477 for ESM and diary data, respectively. Next, a model with gender as a level 2 predictor was tested, but gender was not found to have a statistically significant effect on PoTJ for either ESM or diary data. Therefore, gender was not included in the final model to maintain parsimony. The fixed coefficients in the final model were reported as standardized betas, similar to a previous ESM study (Stieger et al., 2022). Based on the correlation results, potential variables that were significantly associated with PoTJ were included as predictors of level 1, with

Table 1 PoTJ, Potential impact variables of PoTJ and its measurement

Questions	Responses	Measurement object
How did you feel about the speed of time passing?	1 Extremely slow 2 Very slow 3 Generally slow 4 Somewhat slow 5 Neither fast nor slow 6 Somewhat fast 7 Generally fast 8 Very fast 9 Extremely fast	Passage of time judgment
Did you expect this time to end as soon as possible?	1 Extremely didn't expect 2 Very didn't expect 3 Generally didn't expect 4 Somewhat didn't expect 5 Unclear 6 Somewhat expect 7 Generally expect 8 Very expect 9 Extremely expect	Time expectation
How have you been paying attention to time?	1 Extremely inattentive 2 Very inattentive 3 Generally inattentive 4 Somewhat inattentive 5 Unclear 6 Somewhat attentive 7 Generally attentive 8 Very attentive 9 Extremely attentive	Attention to time
What was your level of alertness?	1 Extremely dozy 2 Very dozy 3 Generally dozy 4 Somewhat dozy 5 Neither dozy nor alert 6 Somewhat alert 7 Generally alert 8 Very alert 9 Extremely alert	Alertness
Please rate the positivity or negativity of your average emotions	− 4 Extremely negative − 3 − 2 − 1 0 Neutral 1 2 3 4 Extremely positive	Emotional valence
Please rate the average arousal/intensity of your emotions	0 Almost none 1 2 3 4 Strong 5 6 7 8 Extremely strong	Emotional arousal

PoTJ serving as the dependent variable. The participant's data were clustered to build the HLM, and the lme4 packages in R were used for these computations (Bates et al., 2009). The final potential model is displayed below:

level 1 (within individual):

$$PoTJ_{ij} = \beta_{0i} + \beta_{1i}AT_{ij} + \beta_{2i}AL_{ij} + \beta_{3i}TE_{ij} + \beta_{4i}VA_{ij} + \beta_{5i}AR_{ij} + \varepsilon_{ij}$$

level 2 (between individual):

$$\beta_{0i} = \gamma_{00} + \mu_{0i}$$

Level 2:

$$\beta_{1i} = \gamma_{10}; \beta_{2i} = \gamma_{20}; \beta_{3i} = \gamma_{30}; \beta_{4i} = \gamma_{40}; \beta_{5i} = \gamma_{50}.$$

Note: $PoTJ_{ij}$ refers to the sense of the passage of time of participants i at the j-th sampling, which was predicted by potential factors, namely AT (attention to time), AL (alertness), TE (time expectation), VA (emotional valence), and AR (emotional arousal).

(C) To examine the relationship between the ESM and the diary data, we conducted a correlation analysis between the mean, maximum, and minimum values of PoTJ obtained from ESM as well as the PoTJ at five time points and the diary data.

Results

ESM data results

Correlation results for ESM data

Alertness, emotional valence, and emotional arousal were significantly positively correlated with PoTJ ($r = 0.226$, 95% CI [0.185 0.266], $r = 0.250$, 95% CI [0.209 0.290], $r = 0.233$, 95% CI [0.192 0.274], $ps < 0.001$), while time expectation was significantly negatively correlated with PoTJ ($r = -0.219$, 95% CI [− 0.260 − 0.178], $p < 0.001$). In contrast, attention to time was significantly but weakly correlated with PoTJ ($r = -0.060$, 95% CI [− 0.102 − 0.016], $p = 0.007$). Descriptive statistics and correlational analyses of the ESM variables are presented in Table 2 (for more information of descriptive statistics, see Appendix Fig. 2).

HLM results for ESM data

Based on the results of the correlation analysis, an HLM was developed with alertness, time expectation, emotional valence, and emotional arousal as independent variables and PoTJ as a dependent variable. Related descriptive of results, such as β, *se*, and *t* of each variable are shown in Table 3.

