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Different methods for reproducing time, different results

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Abstract

One of the most widely used tasks for investigating psychological time, time reproduction, requires from participants the reproduction of the duration of a previously presented stimulus. Although prior studies have investigated the effects of different cognitive processes on time reproduction performance, no studies have looked into the effects of different reproduction methods on these performances. In the present study, participants were randomly assigned to one of three reproduction methods, which included (a) just pressing at the end of the interval, (b) pressing to start and stop the interval, and (c) maintaining continuous pressing during the interval. The study revealed that the three reproduction methods were not equivalent, with the method involving keypresses to start and stop the reproduction showing the highest accuracy, and the method of continuous press generating less variability.

Keywords

Time perception; Time reproduction; Method comparison; Motor responses

Most internal-clock models assume that temporal judgments are made via different processing stages. The first is the clock stage, consisting of a pacemaker emitting pulses that

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are gated to an accumulator; the second is the memory stage, conceptualized as storing accumulated pulses in working memory for comparison with a long-term memory representation of pulses accumulated on past trials; and finally, the decision stage, in which a mechanism compares the current duration value with those stored in memory to decide on the adequate temporal response (e.g., Treisman, 1963). In their attentional gate model, Block and Zakay (1996) proposed an attentional component in addition to the clock process for explaining the influence of a person's attentional resource allocation on temporal processing. The model predicts that temporal performance will be adversely affected by the attentional, or workload, demands of any nontemporal task conducted together with the temporal task (Block, Zakay, & Hancock, 2010).

Several approaches have been applied to describe how temporal intervals in the seconds-to-minutes range are processed in humans and animals, and the task employed for studying this processing depends on the specific question being addressed. Four main tasks are available for investigating the mechanisms involved in time perception. These include (1) comparison (or time discrimination), (2) time production, (3) verbal estimation, and (4) time reproduction (Grondin, 2008, 2010; Zakay, 1990). Researchers have used the entire repertoire of tasks, but in most cases have provided no rationale for the selection of the specific task used in the investigation. Given the intricacies of the temporal processes, it is critical to select the appropriate method, since the tools of measurement could affect the test performance (Zakay, 1990). In comparison tasks, participants are required to compare the relative durations of two intervals that are sequentially presented (usually standard–comparison) and then to differentiate between their time frames (e.g., which one was longer or shorter, or was the second interval shorter or longer than the first). In time production tasks, participants are required to produce a temporal interval equivalent to a duration that was previously indicated—that is, to translate an objectively labeled duration to a subjectively experienced duration. In verbal estimation tasks, participants experience the target duration and then are required to translate the experienced duration (subjective duration) into chronometric units (objective duration). Time production and verbal estimation tasks are suitable methods for investigating individual differences in the speed rate of the internal clock, but verbal estimation methods yield less accuracy and produce more variability than do time production methods, because participants have a tendency to round off the time duration (Grondin, 2008, 2010; Zakay, 1990). The present study focused on the time reproduction task and, in particular, on the effects of different methods of reproduction on temporal performances. In a time reproduction task, participants are usually first presented with a sample duration and are then required to produce a motor action (e.g., to press a button) to reproduce the previously presented duration.

Several reasons may account for the temporal errors that can occur at different stages of temporal processing. Most studies have focused on the properties of the pacemaker and shown how dopaminergic activity in the basal ganglia (Rammsayer, 1999), emotions (valence and arousal: see Angrilli, Cherubini, Pavese, & Manfredini, 1997), and age (Friedman & Janssen, 2010; Perbal, Droit-Volet, Isingrini, & Pouthas, 2002) can modulate the rate of the pacemaker. In addition to the pacemaker, cognitive processes, such as working memory and attention, are expected to influence temporal performance in a time reproduction task. Indeed, the target duration is first estimated, and then stored in short-term memory in order to be subsequently reproduced. Correlations have been observed between memory span and performance in time reproduction tasks (Baudouin, Vanneste, Isingrini, & Pouthas, 2006).

