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Running head; What factors underlie our experience of the passage of time?

What factors underlie our experience of the passage of time? Theoretical consequences

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Abstract

The aim of this study was to examine the factors that explain variations in the conscious experience of time. The level of difficulty of the task, emotional valence and duration of stimuli were tested in three different experiments with two ranges of durations, one of seconds and the other one of minutes. The results showed that the passage of time was judged faster with durations in the seconds than in the minutes range. However, for all duration values, each change in the features of the task produced changes in the judgment of the passage of time. The subjective feeling of an acceleration of the passage of time therefore increased linearly with the increase in the level of difficulty of the task and with the positive valence of the emotional stimuli. It also varied linearly with the length of real time, increasing in the same proportion as the decrease in stimulus duration, regardless of the associated range (seconds or minutes). Our theory is that the judgment of the passage of time might be a generic way of describing the most salient internal or external contextual changes experienced.

Keywords: Time; Experience of time; Consciousness

Judging the different aspects of time is part of our daily activities. Every day, we estimate the duration of events or that of the interval between two events. Every day, we notice that time passes faster or slower than it really does. For decades, researchers have used an experimental approach to examine human abilities to judge durations and the factors explaining their variations. However, the judgment of the passage of time (PoT) has not been subject to the same experimental analysis involving supposedly more objective tests (Larson 2004; Wearden 2015; Droit-Volet 2018). The aim of this exploratory study was to fill this gap in the literature by experimentally examining the factors behind variations in our awareness of changes in the speed of the passage of time.

Nonetheless, in recent years, the PoT judgment has been examined in more details in correlation studies using the Experience Sampling Method (ESM), which makes it possible to evaluate PoT judgments in daily life (Larson and von Eye 2006; Droit-Volet and Wearden 2015). With this method, participants are informed that they will have to judge the speed of the passage of time at different times of the day, for several days of the week. They receive phone calls during which they have to rate the speed of the passage of time using a Likert scale going from “very slow” to “very fast”. They also have to answer a series of questions designed to assess the context in which the temporal judgment is made. Droit-Volet and Wearden (2015) asked participants questions about the valence of their emotion at the time of the temporal judgment as well as about the difficulty of the activity they had just been performing and its level of attentional demand. Larson and van Eye (2006) asked about “emotional engagement” (“how emotionally involved were you in the activity”) and “intellectual engagement” (“how intellectually involved or 'into' the activity were you?”) (p. 124). The statistical analyses performed in these ESM studies have shown that the activity undertaken and the emotion felt are significant predictors of the judgment of the passage of time. Indeed, the participants experienced an acceleration of the passage of time when the activity performed was judged difficult and attentionally demanding or required more “intellectual engagement”. They also reported that time passed more quickly when they felt happier, and that it slowed down when they felt sadder. These results have been replicated in subsequent ESM studies demonstrating that emotions and task difficulty are two major predictors of PoT judgment in daily life (Droit-Volet and Wearden 2016; Droit-Volet, et al. 2017; Droit-Volet 2019a).

To account for fluctuations in the awareness of the passage of time with activity and emotion, Droit-Volet juxtaposed the PoT judgment based on “Self-duration” with that based on “World-duration” (e.g., Droit-Volet 2018; Droit-Volet & Dambrun 2019). The first corresponds to judgments of the passage of time resulting from intra-individual analyses of a temporal extension or contraction of the minimal self. The minimal self is the consciousness of oneself as an immediate subject of experience (Gallagher 2000, 2013). In other words, the passage of time is judged to accelerate or decelerate relative to participants’ awareness of changes in their different states, including the prevailing emotional feelings. The second is the representation of external time, as indicated by our watches, that flows at a constant rate in a uniform and universal way. World-duration is therefore used as a reference allowing individuals to state that time passes faster or slower than it really does. In sum, according to this theoretical approach, the awareness of the passage of time would be based on the introspective analysis of the self in its context and not the processing of event-durations.

This assumption is supported by the results of ESM studies which have found that the PoT judgment in everyday life was related to the non-temporal context of judgment (activity, emotion) and not to temporal information (Droit-Volet and Wearden 2016; Droit-Volet et al. 2017). Indeed, these studies showed no relationship between the feeling about the speed of the passage of time at a given time and the values of estimated

durations (< 60 s); An overestimation of short durations did not translate into the feeling that time is passing faster. The ESM studies nevertheless found that the PoT judgment was significantly correlated with the judgment of long durations of several minutes. The mechanisms underlying estimates of short and long durations are likely to differ. The processing of short durations involves an internal clock-like system, as has been well established in the literature (e.g., Gibbon et al. 1984, for a review Merchant et al. 2013). In contrast, the processing of long durations of several minutes would involve memory reconstruction processes that make use of non-temporal information stored in memory during the interval to be processed (Droit-Volet et al. 2018). Similar results on the dependence of time estimates on non-temporal information have been found in studies on retrospective timing in which participants do not know in advance that they will have to judge time events and the internal clock is not activated (Block 1992; Block et al. 2018). Therefore, Droit-Volet et al. (2017) concluded that the PoT judgment, even in a prospective timing condition, would be based on memory mechanisms like in the retrospective time judgment.

