SINGING AND COUNTING IMPROVE THE TIMING OF LONG INTERVALS

Simon Grondin
Université Laval
Québec, Canada

Peter R. Killeen
Arizona State University
Tempe Az, U.S.A.

Abstract

This article analyzes sequences of temporal intervals produced by a series of finger taps. The dependent variables of interest are the mean produced intervals (MPI), and their variability (SD). Six target intervals (3 to 18 s) and 4 experimental conditions for keeping track of time were studied: No counting between the taps, counting numbers, singing a well-known song and singing a song selected by the participant. The lowest accuracy was observed in the no-counting condition, where both the deviations from the targets and the SD were the largest. With the longer intervals (15 and 18 s), the deviation from the target in the well-known song condition was significantly smaller than in the no-counting and number-counting conditions. The mean individual Weber fraction passes from 0.14 when counting was prohibited, to 0.07 with the explicit counting, to 0.06 and 0.05 when singing. Moreover, the coefficient of variation (CV=SD/MPI) in the no-counting condition was not constant.

There are several propositions in the time perception and timing literature regarding the nature of the mechanism for keeping track of time. The most often-cited contemporary model is a central clock comprising a pacemaker–counter process (Killeen & Weiss, 1987). In this theory, temporal judgments are based on the output of a pacemaker—pulses—which are emitted at a rate that is constant or variable, and accumulated in a counter.

The purpose of this experiment is to analyze humans' ability to keep track of time, as they produce a series of intervals with finger taps over a large range of durations in conditions when intervals are segmented or not segmented. The mean deviation from the target interval and the variability of the inter-tap intervals are the dependent variables of interest.

The segmentation techniques required of participants in the present experiment are: (a) counting seconds, which is a classical way of segmenting temporal information; or singing songs: (b) either a well-known tune, or, in another condition, (c) a song of the participants' choice. Segmentation both reduces a given chunk of temporal information into smaller pieces, its subintervals, and induces an internal rhythmic activity and a framework for accumulating counts. The segmentation rhythm should stabilize the pacemaker, and the lyrics of a well-known song should permit their registration at least as accurately as with numerical counting.

If knowledge of a song provides a stable tempo, singing might be a more accurate strategy than counting to keep track of time over a long period. Given the capacity of people for recovering songs from memory or producing tempo on different days (Halpern, 1988; Levitin & Cook, 1994) and their ability to judge the slight tempo variations of a musical excerpt (Grondin & Laforest, 2004), we expect that singing will provide an efficient strategy for tracking time.

Method

Participants

Twelve 21- to 25-year-old volunteers, 9 females and 3 males, participated in this experiment. All were paid $32 Canadian for their participation.

Apparatus and Stimuli

The experiment was under control of a Zenith micro-computer with timing accurate to 1 ms. The computer was linked to a response box that contained the pushbutton used to produce the intervals. The auditory markers defining the target interval that the participant had to produce were a 15-ms 5-kHz tone.

Procedure

Each trial started with the presentation of a series of 4 successive auditory markers defining 3 examples of the target intervals to be produced (input phase). The task of the participant was to produce a series of 31 taps demarking 30 intervals of durations equal to the target interval. After the targets were presented, participants were free to start the production task at any time.

There were 28 experimental conditions, 4 counting situations (no count, count seconds, forced song, and chosen song) times 7 targets (3, 6, 9, 12, 15, 18 and 21 s). Each participant completed four sessions, one for each counting type. Because of problems with the computer program, data collected in the 21-s condition were not reliable and this condition was not retained for analysis.

In the no-segmentation condition participants were asked to not count, sing, or adopt cyclic activities (moving neck, tapping foot, …), and they reported to have conformed to our demand. In the mediated conditions, the participants were instructed to count seconds or sing during the input phase, and to continue during the production phase. The forced song was *Au clair de la lune*, a song that each participant reported to know very well. Its structure is very simple, 4 beats at the quarter note. In the other singing condition, the participants were free to select a song of their choice. They were also free to count/sing aloud or to themselves. For both the input and the production phases, the participants were instructed to try to keep their tempo constant, and to return to the beginning of the song once they reached the target. In the case of *Au clair de la lune*, they were also told to return to the beginning of the verse if they reached the end of it before the target duration.

Each participant was assigned to one of eight orders of a Latin square involving 4 conditions, here counting or not, and singing (twice). These participants produced 3-s intervals first, and 21-s intervals last, in an increasing order. Four other participants were tested in a reversed order (21 s first, and 3 s last). There were 4 experimental sessions, one per condition. There was at least one hour between each session, and each session lasted roughly one hour.