Table 2 Descriptive statistics and correlations for study variables in ESM data

Variable	*n*	Mean	*SD*	1	2	3	4	5	6
PoTJ	2067	5.95	1.74	–					
Alertness	2067	6.06	1.98	0.226***	–				
Attention to time	2067	4.51	2.09	− 0.060**	0.153***	–			
Time expectation	2067	4.45	2.02	− 0.219***	0.056*	0.337***	–		
Emotional valence	2067	5.72	1.54	0.250***	0.328***	0.051*	− 0.048*	–	
Emotional arousal	2067	3.90	1.96	0.233***	0.281***	0.244***	0.094***	0.274***	–

***$p < 0.001$

**$p < 0.01$

*$p < 0.05$

Table 3 Results of the HLM for PoTJ in ESM data

Effect	Fixed					Random	
	Coeff	β	*B*	SE	*t*	Coeff	SD
Intercept ($N = 99$)	γ_{00}		5.356	0.201	26.63***	μ_{0i}	0.867
Within-person ($N = 2067$)							
Alertness	γ_{10}	0.105	0.092	0.018	5.16***		
Time expectation	γ_{30}	− 0.267	− 0.229	0.017	− 13.55***		
Emotional valence	γ_{40}	0.115	0.129	0.023	5.60***		
Emotional arousal	γ_{50}	0.094	0.083	0.021	4.01***		

Conditional $R^2 = 0.412$, marginal $R^2 = 0.120$, AIC = 7290.460, BIC = 7329.897

***$p < 0.001$

Among the variables, alertness, time expectation, emotional valence, and emotional arousal were able to significantly predict individuals' PoTJ ($ps < 0.001$).

Diary data results

Correlation results for diary data

Alertness, emotional valence, and emotional arousal were significantly positively correlated to PoTJ ($r = 0.195$, 95% CI [0.100 0.287], $r = 0.123$, 95% CI [0.026 0.217], $r = 0.259$, 95% CI [0.166.348], $ps < 0.05$), while time expectation was significantly negatively correlated to PoTJ ($r = -0.138$, 95% CI [− 0.232 − 0.042], $p < 0.01$). Attention to time was not significantly correlated with PoTJ ($r = 0.073$, 95% CI [− 0.024 0.169], $p = 0.140$). Descriptive statistics and correlational analyses of the diary variables are presented in Table 4.

HLM results for diary data

Based on the results of the correlation analysis, an HLM was developed with alertness, time expectation, emotional valence, and emotional arousal as independent variables and PoTJ as a dependent variable. β, *se*, and *t* of each variable are shown in Table 5. Among the variables examined, both time expectation and emotional arousal emerged as significant predictors of individuals' PoTJ ($ps < 0.01$), whereas alertness and emotional valence did not exhibit significant predictive power for individuals' PoTJ ($ps > 0.05$).

The relationship between ESM and diary data of PoTJ

Due to the different missing data among different time points, the sample sizes for pairwise correlation analyses varied. To present the relevant correlation data between ESM and Diary, only correlations for relevant time points are presented in the table. The results showed a significant positive correlation between of-the-day PoTJ and in-the-day PoTJ, including the maximum, minimum, and mean in-the-day PoTJ, as well as that obtained at each time point (refer to Table 6). The correlations between of-the-day PoTJ and mean and T5 of in-the-day PoTJ were particularly strong ($rs > 0.5$), indicating that the PoTJ of the whole day was more influenced by the daily average and latest in-the-day PoTJ.

Table 4 Descriptive statistics and correlations for study variables in diary data

Variable	*n*	Mean	SD	1	2	3	4	5	6
PoTJ	407	5.95	1.74	–					
Alertness	407	6.07	1.65	0.195***	–				
Attention to time	407	5.33	1.71	0.073	0.122*	–			
Time expectation	407	4.35	2.07	− 0.138**	0.011	0.148**	–		
Emotional valence	407	5.72	1.58	0.123*	0.373***	0.067	0.060	–	
Emotional arousal	407	4.59	1.74	0.259***	0.420***	0.313***	0.173***	0.281***	–

***$p < 0.001$

**$p < 0.01$

*$p < 0.05$

Table 5 Results of the HLM for PoTJ in diary data

Effect	Fixed					Random	
	Coeff	β	*B*	SE	*t*	Coeff	SD
Intercept ($N = 90$)	γ_{00}		5.382	0.409	13.17***	μ_{0i}	0.970
Within-person ($N = 407$)							
Alertness	γ_{10}	0.060	0.056	0.047	1.19		
Time expectation	γ_{30}	− 0.162	− 0.121	0.036	− 3.39***		
Emotional valence	γ_{40}	0.054	0.052	0.047	1.11		
Emotional arousal	γ_{50}	0.171	0.152	0.049	3.11**		

Conditional $R^2 = 0.484$, marginal $R^2 = 0.069$, AIC = 1397.484, BIC = 1425.546