The hypothesis that there is no relationship between PoT judgment and duration processing is deduced from ESM findings on the lack of correlation between the PoT judgment and the judgment of short durations (< 60). However, although interesting, the ESM studies pose various methodological problems. First, the interval duration considered by participants in their PoT judgments was not controlled, even if we may suppose that in their everyday lives, they considered the duration of their current activity, i.e. a period of several minutes. Second, the results of these ESM studies are based on correlation analyses, and not the causal link between the non-temporal factors and the PoT judgment. There are very few studies that have experimentally investigated PoT judgments in the laboratory (Sucala et al. 2011; Wearden et al. 2014). As in the ESM studies, they showed that the task was perceived as passing faster when it was difficult than when it was easy. However, these studies have only examined one factor (task difficulty) and not other factors on which PoT judgments could also depend, such as emotion. In addition, and more critically, they have only examined one duration, namely of several minutes. The participants had to judge the passage of time for a single interval of 4 minutes in Sucala et al.'s study (2011), and of 3 minutes in Wearden et al.'s study (2014). None of these studies tested different durations in different time ranges from a few seconds to several minutes, as would be necessary in order to examine the real influence of durations on PoT judgments.

There still has not enough laboratory-based research into PoT judgments. The aim of the present study was thus to begin to investigate the effect on the PoT judgment of different types of non-temporal factors, i.e. task difficulty (Experiment 1) and the emotional valence of the stimuli (Experiment 2), with the duration maintained constant, for durations in the range of seconds and minutes. Another aim was to examine the effect on the PoT judgment of varying temporal information (Experiment 3) when the non-temporal information was controlled for. Our hypothesis was that the PoT judgment would vary with the changes in the non-temporal factors, whatever they were (task difficulty or emotion) for the interval durations in the minutes range, and those in the seconds range. However, in a prospective PoT judgment paradigm, i.e. when participants know that they have to judge the passage of time, we can assume that stimulus durations have a greater influence on the PoT judgment in the seconds than the minutes range because the former involves the mobilization of an internal clock system as explained above.

1. Experiment 1 – Task Difficulty

2.1 Method

2.1.2 Participants

The final sample was composed of 83 participants (72 women and 11 men), all of them students at University Clermont Auvergne (mean age = 19.10, $SD = 1.49$), who received a course credit for their participation. All individual participants signed an informed consent form describing the procedure used, that was in accordance with the 1964 Helsinki declaration and approved by the Research Ethics Committee of the University Clermont-Auvergne (IRB00011540-2019-33) following the French Ethical law.

2.1.2 Material

The experiment was presented on a 17-inch PC screen with a 1920x1080-pixel resolution, and a 60 Hz refresh rate. Obviously, no temporal information (clock, watch, etc.) was available. Data collection and stimuli presentation were handled with E-prime software v 2.0 (*Psychology Software Tools, Pittsburgh, PA, USA*). The participants sat in front of the screen (50-cm distance) and responded using the computer keyboard. For the non-temporal task, we used sequences of digits displayed (black on a white background) in “Courier New”, font size 18, in the center of the screen. Based on a pilot study involving five participants, the non-temporal task was subdivided into 3 levels of difficulty. The difficulty level was defined in terms of the number and order of the digits to be reproduced. The digit sequences contained different numbers presented in random order. For the first level of difficulty of the non-temporal task, named “Easy”, a sequence consisted of two digits (e.g., 85), and the participants had to type the digits on the normal computer keyboard in the same order in which they had appeared. For the second level, “Medium”, a sequence consisted of six digits (e.g., 716483) and the participants again had to reproduce it in the correct order. For the “Difficult” level, six digits were also presented per sequence (e.g., 284106), but the participants had to reproduce it in the reverse order (601482). As explained in the procedure, the number of digit sequences per trial obviously depended on the trial duration.

2.1.3. Procedure

All the participants performed 18 trials, i.e. 6 trials for each of the 3 difficulty levels of the non-temporal task (easy, medium, and difficult). Each trial therefore consisted of a series of 2- or 6-digit sequences to be reproduced either in the forward order or in the backward order. The trials were presented randomly. For each digit sequence, the participants were presented with a fixation mark (+) displayed for 500 ms in the center of the screen. The digit sequence then appeared for up to 1000 ms followed by a 500-ms blank screen. A text box was then presented for 5000 ms with the response instruction and the participant reproduced the digit sequence as quickly as possible. The inter-sequence interval varied according to the trial duration.