Results

For each interval production series, the mean produced intervals (MPI) the standard deviation (SD) of the produced intervals, and their Weber fraction, or coefficient of variation, *CV=SD/MPI*, were calculated.

Mean produced intervals

The average MPIs are shown in Figure 1. Participants' MPIs were close to the target intervals in all segmentation conditions for all target intervals, with data from the *No-count* condition falling systematically above the target for all conditions. In all experimental conditions the average temporal productions were proportional to the target times. The lines in Figure 1 have zero intercepts and slopes of 1.11 (no-counting), 1.04 (counting), 0.98 (Lune), and 1.00 (optional song).

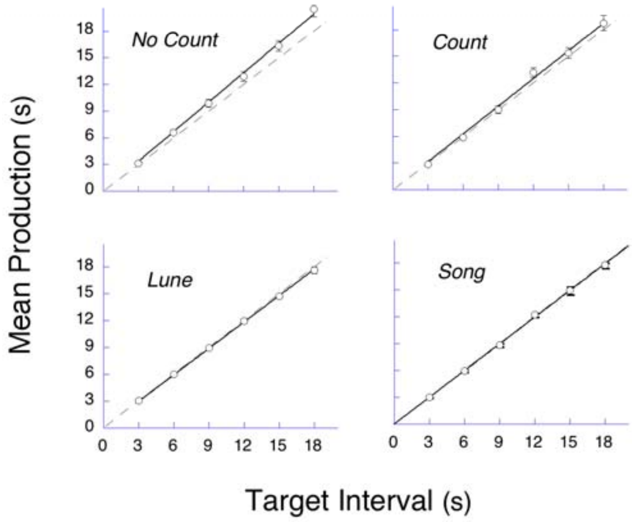

Figure 1. Mean produced interval as a function of target interval for each segmentation condition (bars are standard errors). The dashed lines show perfect performance. The continuous lines are regressions through the origin.

Figure 2 shows the group average deviation between target and mean interval reproduced for all experimental conditions. Whereas the no-counting condition clearly shows deviations that increase with longer targets, there was no systematic deviation in the singing conditions. In the explicit-counting condition the intervals produced were smaller than the target from 3- to 9-s conditions, but larger than the target in the longer-interval conditions.

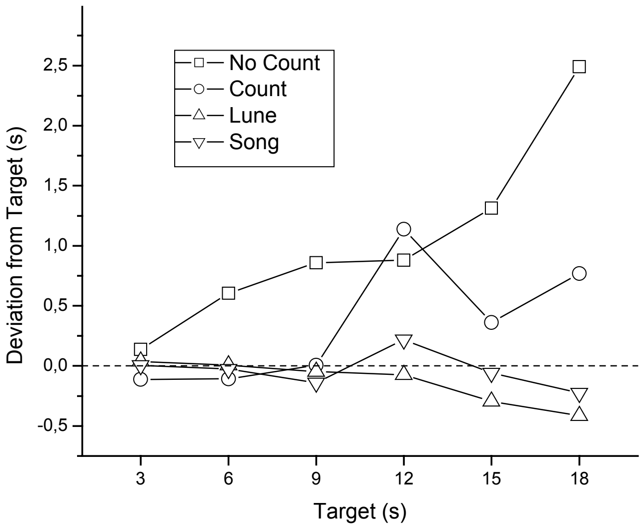

Figure 2. Mean deviations from the target interval as a function of target interval for each segmentation condition. Dashed line is at 0 deviation.

A 4 x 6 ANOVA with repeated measures on the deviation from target revealed a significant segmentation condition effect, $F(3,33) = 6.28$, $p < .01$, but no significant target effect. Most importantly, there is a significant interaction between these factors, $F(4.56, 50.14) = 3.18$, $p = .017$. Post hoc analysis revealed that there are no segmentation condition differences at 3 s ($p = .518$), 6 ($p = .102$), 9 ($p = .102$), and 12 s ($p = .112$). Significant differences were observed at 15 s, $F(3,33) = 3.04$, $p < .05$, with the Tukey test revealing significant differences ($p < .05$) between the *Lune* condition and the no-counting and the explicit-counting conditions. At 18 s, there are significant differences, $F(3,33)=8.42$, $p < .01$, between the no-counting condition and the other three conditions.

