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Relationship between daily fluctuations of body temperature and the processing of sub-second intervals

Giovanna Mioni [a,b,*], Katherine Labonté [a], Nicola Cellini [b], Simon Grondin [a]

[a] École de Psychologie, Université Laval, Québec, Canada
[b] Department of General Psychology, University of Padova, Italy

HIGHLIGHTS

- Temporal performances were independent of body temperature
- Time performances within the same temporal task were consistent across different temperature interval
- The abilities for processing very brief intervals are reliable across the time of the day

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ABSTRACT

In 1933, Hoagland proposed that temporal processing was based on an internal clock controlled by a temperature-dependent chemical pacemaker. Several studies have tested this hypothesis, mainly using intervals above 1 s, and the global picture about the impact of temperature remains unclear. The present study aims to investigate the relationship between daily fluctuations of body temperature and the processing of sub-second intervals. In a within-subject design, twelve university students performed a finger tapping task, a time reproduction task, and a time discrimination task at three different time of the day, 9 am, 1 pm and 5 pm, and using four sub-seconds intervals (450, 550, 650 and 750 ms). As expected, we observed different degrees of body temperature across the time of the day, with the lower temperature recorded in the morning and the higher in the late afternoon. Results showed that temporal performances were independent of body temperature, regardless of the temporal task used and of the standard interval tested, indicating that performances within the same temporal task were consistent across different temperature levels. Our study provides evidence that the abilities for processing very brief intervals are reliable across the time of the day and are not modulated by the body temperature.

1. Introduction

Explanations of timing performances have often relied on the assumption that there is an internal clock [12,13]. According to this account, a pacemaker generates pulses, and the number of pulses generated is stored into an accumulator. Thus, the number of pulses counted during a given time interval provides an internal representation of this interval. Hence, the higher the pulses rate of the neural pacemaker, the finer the temporal resolution of the internal clock, which should result in better performances in time perception tasks. Obviously, the assumption of a timing process based on the internal clock suggests a biological timing mechanism underlying time perception. Although the concept of an internal clock underlying temporal processing has been a central feature of many theoretical accounts of time perception [14], the neurobiological basis of the assumed neural timing mechanism is still unknown. Variations at the level of the pacemaker might be associated with physiological changes such as changes in body temperature measured at different times of the day [1,20,30,36,41]. Hoagland [21]) was probably one of the first authors that proposed the model of an internal clock controlled by a temperature-dependent chemical pacemaker underlying temporal processing. According to his model, subjective or internal time is determined by the velocity of chemical processes in the brain. Since heat speeds up chemical reactions, he concluded that the speed of counting as well as time judgments depend on temperature.

A review on this issue published in 1995 by Wearden and Penton-Voak provides partial support to the notion that there is a relationship between body temperature and time judgments; indeed, the relation would depend on the temporal intervals employed and on the tasks used to measure time. Many of the studies included in the review

* Corresponding author at: Department of General Psychology, University of Padova, Via Venezia, 8, 35131 PADOVA, Italy.
E-mail address: mioni.giovanna@gmail.com (G. Mioni).

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employed durations longer than several seconds (from 1 s up to 100 s). As suggested by the authors, in all of these studies participants could likely have used chronometric counting for performing the tasks, biasing the results since it is often reported that counting improves timing accuracy [9,17,19]. Moreover, different methods have been used to manipulate and to test the association between temporal perception and variations in body temperature, such as fever occurring naturally as the result of illness, heated rooms, suits, helmets, and diathermy-the passage of high-frequency electric current through the body [41]. Lately, Rammsayer [36]) tested participants in a time discrimination task and two finger tapping tasks (second tapping and speeded tapping) after exposing them to 3-h of 52 °C of ambient temperature. Two short standard durations of 50 ms and 1000 ms were used in the time discrimination task. Results showed no relationship between body temperature and performance at the finger tapping tasks neither between body temperature and discrimination threshold. Aschoff [1]) showed that *the production* of long temporal (1-h interval) was independent of body temperature (rectal temperature) but *the perception* of short time interval (10 s) was related to body temperature (see also [2]), supporting the hypothesis that humans sometimes use a temperature-sensitive mechanism to regulate their time judgments.