The participants were randomly assigned to one of two duration groups, one with trial durations in the range of seconds ($N = 42$) and the other with trial durations in that of minutes ($N = 41$). In the seconds group, the trials varied between 30 s, 33 s and 36 s, and in the minutes group between 90, 99 and 108 s. Consequently, the number of digit sequences to be reproduced per trial varied as a function of the trial duration. To avoid the methodological bias linked to the number of sequences, we maintained the same number of sequences for the different trial durations by varying the length of the inter-sequence intervals. In the seconds group, all trials contained 4 digit sequences with an inter-sequence interval varying between 400 and 650 ms for 30 s, 1000 and 3000 ms for 33 s, and 1000 and 3000 ms for 36 s. In the minutes group, the trials were composed of 12 digit sequences with inter-sequence intervals between 375 and 625 ms for 90 s, 1000 and 1450 ms for 99 s, and 1200 and 2750 ms for 108 s. The 6 trials for each task-difficulty level therefore consisted of two trials for each of the 3

trial durations. However, the trial durations were similar across the different levels of difficulty of the non-temporal task.

After each trial, the participants gave their judgment of the passage of time. The question “How did time pass for you during the activity compared to the time of a clock?” appeared with a 7-point Likert-type scale going from (1) “very slowly” to (7) “very fast”, and the participants responded on the computer keyboard. Before the testing trials, the participants were given 2 demonstration trials.

2.2 Results & Discussion

Non-temporal performance

For each participant, we calculated the number of correctly reproduced digit sequences as a proportion of the total number of sequences presented in each difficulty condition of the non-temporal task. An ANOVA was carried out on the non-temporal performance with the level of task difficulty (easy, medium, difficult) as within-subjects factor and the duration group (seconds, minutes) as between-subjects factor. The ANOVA showed a significant main effect of task difficulty, $F(1.88, 151.93) = 888.12, p < .0001, \eta_p^2 = .92$ (Fig. 1). The non-temporal performance therefore decreased with the level of task difficulty, as indicated by the linear effect of task difficulty ($M_{\text{easy}} = .96, SE_{\text{easy}} = .004, M_{\text{medium}} = .57, SE_{\text{medium}} = .02, M_{\text{difficult}} = .18, SE_{\text{difficult}} = .017, F(1, 81) = 2067.01, p < .0001, \eta_p^2 = .96$). The main effect of duration also reached significance $F(1, 81) = 9.22, p = .003, \eta_p^2 = .10$, as did the duration x task difficulty interaction, $F(1.88, 151.93) = 3.20, p = .045, \eta_p^2 = .038$, although the effect size was low. This indicates that the proportion of correct responses tended to be higher in the minutes range ($M_{\text{long}} = .60, SE_{\text{long}} = .017$) than in the seconds range ($M_{\text{short}} = .533, SE_{\text{short}} = .017$), especially for the highest task-difficulty level.

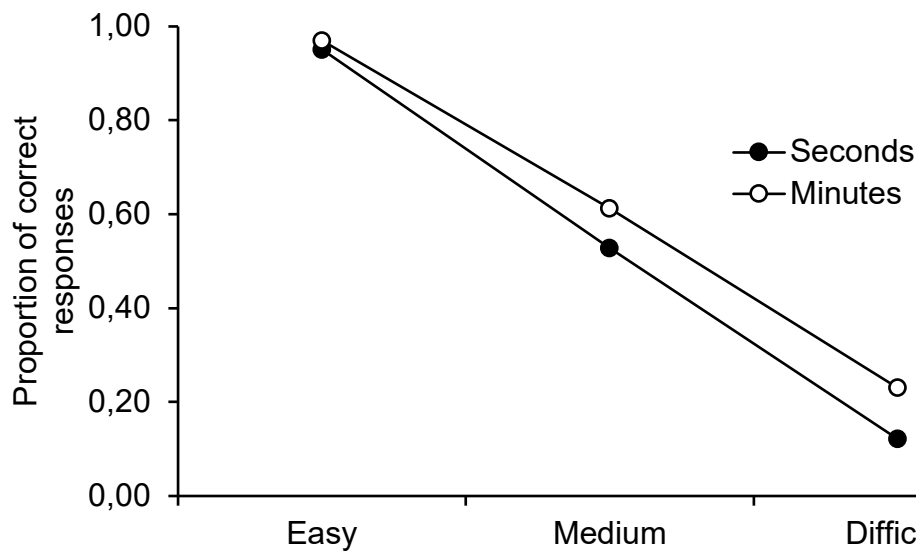


Fig. 1. Proportion of correct responses for the non-temporal task plotted against the task-difficulty level for the durations in the seconds and the minutes ranges.