The deviation from the targets, especially the systematic ones observed in the no-counting condition, might be the result of a gradual drift during the course of a series of interval productions. If drift explains deviations from the target, there must be a systematic difference between the length of the first and the last intervals produced within a series, with the last intervals being the farther away from the target. Figure 3 shows, for each of the four experimental conditions, the mean productions for the first and last trials in each of the target durations. The results show that in many cases a large deviation from target was already observable at Trial 1. For instance, the large deviation from target observed at 15 and 18 s in the no-counting condition was already present when the participants began their series of productions. The deviations from targets therefore do not seem to result from drift.

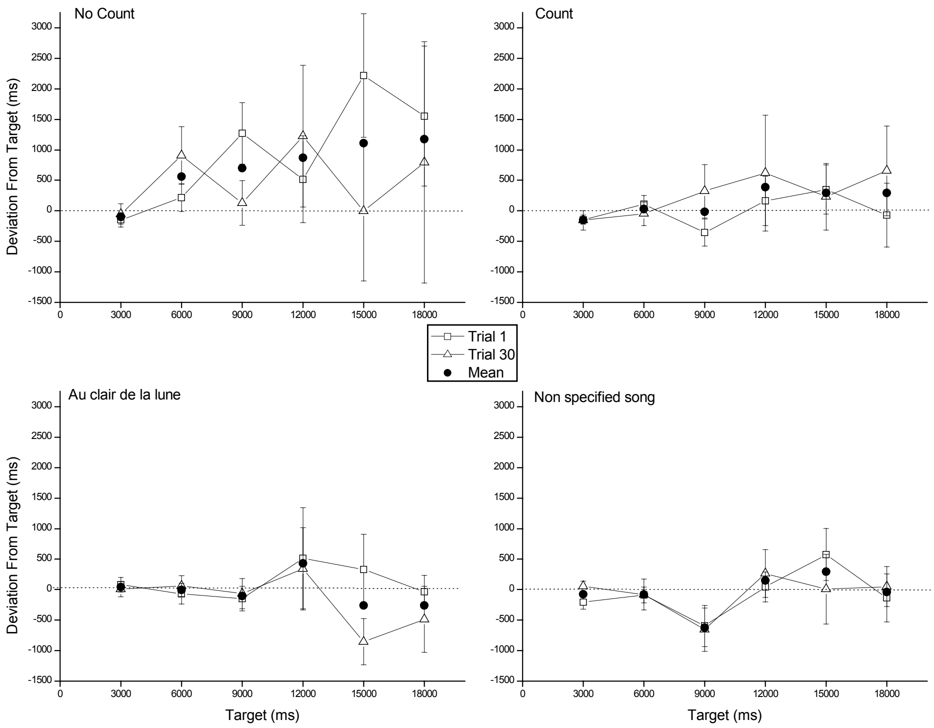

Figure 3. Group average deviation from target in each experimental condition at Production 1, Production 30, and with mean of Productions 1 and 30.

t-tests were performed on each pair of points in Figure 3. Over the 24 conditions, only 2 were significant: 9 s in the no-counting condition, $t(11)=2.67$, $p < .05$, indicating that the deviation from target was larger at the first than at the last trial; and at 15 s in the *Lune* condition, $t(11)=2.21$, $p=.05$.

Variability of estimates

Figure 4 shows how the variability of the MPI increases with the target interval. The variability about the mean productions increased as predicted by Weber's law, but not in the manner predicted by Weber's law: In the count and no-count conditions, variability accelerated with target durations. This deviation causes a systematic departure not only from

Weber's law, but also from its generalized form that allows a greater than zero intercept for the SD (Killeen & Weiss, 1987). Variability was substantially reduced by counting and further reduced by singing, with little difference due to the particular song that was sung. The reductions were greatest for the longest intervals.