A variation in body temperature not only occurs after heating a room, but there is also a natural variation in the body temperature related to the circadian rhythm, with the lower temperature recorded in the morning and the higher in the late afternoon [4,25,26]. Some chronobiological studies also reported that time perception seems to fluctuate across the day [6,10,27,28,32]. Kuriyama et al. [27]) analyzed accuracy in a time production task (10-s) at 4 times of the day respectively, 9 am, 1 pm, 5 pm and 9 pm and found that produced time accuracy decreased from morning to evening. Moreover, they found a significant correlation between mean body temperature (averaged across the day) and time production. More recently, Corréa et al. [10]) used a temporal preparation task that measures temporal orienting in participants of different chronotypes, i.e., morning-type and evening-type participants. Results showed that participants were most vigilant at their optimal time of day according to their specific chronotype but that synchrony did not influence temporal orienting performance, indicating a dissociation between circadian timing and temporal preparation.

To sum up, although several studies were performed to further explore Hoagland's biochemical-clock hypothesis, existing data appear to be highly inconsistent. Furthermore, to our best knowledge only Rammsayer [36]) tested the association between body temperature and temporal perception with intervals in the milliseconds range, and no one has investigated whether this relationship is consistent across different times of the day.

To address these issues, we employed three temporal tasks (spontaneous motor tempo, time discrimination and time reproduction tasks) and four standard intervals (450, 550, 650 and 750 ms). Participants were tested at three different times of the day: 9 am, 1 pm, and 5 pm, which are considered critical times for detecting differences in body temperature [25]. The goals of the study were to determine if spontaneous motor tempo and time perception are modulated by different levels of body temperature measured at different times of the day.

2. Method

2.1. Participants

Twelve right-handed volunteer students or employees (age = 26.00 years, *SD* = 4.26) from Université Laval took part in the study. All participants were non-smokers and were asked not to drink coffee before an experimental session. The study protocol was approved by the Research Ethics Committee of Université Laval and was conducted in accordance with accepted international ethical standards [34]. Each participant gave written informed consent to participate and received 72$ for taking part in the experiment.

2.2. Material and stimuli

All tasks were completed in a dimly lit room. The temporal stimuli used were 1-kHz pure tones generated by an IBM Pentium IV microcomputer running E-Prime software. The computer was equipped with an SB Audigy 2 sound card, and the sounds were delivered binaurally through headphones (Sony MDR-V600) at an intensity of about 70 dB SPL. The intervals to be discriminated were silent durations (empty intervals) marked by 10-ms tones. Finally, BD Basal digital thermometer was used for measuring body temperature.

2.3. Procedure

Each participant was tested on 12 different sessions that were set on different days at different time of the day (9 am, 1 pm and 5 pm). Each session lasted approximately 30 min. The experimental procedure included four standards durations (450, 550, 650 or 750 ms) × three time slots (9 am, 1 pm and 5 pm). The order of presentation of the standard durations and the order of the time slots were balanced between participants according to Latin squares. During each session, participants first performed the spontaneous motor tempo task (first observation), the time discrimination and time reproduction tasks (at 450, 550, 650, or 750 ms), and again the spontaneous motor tempo task (second observation). The discrimination task was always performed before the reproduction task. The session ended with the measurement of participant's body temperature (three consecutive observations). Also, participants were told not to use any counting strategy during the experimental sessions.

2.3.1. Body temperature measure

Participants' oral temperature (in Celsius degree; °C) was measured at the end of each session to eliminate the possibility of cold or hot food intake just before the measurement. Oral temperature was recorded three times consecutively and the mean value was used for the analyses. Participants were told not to move and to keep their mouth closed until their temperature was registered by the thermometer.

2.3.2. Spontaneous motor tempo task

With their right hand, participants had to tap regularly 31 times on the spacebar in order to produce 30 inter-tap intervals at a rhythm as comfortable and natural as possible. A 20-ms tone identified the end of the trial. Participants were asked to keep their forearm on the desk and could only flex their wrist to move their hand up and down. They had to use only one finger but they could choose the one they felt the most comfortable to use in order to minimize motor variability. The spontaneous motor tempo task was repeated at the beginning and at the end of each session to detect any influence of the discrimination and reproduction tasks. The dependent variables were the mean inter-tap interval.

2.3.3. Discrimination task

The time discrimination task included 3 blocks of 64 trials each. The standard interval (450, 550, 650 or 750 ms) was presented 8 times at the beginning of the task. For each standard interval 4 longer and 4 shorter comparison intervals were presented. On each trial, participants had to indicate whether the comparison interval was shorter or longer than the standard interval by pressing with their index fingers two designated keys on the keyboard. The next trial began 1.5 s after the participant's response. When the standard interval was 450 ms the comparison intervals ranged from 401 ms to 499 ms; when the standard interval was 550 ms the comparison intervals ranged from 490 ms to 610 ms; when the standard interval was 650 ms the comparison intervals ranged from 579 ms to 721 ms and when the standard