Passage of time judgment

Fig. 2 shows the mean PoT judgments plotted against the three task-difficulty levels for the seconds and the minutes groups. An ANOVA was performed on the PoT judgment with the two factors described above (task

difficulty, duration group). This ANOVA revealed a significant main effect of task difficulty, $F(1.50, 121.82) = 347.62$, $p < .0001$, $\eta_p^2 = .81$, with no interaction involving this factor ($F > 1$). There was only an additional main duration effect, $F(1, 81) = 15.13$, $p < .0001$, $\eta_p^2 = .16$, indicating that the passage of time was judged as slower for the durations in the minutes range ($M = 4.41$, $SE = .103$) than those in the seconds range ($M = 4.97$, $SE = .102$). Therefore, the statistical analysis demonstrated that the PoT judgment varied directly with the difficulty of the task as indicated by the linear effect of task difficulty, $F(1, 81) = 419.63$, $p < .0001$, $\eta_p^2 = .84$. Time was thus judged as passing slower for the easy task ($M = 2.92$, $SE = .115$) than for the medium ($M = 5.26$, $SE = .09$) or the difficult task ($M = 5.89$, $SE = .093$), and for the medium than for the difficult task (all Bonferroni tests, $p < .0001$).

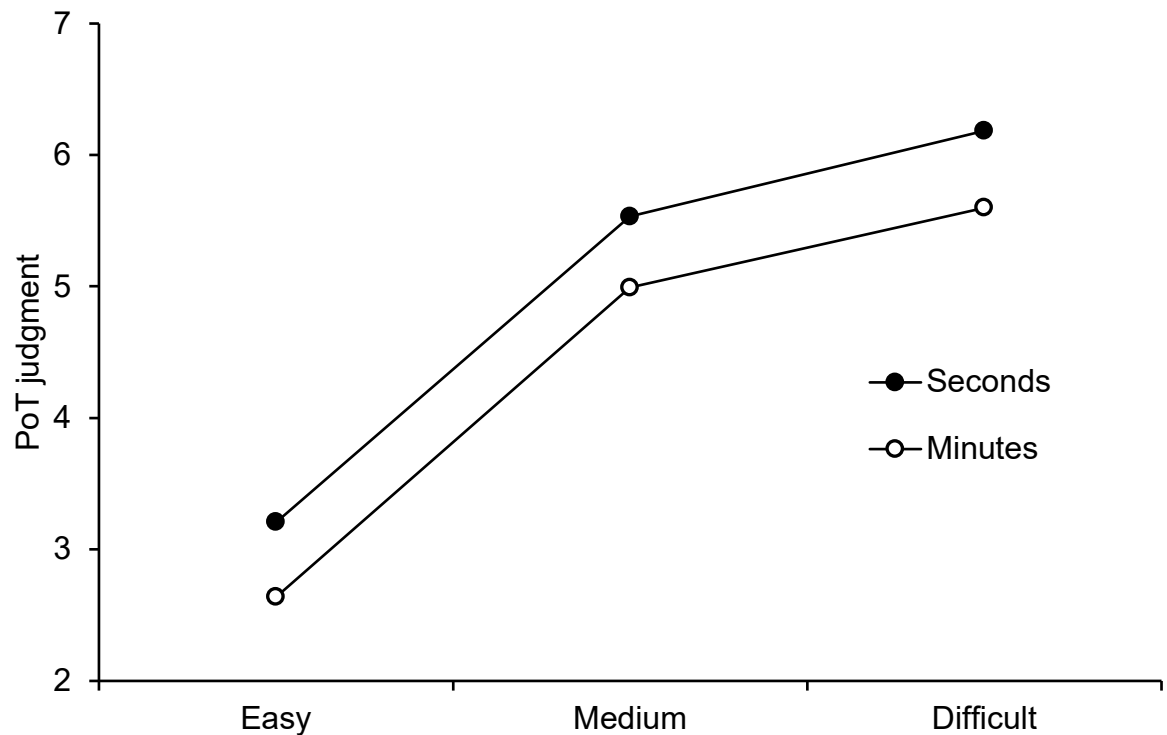


Fig. 2. Mean passage of time judgments plotted against task-difficulty level for the durations in the seconds and the minutes ranges.