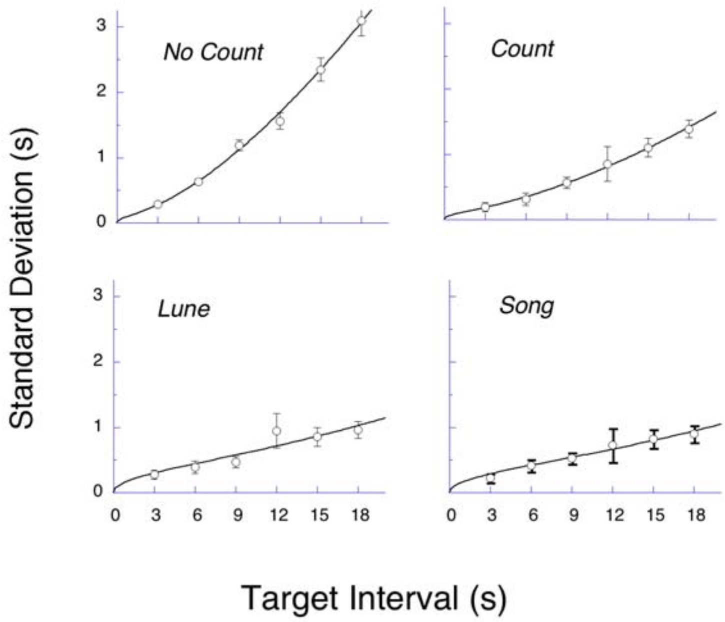

Figure 4. Average standard deviations as a function of target interval. The bars represent standard errors. The lines are from a generalization of Killeen & Weiss's (1987), Eq. 9: $\sigma_t = \sqrt{(at)^m + bt + c}$ where $m = \{2, 3\}$ represents the failure mode of the counter (Bizo et al., 2006).

We calculated the overall Weber fraction for each participant in each experimental condition as the slope of a simple proportional relation: SD as a function of target duration. We assume that the nontemporal variability such as that associated with the motor component involved in the production process contribute minimally to the observed variability, and thus set the intercept to 0. The mean Weber fractions were: 0.136, 0.069, 0.058 and 0.054 in the no-count, explicit counting, *Lune* and free-choice song conditions. A one-way ANOVA with repeated measures showed significant differences between these means, $F(1.468, 16.152) = 12.78$, $p < .01$. The Tukey test revealed that the results in the no-counting condition differ significantly from those in each of the other three conditions, not a surprise in light of Figure 4.

Another way to approach the variability issue is to consider the Weber fraction at each target level. A 4 x 6 ANOVA with repeated measures revealed a significant effect of segmentation condition, $F(1.62,17.85) = 9.10$, $p < .01$, but not of target duration. Most importantly, there is a significant interaction between these factors, $F(3.37, 35.98) = 3.74$, $p < .05$.

A one-way ANOVA with repeated measures was conducted on each of the four segmentation conditions. In the no-counting condition, not only does the SD increase with longer target intervals as expected, but so also does the Weber fraction. The ANOVA revealed significant differences among the target conditions: $F(3.393, 37.327) = 4.44$, $p < .01$, with a Tukey test showing that the 3-s condition differed from the 18-s condition. Whereas the Weber fractions increased with longer intervals in the no-counting condition, there was no such pattern in the singing conditions, where Weber fractions tended to *decrease* with interval length. The ANOVA on the counting condition ($p = .28$) and on the *Lune* condition ($p = .24$) revealed no significant differences among conditions.

Discussion

The analysis of the MPI revealed two critical things. First, the singing conditions showed a precise increase of the mean production as a function of the target duration, but the other two conditions deviated (Figure 2). In the no-counting and explicit-counting conditions, the slopes of the zero-intercept regressions were 1.11 and 1.04, respectively. In most reports on the psychophysical law involving time *perception*, the relation is reported to be linear or concave revealing that long intervals are perceived as slightly shorter than their real value (Eisler, 1976). Sub-unitary slopes for magnitude estimates, entail slightly supra-unitary slopes for *production*, as the latter are the inverse of the ones predicted for perception. In a reproduction task, such as that studied here, these mild tendencies are expected to approximately cancel, with reproduction functions being generally accurate and unbiased. Our data are consistent with this inference.

The experiment provides a graphic demonstration that the Weber fractions are much lower when intervals are segmented: The coefficient of variation estimated in the no-counting condition is halved with explicit counting. Singing provided some additional benefit compared to count of numbers. Not only did singing reduce mean deviation from targets, it also reduced Weber fractions by about 15 to 20% below those attained with explicit counting.

These results contrast with those reported by Hinton and Rao (2004). For a range of durations comparable to that of the present experiment, Hinton and Rao reported a constant coefficient of variation in a no-counting (no segmentation) condition. No such constancy was observed here: The CV increased with longer target durations. What is more, Hinton and Rao (2004) also reported a monotonic decrease of the CV with intervals length when counting. Once again, our data conflict with this conclusion because there was clearly no continued decrease of the CV in either the counting conditions.

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