Other sources of variation in time reproduction tasks are connected with the motor action required to reproduce the duration. Participants need to integrate their motor action in order to produce a precise buttonpress to reproduce the temporal interval. Moreover, preparing and executing a motor action requires cognitive resources that might result in additional variance (Caldara et al., 2004). For instance, we can assume that people suffering from deficits in the planning, preparation, and execution of motor movements could have poor temporal performance in a temporal reproduction task due to their motor-related deficits rather than to their inability to estimate time (Bloxham, Dick, & Mooret, 1987; Stuss et al., 1989).

The aim of this study was to investigate the possible effects of different time reproduction tasks. In this study, we compared three methods often employed for reproducing time intervals. In Method 1, the task required only pressing at the end of the reproduction; in Method 2, the task required pressing to start and stop the reproduction; finally, for Method 3, the task required continuous pressing to reproduce the duration. We expected that differences in temporal performance between the methods would be due to the different cognitive and motor components involved.

According to the attentional gate model (Block & Zakay, 1996), performance in temporal tasks is correlated with the amount of attentional resources dedicated to the temporal tasks. Dividing attention between two concurrent tasks reduces the amount of attention to the temporal task; subsequently, fewer signals pass through the gate, and fewer signals are stored in the reference memory (Block & Zakay, 1996). Therefore, if preparing and executing a motor action required greater amounts of cognitive resources, we would expect to find different temporal performances in Methods 1, 2, and 3. Participants using Method 2 (pressing to start and stop the reproduction) should obtain poorer performance than participants using either Method 1 or 3. In fact, Method 2 requires greater involvement of the motor component, since it requires preparing twice the number of motor actions. Also, participants using Method 3 should obtain lower performance than participants using Method 1, considering that Method 3 requires maintaining a motor action continuously during the temporal reproduction. This continuous motor action can be seen as an additional task requirement, though admittedly not a very demanding one; nonetheless, it should reduce the cognitive resources dedicated to time (Block et al., 2010). The present experiment also included a concurrent-task condition, in order to prevent explicit counting. This condition should impair the temporal performance in each method condition.

Method

Participants

We enrolled 60 university students from the University of Padua (Italy). The participants were randomly assigned to one of three experimental groups, with 20 in each experimental group: “press to end the reproduction” (Method 1), “press to start and end the reproduction”

(Method 2), and “keep pressing to reproduce” (Method 3). The mean ages for the participants in each group were, respectively, 23.00 years (*SD*=3.04) in Method 1, 23.30 years (*SD*=2.90) in Method 2, and 23.30 years (*SD*=2.72) in Method 3. No age differences were found between the groups (p>.05).

Procedure

All participants were tested in a quiet room in the Department of General Psychology at the University of Padua. Each testing session lasted approximately 30 min. All tasks were presented on a 15-in. PC monitor, and participants were seated at a distance of approximately 60 cm. We used E-Prime 2.0 to program and implement the tasks. All of the participants provided informed consent to complete the study protocol procedures.

Materials

Participants were asked to reproduce the duration of a previously seen sample duration. The stimulus employed was a smiley face presented at the center of the computer screen for one of these durations: 1, 4, 9, 14, and 18 s. Each duration was randomly presented four times, for a total of 20 trials. Participants were first presented the sample duration, and after a 500-ms interstimulus interval, a question mark appeared on the computer screen, and participants were instructed to reproduce the duration (by pressing the spacebar) by means of the assigned reproducing method. During the reproduction phase, the stimulus (smile face) reappeared at the center of the computer screen. For Method 1 (pressing to end the reproduction), a question mark appeared on the screen for 500 ms, and then the stimulus appeared at the center of the computer screen. Participants were required to press the spacebar to erase the stimulus when they judged that the previously displayed duration had ended (see Fig. 1a). In Method 2 (pressing to start and end the reproduction), participants were asked to press the spacebar to display the stimulus on the screen for an amount of time equivalent to how long it had been displayed. When the same amount of time had elapsed, participants were required to press the spacebar again to erase the stimulus (see Fig. 1b). In Method 3 (keep pressing to reproduce), participants were required to continue pressing the spacebar for the same amount of time that the sample stimulus had been presented (see Fig. 1c).