***$p < 0.001$

**$p < 0.01$

Table 6 The correlation results among PoTJ of ESM and diary

Variables	ESM		Diary		*df*	*r*	CI
	M	SD	M	SD			
Max	7.13	1.27	6.19	1.54	401	0.496***	[0.409, 0.584]
Min	4.64	1.70	6.19	1.54	401	0.447***	[0.348, 0.542]
Mean	5.99	1.23	6.19	1.54	401	0.616***	[0.525, 0.694]
T1	5.75	1.71	6.14	1.56	357	0.430***	[0.320, 0.529]
T2	5.90	1.72	6.15	1.55	337	0.414***	[0.306, 0.519]
T3	5.84	1.82	6.16	1.52	339	0.434***	[0.309, 0.539]
T4	6.17	1.59	6.18	1.57	339	0.383***	[0.271, 0.497]
T5	6.23	1.70	6.17	1.52	375	0.504***	[0.395, 0.591]

***$p < 0.001$

Discussion

To better understand individuals' experience of the passage of time in everyday life, the present study adopted the ESM and diary method to investigate whether PoTJ is related to alertness, attention to time, and time expectation and whether the relationship between PoTJ and these factors, as well as emotional valence and emotional arousal, are stable across different periods of time. Alertness was found to be positively correlated with PoTJ, while time expectation was negatively correlated with PoTJ. The study also verified that emotional valence and emotional arousal were positively correlated with PoTJ for fixed periods in daily life. Furthermore, alertness, time expectation, emotional valence, and emotional arousal could predict individuals' awareness of the passage of time in the past half hour. In contrast, time expectation and emotional arousal were able to predict individuals' PoTJ for the past day. These results suggest that along with emotional valence and emotional arousal, alertness, and time expectation are essential factors influencing PoTJ. Besides, the finding that PoTJ was influenced by different factors for different lengths of time reminds us to understand PoTJ from a dynamic perspective. Furthermore, the PoTJ of the whole day correlates with averaged PoTJ of five half hours, and the latest in-the-day PoTJ implies that overall perception of time passage is influenced by both cumulative and recent time-related experience.

The relationship between alertness, time expectation, and PoTJ

To the best of our knowledge, the present study is the first ESM study to directly reveal the effects of alertness and time expectation on PoTJ. The results show that alertness and time expectation were correlated to PoTJ, and both were able to predict individuals' PoTJ for a short period of time (i.e., half an hour), while time expectation could predict PoTJ over a longer period of time (i.e., a day) in daily life. The potential mechanisms are discussed below.

The present study verified the hypothesis and found that individuals felt that time passed more quickly when they were alert and more slowly when they were dozy. Similar to the findings of previous research, the dozier an individual was, the more time overestimation occurred (always interpreted as time passing more slowly) (Kuriyama et al., 2005). Previous studies indicate that when individuals show strong alpha power, they engage in time overestimation (Mioni et al., 2020) and have a low level of alertness (Cajochen et al., 1997; Klimesch et al., 1998). Moreover, for a period of several minutes, time overestimation is correlated with the slow passage of time (Droit-Volet et al., 2017). Therefore, the significant correlation between alertness and PoTJ may be due to the fact that higher alertness induces a shorter subjective duration, leading to a faster PoTJ when subsequently compared with objective duration (Craik & Sarbln, 1963). It should be noted that although a significant correlation between alertness and PoTJ was found based on diary data, alertness did not predict PoTJ of the day. This may be because the level of alertness varies dynamically throughout the day, so it is less predictive of PoTJ over a more extended period. However, alertness inevitably affects PoTJ in the day. Also, the significant but weak correlation between alertness and arousal indicates that they are not equivalent.

Regarding time expectation, the present study verified a significant negative correlation between time expectation and PoTJ. Similar to the findings of previous research, it was found that when individuals wanted time to pass more slowly, they felt that time passed more quickly, whereas when individuals wanted time to pass quickly, this produced a slower passage of time (Gable & Poole, 2012; Gable et al., 2016, 2022). Why do we feel that time moves more quickly when we expect it to be slow? The possible mechanism behind this is that PoTJ stems from the difference between distorted subjective duration and objective duration (over the past 30 min or the past day, in this study) (Craik & Sarbln, 1963). Previous investigations have found that time expectation may distort individuals' duration perception. Individuals overestimate time when they want it to speed

up, such as when they are presented with images they do not like, are required to say words they do not want to say or are required to hide something (Jia et al., 2021; Matsuda et al., 2020; Moskowitz et al., 2017). In contrast, individuals underestimate time when they want it to stand still, for instance, when presented with their preferred stimuli (Conti, 2001; Danckert & Allman, 2005; Gable & Poole, 2012). Due to the nature of this research paradigm, participants were able to naturally compare fixed objective duration with its corresponding subjective duration when judging the rate of time passage, thus producing different levels of time passage. Furthermore, both ESM and diary data validated the negative correlation between time expectation and PoTJ, suggesting that the effect of time-related expectations on PoTJ may be stable across different periods. Additionally, the different effect between time expectation and attention to time on PoTJ indicates that they are not equivalent.