2. Experiment 2 – Emotions

3.1 Method

3.1.1 Participants

The sample was composed of 83 new students (80 women and 3 men; mean age = 19.07, $SD = 0.99$) who participated in this study conducted in accordance with the 1964 Helsinki declaration in exchange for a course credit. They signed an informed consent form with the procedure approved by the Research Ethics Committee of the University Clermont Auvergne (IRB00011540-2019-33).

3.1.2 Material

The material used was the same as that used in Experiment 1, except for the emotional stimuli. The emotional stimuli used consisted of videos from 3 emotional categories with a different emotional valence: negative, neutral and positive. Videos were used instead of static images in order to maintain the emotion induced in the case of long durations of several minutes (Droit-Volet et al. 2019b). The videos were composed of pictures of a given emotional valence extracted from the International Affective Picture System (IAPS; Lang, Bradley and Cuthbert 2005). All the pictures were thus assessed as positive on a 9-point emotional valence scale (from 7.01 to 8.28) for the positive videos, or as neutral (from 4.03 to 4.99) and negative (from 2.06 to 3.16) for the neutral and the negative videos, respectively. The positive pictures showed people enjoying themselves, baby animals and facial expressions of joy. The neutral valence pictures represented inanimate objects and neutral facial expressions, and the negative pictures presented landfill sites, war images and people with sad expressions and/or crying. The negative pictures were thus associated with the emotion of sadness. To create smooth animated transitions between the images presented in the videos, we used the software OpenShot Video Editor (*OpenShot Studios, Rockwall, TX, USA*). The number of images used was similar for the different emotional videos, varying between 12, 14 or 16 images for the durations in seconds and 36, 42 and 48 images for those in minutes. The presentation duration of the images as well as the duration of the animated transition between the images varied between the videos. For each duration range (seconds, minutes), we created 27 videos (54 in total): 9 videos for each of the 3 emotional valences (negative, neutral and positive valence), i.e. 3 for each of the 3 durations (30, 33, 36 seconds or 90, 99, 108 seconds).

3.1.3 Procedure

The participants were randomly assigned to the seconds ($N = 41$) or the minutes group ($N = 42$). The presentation duration of the emotional stimuli varied between 30, 33 and 36 seconds in the seconds group, and 90, 99 and 108 seconds in the minutes group. In each group, the participants were presented with 18 trials, with 6 trials for each of the 3 emotional stimuli (negative, neutral, positive), i.e. 3 trials per tested duration. The trial order was random. The emotional stimuli were also randomly chosen for each trial among the videos in such a way that the number of images and their presentation duration varied from one trial to another but were similar across the emotional conditions. On each trial, the participants pressed the space bar to watch the emotional stimuli when ready. Then, as in Experiment 1, they gave their judgment on the passage of time on a 7-point scale going from (1) “very slowly” to (7) “very fast”.

3.2 Results & Discussion

We performed an ANOVA on the PoT judgment with the emotion as within-subjects factor and the duration group as between-subjects factor. The analysis showed a significant main effect of the emotion on the PoT judgment, $F(1.67, 134.99) = 8.17, p = .001, \eta_p^2 = .092$. As in Experiment 1, there was also a main effect of the duration group, $F(1, 81) = 10.74, p = .002, \eta_p^2 = .117$, indicating that time was judged to pass slower in the range of minutes ($M = 3.74, SE = .107$) than in that of seconds ($M = 4.24, SE = .108$). The emotion x duration interaction also reached significance, $F(2, 134.99) = 6.28, p = .002, \eta_p^2 = .07$.

Parsing the emotion x duration interaction indicated that the effect of the emotion was significant in all the duration groups, and was so for both the seconds and the minutes ranges ($F(1.773, 70.92) = 7.45, p = .001, \eta_p^2 = .16; F(1.446, 59.27) = 7.04, p = .002, \eta_p^2 = .15$, respectively). However, there was no difference in the PoT judgment for the neutral stimuli between the two duration ranges ($M_{\text{seconds}} = 4.057, SE_{\text{seconds}} = 0.144; M_{\text{minutes}} = 3.992, SE_{\text{minutes}} = 0.142, F > 1$), while the PoT was judged slower in the minutes range than in the seconds range

for both the negative emotional stimuli ($M_{\min.} = 3.425$, $SE = 0.146$; $M_{\sec.} = 4.093$, $SE = 0.148$; $F(1, 81) = 10.38$, $p = .002$, $\eta_p^2 = .114$), and the positive emotional stimuli ($M_{\min.} = 3.806$, $SE = 0.123$; $M_{\sec.} = 4.565$, $SE = 0.124$); $F(1, 81) = 18.93$, $p < .001$, $\eta_p^2 = .189$). In fact, the PoT judgment for the neutral emotional stimuli did not differ from that for the negative emotional stimuli in the seconds condition (Bonferroni test, $p > .05$), or from that for the positive emotional stimuli in the minutes condition ($p > .05$). This suggests that the negative emotional effect is reduced with the short durations and that the positive emotional effect is reduced with the long durations. Nevertheless, whatever the duration condition (seconds or minutes), the passage of time was always judged faster with the positive than the negative emotional stimuli (4.565 vs. 4.093; 3.81 vs. 3.43, respectively, all $p < .05$).