All participants were instructed to perform the time reproduction task in simple and concurrent-task conditions (20 trials in each condition). In the simple condition, the participants were instructed not to count and had to pay attention to and reproduce the stimulus duration. In the concurrent condition, participants were instructed to read aloud digits displayed at the center of the stimulus. These digits ranged from 1 to 9 and were randomly presented with an interdigit interval that varied from 400 to 800 ms. This procedure was employed to prevent participants from counting (Perbal et al., 2002). Participants completed a practice phase before beginning the reproduction task, in which they were asked to reproduce each duration once. No feedback was provided to the participants.

Statistical analysis

The data were analyzed in terms of the *absolute error* (AE), the *estimated-to-target-duration ratio* (RATIO), and the *coefficient of variation* (CV). The AE was calculated by putting in absolute value the difference between the time reproduction (R_d) and the target duration (T_d), divided by the target duration [AE=$|R_d - T_d|/T_d$] (Brown, 1985; see also Glicksohn & Hadad, 2012). A greater AE indicated lower performance, since the time reproduced was farther from the target duration. The RATIO was obtained by dividing each participant's time performance by the time duration of the interval presented for that trial [RATIO=R_d/T_d]. This also provided an index of the direction of errors, with coefficients above and below 1.0 being indicative of overreproduction and underreproduction, respectively. The CV was computed by dividing the standard deviation by the mean judgment, which followed procedures developed by Brown (1997). The CV index represented the variability in temporal judgments for each participant, and evaluated the consistency of time performance for the same target duration.

Separate mixed-model analysis-of-variance (ANOVA) models were computed for each dependent variable, with Method (1, 2, and 3) as the between-subjects factor and Condition (simple and concurrent) and Stimulus Duration (1, 4, 9, 14, and 18 s) as the within-subjects factors. All significant analyses were followed by post-hoc analyses performed with Bonferroni correction to reduce the Type I error rate, and the effect size was estimated as partial eta squared (η^2_p).

Results

Absolute error

The mean AEs in each duration condition and each method condition are reported in Fig. 2. An ANOVA conducted on AEs revealed significant effects of condition [$F(1, 57)=26.22$, $p<.001$, $\eta^2_p=.315$] and duration [$F(4, 228)=31.26$, $p<.001$, $\eta^2_p=.354$]. Participants were less accurate in the concurrent than in the simple condition (concurrent, *M*=.29, *SD*=.01; simple, *M*=.21, *SD*=.13); post-hoc analysis showed that the AE was higher for the 1-s duration than for the other durations, and no difference was found between the two longer durations (14 and 18 s). The analysis also revealed a significant Condition×Duration interaction [$F(4, 228)=4.11$, $p<.05$, $\eta^2_p=.067$]. Post hoc analyses indicated that participants were less accurate in reproducing 1 s in the simple condition but were equally accurate in reproducing the other durations; in the concurrent-task conditions, significant differences were found between all durations. An effect of method was not found ($p>.05$), but interestingly, method interacted with the Duration factor [$F(8, 228)=2.18$, $p<.05$, $\eta^2_p=.067$; see Fig. 2]. Post-hoc analyses revealed no effect of duration within Method 1, but significant differences between 1 s and longer durations (14 and 18 s) in Methods 2 and 3. A significant difference between the methods was observed at 1 s, indicating that participants using Method 2 were less accurate than those using Method 1; no method effect was found with the 4- and 9-s durations; and significantly better performance was obtained with Method 2 than with Method 3 in the 14- and 18-s conditions.

Estimated-to-target-duration ratio

The mean ratios for the simple and concurrent conditions in each duration condition are reported in Fig. 3a. The analysis of relative errors revealed a significant main effect of method [$F(2, 57)=5.99$, $p<.001$, $\eta^2_p=.174$], indicating that the participants who used Method 3 underreproduced the duration more than did the participants who used Method 2. We found no significant differences between Method 1 and the other two methods (Method 1, *M*=0.94, *SD*=0.02; Method 2, *M*=1.02, *SD*=0.02; and Method 3, *M*=0.88, *SD*=0.03; see Fig. 3b). A significant effect of duration was found, $F(4, 228)=58.67$, $p< .001$, $\eta^2_p = .507$], which indicated that participants overreproduced the 1-s duration and underreproduced the longer durations. Moreover, the Condition×Duration interaction was significant [$F(4, 228)=24.65$, $p<.001$, $\eta^2_p=.302$] (Fig. 3c): Participants overreproduced the 1-s duration, and the ratio was higher in the concurrent condition, whereas durations longer than 4 s were underreproduced, and the ratios were significantly lower at 14 and 18 s in the concurrent than in the simple condition. The condition effect and the other interactions were not significant (*p*s>.05).