The relationship between attention to time and PoTJ

In contrast to previous studies, we did not find a relationship between attention to time and PoTJ. Previous ESM studies indicate that when individuals allocate more attention to current activities, which could also be described as allocating less attention to temporal information, time passes quickly (Droit-Volet & Wearden, 2015, 2016). In fact, even with the same experimental design, a study from the same lab found no significant correlation between attention to current activities and PoTJ (Droit-Volet et al., 2017). This implies that the impact of attention to time on PoTJ may be unstable, and more research is needed to examine the relationship between them. Moreover, past studies have utilized questions such as, "At this moment, what is your impression of the speed of passage of time? (1 to 7, from 'very slow' to 'very fast')", "Is this activity (a) difficult or (b) does it capture your attention? (1 to 7, from 'not at all' to 'a lot')", to investigate individuals' PoTJ and attention allocation. Instead, we looked at how much an individual paid attention to time in the past 30 min (or the past day) and how quickly the past 30 min (or the past day; see Table 1) had gone by. Different measurement methods and durations may lead to this inconsistent finding. Clearly, the effect of an individual's level of attention to time on PoTJ requires further study.

The relationships between PoTJ from ESM and diary data

We observed strong correlations between of-the-day PoTJ and both the averaged in-the-day PoTJ and the latest PoTJ. This finding suggests that the overall perception of time passage is influenced by cumulative and recent time-related experience, implying that the sense of passage of time over a longer period of time may be more dependent on memory and analytical judgment. Interestingly, we found that extremely fast and slow in-the-day PoTJ still significantly correlated with of-the-day PoTJ, but the correlation was weaker than that with the latest and the averaged in-the-day PoTJ. Some reasons may account for these results, for instance, it is possible that the maximal and minimal in-the-day PoTJ cancel out each other in generating of-the-day PoTJ, so that the extremum of in-the-day PoTJ leads to a smaller correlation coefficient. Researchers should examine the sources of PoTJ for different periods of time and distinguish whether PoTJ comes from current sensations or from analytical judgments. A dynamic approach should be used to investigate how the current sensation of time passing is influenced by previous experiences to help unravel the mechanisms underlying PoTJ.

Limitations and recommendations for future study

The present study identified some factors affecting PoTJ in daily life, but it has some limitations. First, all these data were based on individuals' subjective reports of the past half hour or the past day and, therefore, lacked a diversity of time scales and objective data. Furthermore, because the participants were already aware of the time scale, the present study did not measure subjective duration. Future investigations are necessary to validate our results and explore the mechanisms of PoTJ. For example, further exploration of the association between alertness and PoTJ at different durations to increase the variety of durations, and simultaneously measure psychophysiological indicators of individuals, are needed to obtain objective data. Future studies should also include subjective duration measurements to assess the relationship between subjective duration and the sense of time passing in daily life to gain more insight into the mechanisms of the sense of time passing. More research is needed to determine what causes differences in the factors that affect PoTJ at different duration ranges.

Conclusion

The present study identified and replicated some factors that influence the sense of time passing in daily life, specifically, alertness, emotional valence, and emotional arousal were positively correlated with PoTJ, while time expectation was negatively correlated with PoTJ. All above factors predicted PoTJ over a relatively short period of time, but only emotional arousal and time expectation significantly predicted PoTJ over a longer period of time, i.e., a whole day. Furthermore, the PoTJ of the whole day strongly correlates with the latest and averaged in-the-day PoTJ, which means there are some close connections between of-the-day PoTJ and in-the-day PoTJ. Seeking what factors leading to this interesting

phenomenon may help to clarify the underlying mechanisms of sense of time passage.

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Data availability The data generated during and/or analyzed during the current study are available in the OSF repository, [https://osf.io/y58fa/].

Declarations

Conflict of interest The author(s) declared that there were no conflicts of interest with respect to the authorship or publication of this article.

Ethical approval Approval was obtained from the Ethics Committee of the Department of Psychology, Tsinghua University. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

Informed consent Informed consent was obtained from all individual participants included in the study, who all signed informed consent regarding the publication of their data.

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