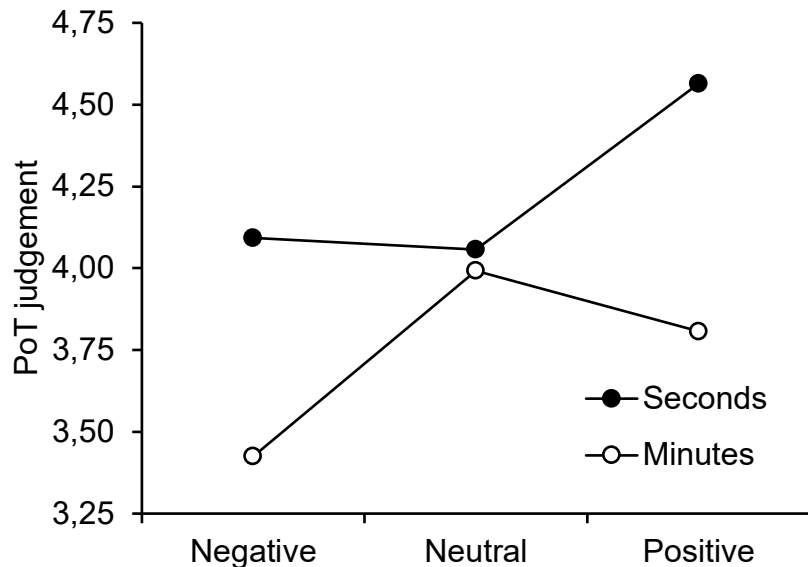


Fig. 3. Mean passage of time judgments plotted against emotional stimuli of negative, neutral or positive valence in the seconds and the minutes ranges.

3. Experiment 3 – Duration

4.1 Method

4.1.1 Participants

82 students participated in this experiment (72 women and 10 men; mean age = 19.59, $SD = 1.34$) in return for a course credit. They signed an informed consent form presenting the procedure validated by the Research Ethics Committee of the University Clermont Auvergne (IRB00011540-2019-33) and conducted in accordance with the 1964 Helsinki declaration.

4.1.2 Material and procedure

The materiel and the procedure were the same as those used in the previous experiments, except that the stimuli to be judged were static neutral images representing a geometric pattern in black and white. The image size was $21.77^\circ \times 16.1^\circ$. There were 54 images with different geometric patterns, i.e. 27 for each duration group. As in Experiments 1 and 2, there were therefore two groups of participants depending on whether the duration of the stimuli was in the seconds ($N = 41$) or minutes range ($N = 41$). However, in the present study, the manipulated factor was neither the task difficulty nor the emotional valence but the stimulus duration *per se*. The stimulus durations were of 22, 33 and 44 seconds in the seconds group and of 66, 99 and 132 seconds in the minutes group. The participants were thus presented with 18 blocks of trials, i.e. 6 trials per stimulus duration. The trial order was

random and the image presented on each trial was randomly chosen in such a way that the images used were similar for the different temporal conditions. As in Experiments 1 and 2, the participants gave their judgments going from 1 “very slowly” to 7 “very fast” after each trial.

4.2 Results

An ANOVA was performed on the PoT judgments with the stimulus duration (short, medium, long) as within-subjects factor and the duration group (seconds, minutes) as between-subjects factor. As illustrated in Fig. 4, the main effect of the stimulus duration was significant, $F(1.70, 135,69) = 120.92, p < .0001, \eta_p^2 = .602$. No stimulus duration x duration group interaction was found ($F > 1$). There was only an additional main effect of the duration group, testifying to the fact that the stimulus durations in seconds ($M = 3.40, SE = .17$) were judged as passing faster than those in minutes ($M = 2.91, SE = .17$), $F(1, 80) = 4.17, p = .04, \eta_p^2 = .05$.

Consequently, whatever the duration range tested, the subjective experience of the speed of time varied linearly with the real time, as indicated by the linear effect of the stimulus duration, $F(1, 80) = 176.978, p < .0001, \eta_p^2 = .69$. Indeed, as confirmed the Bonferroni tests, the PoT was considered to be faster for the shortest duration ($M = 3.79, SE = .136$) than for the medium ($M = 3.24, SE = .133$) or the longest duration ($M = 2.44, SE = .125$), and also for the medium than for the longest duration (all $p < .0001$). In addition, and as indicated by the non-significant interaction between the stimulus duration and the duration group, the experience of an acceleration of time with the changes in real time was similar for a wide range of durations as long as the ratio between stimulus durations was the same. This is, to our knowledge, the first demonstration of the scalar property of time in the domain of the subjective passage of time.