Coefficient of variation

The mean CVs in each method and for each duration condition are reported in Fig. 4. The ANOVA on the CVs revealed significant main effects of condition [$F(1, 57)=3.79$, $p<.05$, $\eta^2_p=.062$] and duration [$F(4, 228)=12.05$, $p<.001$, $\eta^2_p=.174$]. Participants were more variable in the concurrent condition than in the simple condition (concurrent, *M*=.20, *SD*=.01; simple, *M*=.18, *SD*=.01); moreover, participants were more variable when they reproduced brief durations (1 and 4 s) than when reproducing longer durations. The Condition×Duration interaction was significant [$F(4, 28)=2.69$, $p<.05$, $\eta^2_p=.045$], and post-hoc analyses indicated that participants were more variable when they reproduced 14- and 18-s durations in the concurrent condition. A significant effect of method was also found [$F(2, 57)=3.30$, $p<.05$, $\eta^2_p=.104$], indicating that the participants using Method 3 were less variable than the participants using Method 1 (*M*s=.21, .18, and .17 for Methods 1, 2, and 3, respectively). The method effect also significantly interacted with duration [$F(8, 228)=4.18$, $p<.001$, $\eta^2_p=.128$], with post-hoc tests indicating that the participants who used Method 3 were more variable than the participants using Method 2 in the 1-s condition, whereas, with longer durations (9, 14, and 18 s), Method 3 led to less variability.

Discussion

In the present study, we investigated the effects of different time reproduction methods on temporal performance. We compared three different methods in which participants were required to press a key to stop the reproduction (Method 1), press a key to start and stop the reproduction (Method 2), or keep pressing the key during the reproduction (Method 3). To our knowledge, this is one of the first studies to demonstrate directly that different reproduction methods exert an impact on temporal performance. In general, the method in which participants should press to start and stop the reproduction (Method 2) showed higher accuracy (AE) with long durations (14 and 18 s), but the method in which participants should keep pressing to reproduce (Method 3) showed less variability (CV).

More specifically, temporal performance seems to depend on the method employed and on the interval range under investigation. In fact, the study showed that Method 2 (pressing to start and end the reproduction) leads to better accuracy (AE) than do Methods 1 and 3 with longer durations; however, when a short duration is employed (i.e., 1 s), Method 2 generates a higher AE, indicating lower performance. Participants using Method 1 showed good performance only when reproducing 1-s intervals (Fig. 2).

The results obtained with AE were confirmed when we analyzed the data in terms of RATIO scores. The results showed better performance when participants used Method 2, with which intervals were slightly overreproduced. Participants using Method 3 showed very large underreproductions. No differences were found between the participants using Method 1 and those using the other two methods. Overall, the RATIO score results showed that participants generally underreproduced temporal intervals, in particular in the long duration conditions and when a concurrent secondary task was administrated.

Of interest are the results obtained with CVs. Although participants using Method 3 showed the lowest level of accuracy (AE) and underreproduced temporal durations (RATIO) more than did participants using Method 1 or 2, using Method 3 led to the lowest CVs. Interestingly, pressing continuously to reproduce the duration generates less variability than do the other methods, in particular when participants reproduce longer durations (Fig. 4). Indeed, different performance was observed at 1 s than at longer durations: In this condition, better performance was obtained with Method 2.