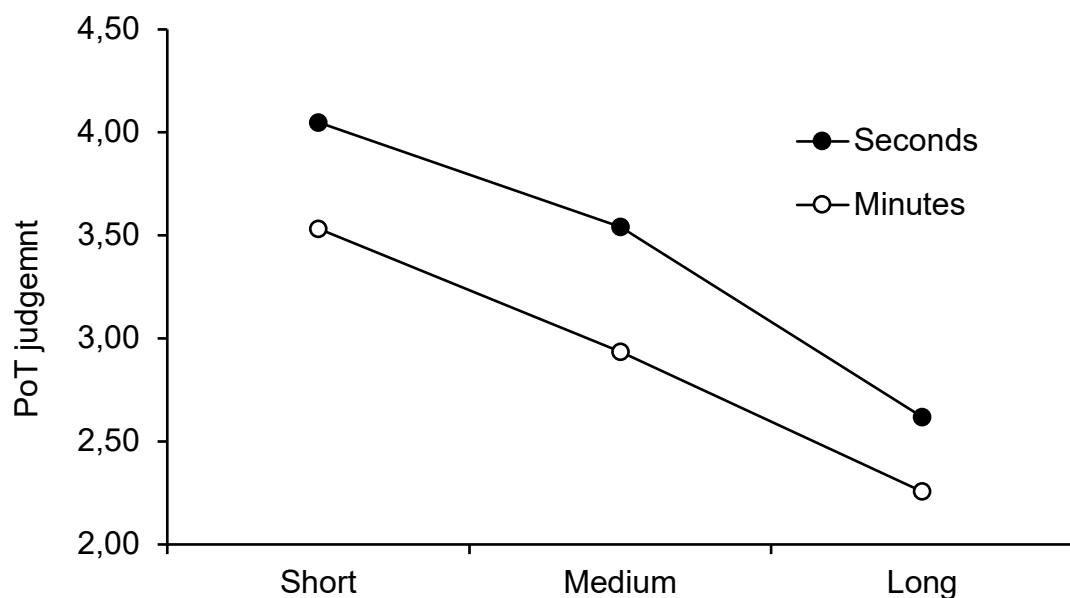


Fig. 4. Mean passage of time judgments plotted against stimulus durations in the seconds and the minutes ranges.

4. General Discussion

In three different experiments, we examined variations in the PoT judgment when the difficulty of the task varied (Experiment 1), when the emotion valence of the stimuli shifted from negative to positive (Experiment 2), while stimuli durations were controlled and, finally, when the duration itself varied (Experiment 3). Our results showed that time was judged to pass more slowly for durations in the minutes than for those in the seconds range. However, for all duration ranges, we observed that each change in the feature of a given task (difficulty of the task, emotional valence, duration) produced a change in the PoT judgment. The judgment of the speed of the passage of time therefore increased linearly with the increase in the level of difficulty of the task, although the duration of the task did not change. This result is consistent with those obtained by Sucala et al. (2011) and Wearden et al. (2014) showing, with a single interval of 3-4 minutes, that the passage of time was felt to be faster as the task difficulty increased. Moreover, our results showed that the PoT was judged to change not only depending on the level of task difficulty but also the emotional valence of the stimuli. Indeed, the speed of the passage of time was judged to increase with the positive valence of the emotional stimuli, regardless of their presentation duration. The participants therefore judged the passage of time independently of durations on the basis of non-temporal information. Nevertheless, when the stimulus durations changed, while the other characteristics of the task remained constant, the PoT judgment also varied according to the duration values. We observed that the speed of the PoT judgment increased as the stimulus durations decreased.