Contrary to our hypothesis, participants showed, in general, better performance when using Method 2. We expected that generating twice as many motor actions would have led to lower accuracy (AE) and higher variability (CV) than would conditions involving only one motor action (i.e., Method 1 or 3). Instead, it might be possible that participants in Method 2 could have prepared their motor action and their response better than did the participants using Method 1 or 3. In fact, as compared to Method 1, in which the onset of the stimulus was fixed and decided by the experimental setting, participants in Method 2 could decide when to start and stop the reproduction. This may have determined a better involvement of attentional resources. In Method 3, as in Method 2, participants could decide when to start and stop the reproduction, but Method 3 required a continuous motor action to reproduce the duration. This additional requirement may have reduced the amount of attentional resource that was dedicated to time (Block et al., 2010). Also, previous studies showed that producing a continuous force (motor action) during the interval to be timed (i.e., Method 3) influences temporal performance. More precisely, subjective duration is reduced when the amount of force required to perform the temporal task is increased (Doob, 1971; Macar, 1980). This might explain the higher rate of underreproduction when using Method 3.

Moreover, the study revealed an effect of duration, which is consistent with Vierordt’s law. In time reproduction tasks, it is known that temporal intervals are overreproduced when the standard duration is short, but underreproduced when the standard duration is long, with an “indifference point” around 2–3 s (Lejeune & Wearden, 2009). In our study, the “critical” duration seems to have been around 4 s, when no over- or underreproduction was observed. In addition, at the 4-s duration, no difference between the methods was observed (see Figs. 2

and 4). Moreover, Fig. 3c indicates that the Vierordt's effect is more pronounced with a concurrent task. The briefer reproduced intervals with longer standard durations could be attributed to loss during retention of the information associated with the standard (Hellström, 2003), given that it is known that intervals longer than 1 s are cognitively mediated (Rammsayer, 2008). This sensitivity to cognitive processing would explain why the effect is stronger in a more cognitively demanding condition (i.e., with a nontemporal task). Assuming that Vierordt's effect is due to a regression toward the mean (central tendency effect), increasing the effect with the long intervals would result in a magnified overestimation of the shortest intervals (at 1 s, in the present study).

Lower accuracy (AE) and higher variability (CV) were observed when participants performed the temporal task together with a concurrent nontemporal task. When participants are performing an attention-demanding secondary task during the retention interval, time perception is inversely related to the difficulty of that task (Block & Zakay, 1996; Block et al., 2010). According to the attentional gate model (Block & Zakay, 1996), temporal information processing can be understood as a process through which the pulses emitted by a pacemaker are accumulated. When the temporal and nontemporal tasks are performed simultaneously, participants have to divide attentional resources between temporal and nontemporal tasks; therefore, fewer attentional resources are dedicated to the temporal task, which results in a lower accumulation of pulses (Block & Zakay, 1996). Participants will be less accurate (AE) and more variable (CV) in the concurrent-task condition because of the lower accumulation of pulses and because of the fluctuations of attention to time. A more precise description of the effect of a concurrent nontemporal task would require systematically manipulating what participants have to do during both the target interval phase and the phase during which they reproduce the target (Sawyer, Meyers, & Huser, 1994).

Taken together, our results showed that not all reproduction methods are equivalent, and that the difference between methods might depend on the range of duration under investigation. In fact, Method 2 seems to generate lower AE and lower underreproduction (RATIO) than do Methods 1 and 3, but only with longer durations (14 and 18 s); moreover, Method 2 does not seem to be suitable when brief durations are investigated (1 s), as is highlighted by higher AEs. However, when the CV is considered, Method 3 leads to the lowest level of variability for longer durations (9, 14, and 18 s), but at 1 s, this method generates the highest level of variability.

Our results are of interest in particular for researchers investigating time perception in clinical populations. Brain-injured patients often present motor and cognitive dysfunctions that cause lower accuracy and higher variability (Brouwer, Ponds, Van Wolffelaar, & Van Zomeren, 1989; Nichelli, Clark, Hollnagel, & Grafman, 1995). Therefore, it is important to select the appropriate method to reduce the variability produced by the task itself, in order to highlight reliable temporal performance.

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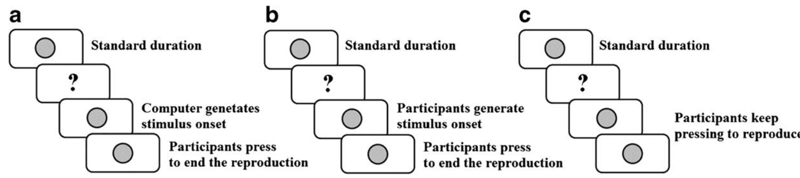

Fig. 1.

Time reproduction methods used in the study. (**a**) Method 1: "Press at the end." (**b**) Method 2: "Press to start and press to stop the reproduction." (**c**) Method 3: "Press continuously" (the beginning and ending of pressing mark the interval)

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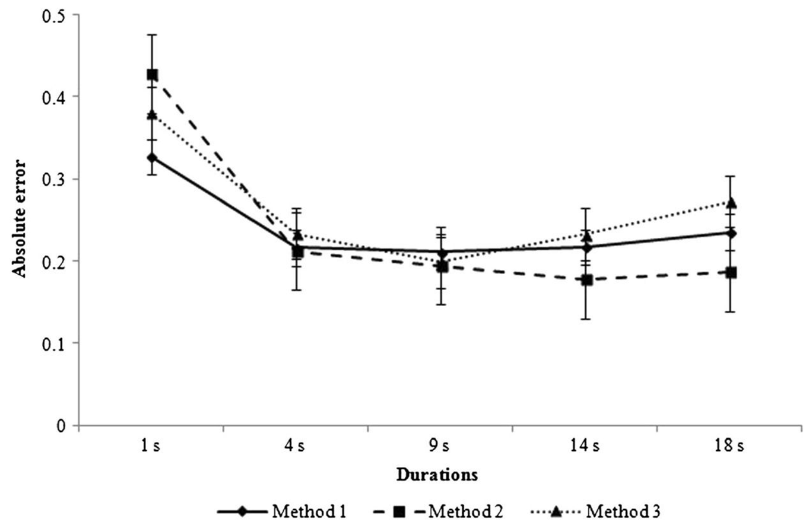

Fig. 2.

Mean absolute errors with each method as a function of standard durations. The error bars indicate standard errors

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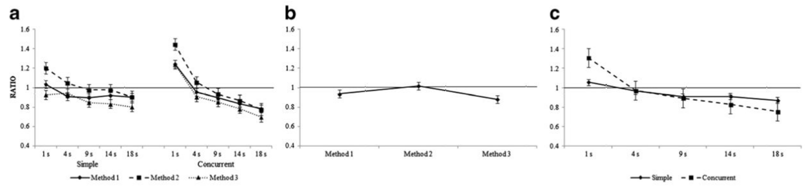

Fig. 3.

Mean estimated-to-target-duration ratios (RATIO) in all experimental conditions (A), for each method (B), and in the simple and concurrent-task experimental conditions as a function of standard durations (C). The error bars indicate standard errors

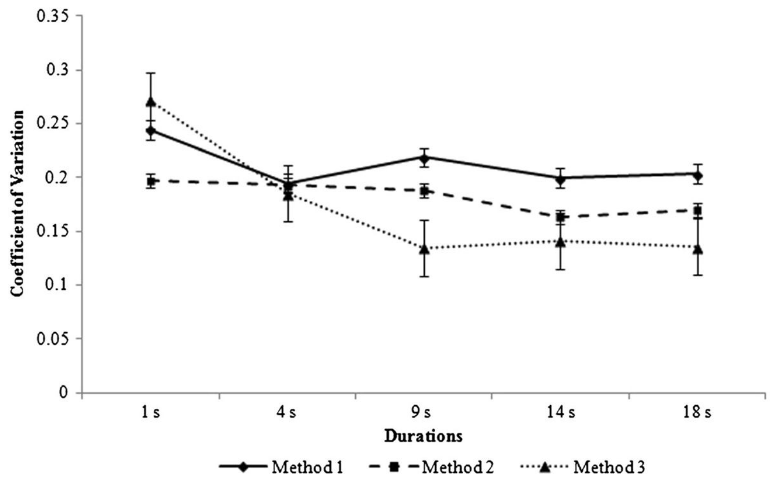

Fig. 4.

Mean coefficients of variation with each method as a function of standard durations. The error bars indicate standard errors