In an experimental prospective timing paradigm such as the one used in our studies, it is assumed that the internal clock system is activated and that it processes time. In other words, participants experience durations by focusing their attention on time (Zakay and Block 1996, 1997; Zakay and Block 2004). However, our results revealed that even if the participants were aware that time was an important feature of the task, their judgments of the passage of time were not always based on temporal information. Indeed, in Experiments 1 and 2, the PoT judgment varied in response to changes in non-temporal information while the target duration remained constant (randomly controlled throughout the non-temporal conditions). We expected that the effect of temporal information on the PoT judgment would be higher for the short durations of a few seconds than for the long durations of several minutes since the mechanisms responsible for processing short and long duration do indeed differ. An internal clock system is thought to provide an accurate representation of time in the case of short durations (for reviews, Merchant et al 2013; Wearden 2016). By contrast, memory-based processes are thought to be involved in the judgment of long durations (Droit-Volet et al. 2018). However, for the PoT judgment, and contrary to our hypothesis, we obtained the same results for all durations. Indeed, a significant main effect of task difficulty on the PoT judgment was observed in Experiment 1, regardless of the duration of the task and the duration range (seconds vs. minutes). A main effect of emotion was also observed on the PoT judgment for the different duration range in Experiment 2 as well as in Experiment 1. In Experiment 2, a significant interaction between emotion and duration range was nevertheless found. However, this interaction only indicated that the participants felt that time passed faster for positive emotional stimuli when presented for a few seconds than for several minutes. Overall, therefore, our results in Experiment 1 and 2 suggest that PoT judgments obtained for a wide range of durations were based on something other than duration processing itself.

However, in our study, the PoT judgment also changed with the real time when the duration was the only feature of the situation that varied. Indeed, in Experiment 3, we found a linear relationship between the stimulus duration and the experience of the passage of time when the difficulty of the task was experimentally controlled. In particular, the participants experienced an acceleration of the passage of time as the duration decreased from

one value to the next, i.e. with a time step of 11 s in the range of seconds and of 33 s in the minutes range. Therefore, a time-measurement mechanism (internal clock) may also contribute in part to the prospective judgment of the passage of time. The fact that the PoT judgment varied in our studies not only when we manipulated all the non-temporal information but also the temporal information suggests that the PoT judgment is not based on a specific factor, but on a number of different factors depending on the salience of the context encountered, i.e. the nature of the experienced or perceived changes. For example, in Experiment 3, the stimulus duration might have influenced the PoT judgment because the variation in the duration of stimulus was the most salient. But, in another context, time would have little or no influence on the prospective judgment of the passage of time, being the level of task difficulty and emotion. Some correlation studies have suggested that other factors may also play a role in PoT judgment such as time pressure, routine of everyday life (Winkler et al. 2017; Wittmann et al. 2015), and boredom (Droit-Volet et al. 2020; Jokic et al. 2018; Witowska et al. 2020; Wittmann et al. 2015). Consequently, one can assume that PoT judgments are inferred not from one and always the same dimension (i.e. task difficulty) but from the most salient contextual (temporal or not) changes encoded and memorized during the interval. PoT judgment would therefore be a generic way of describing the most salient internal or external contextual changes experienced.

Our results therefore suggest that the PoT judgment can also be based on the processing of durations, at least in the prospective PoT judgment paradigm. Finally, the PoT judgment is multi-faceted. We have identified three main types of PoT judgment: Self-duration, World-duration and Self-time perspective. As reported in the introduction, the first of these refers to the intra-subject malleability of time related to introspective analyses of internal states. The second is the representation of external time as indicated by our watches and the third is related to temporality of self in the past-present-future. We may add a fourth type of PoT judgment, namely the event duration measured by an internal clock mechanism: "Event-duration". In this last case, there would be an association between the speed of the passage of time and the measured event-duration values. As found in the present study, the participants had no difficulty judging that time passed faster with short durations than with long durations. In summary, many factors underlie PoT judgments. This would imply that there are different types of PoT judgment, depending on the context and its significance during the interval to be judged as well as on whether the PoT judgment is prospective or retrospective. Further studies are nonetheless needed to determine which of the factors we have seen prevail over the others in the different types of PoT judgment and why.

Furthermore, our studies point out a linear relationship between the PoT judgment and the different levels of any tested factor, regardless of the factor examined. However, it is likely that the PoT judgment curve might not be as linear as observed in our experiments in other circumstances. Under extreme conditions, with a task that is too difficult, or in the presence of more intense emotions, the participants might no longer be able to experience the movements of time with its compression or extension. They could experience timelessness, a time that no longer exists, a time that no longer flows at different speeds (Csikzentmihalyi and Csikzentmihalyi 1988). This is what is reported in deep states of meditation experienced by meditation experts (Droit-Volet and Dambrun 2019) or in car accidents (Noyes and Kletti, 1977; Arstila 2012). Further experimental investigations are thus required to better understand what lies behind our awareness of variations in the speed of the passage of time and why we translate our experience in the present into movements of time and self-duration.

Compliance with Ethical Standards: For the 3 experiments conducted in human adults, all individual signed an informed consent form presenting the procedure validated by the Research Ethics Committee of the University Clermont Auvergne (IRB00011540-2019-33) and conducted in accordance with the 1964 Helsinki declaration.

Conflict of Interest: Natalia Martinelli and Sylvie Droit-Volet declare that their have no conflict of interest.

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