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Effects of visual flicker on subjective time in a temporal bisection task

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Abstract

This experiment investigated the effects of visual flicker on subjective time in humans using a temporal bisection task. A 200–800 ms duration range and 400–1600 ms duration range were presented. Each duration range was presented separately in three different conditions: (1) filled stimuli were presented in both the training and the testing phases, (2) flickering stimuli were presented in the training phase and filled stimuli were presented in the testing phase, and (3) filled stimuli were presented in the training phase and flickering stimuli were presented in the testing phase. Psychophysical functions displacements and bisection point values suggested that flicker increased the speed of the clock; however the direction of the displacement and bisection point changes depended on the phase of the task in which the flicker was presented. This result agrees with the specific storage in either working or reference memory components of Scalar Expectancy Theory of the increased number of pulses from the clock. Weber fractions and difference limens suggested that flicker did not affect subjects' temporal sensitivity.

Keywords: Humans; Internal clock; Temporal bisection; Time perception; Visual flicker

1. Introduction

There is considerable evidence that organisms are quite accurate in timing tasks and that Scalar Expectancy Theory (SET; Gibbon and Church, 1984; Gibbon, 1991; Church, 1997, 2003) provides a good account of how they accomplish it. This theory proposes three stages for processing temporal intervals: an internal clock, memory, and decision. Some properties of the clock have attracted the attention of researchers since SET was proposed. Animal studies provided evidence that the clock can be stopped, reset, and its speed can be increased or decreased (Buhusi and Meck, 2002; Church, 1978, 1984; Drew et al., 2003; Maricq et al., 1981; Meck and Church, 1987; Roberts, 1981). An increase of the clock speed involves an increase of the rate at which the clock emits pulses, whereas a decrease implies a decrease in the rate of pulses. A general result common to different timing tasks (i.e., temporal bisection, peak procedure) is that when the clock speed is increased, the psychophysical functions for the tasks are displaced to the left of the ones obtained when the clock runs at its normal speed, suggesting that stimuli seem to last longer; the opposite occurs for a clock speed that is decreased. Changes in clock speed have been induced pharmacologically in animals and it has been argued that the effective level of dopamine adjusts the speed of the internal clock (Meck, 1983).

In human timing there have also been some physiological investigations in the clock speed by manipulating temperature and dopamine levels (Botella et al., 2001; Gruber and Block, 2003; Rammsayer, 1997; Wearden and Penton-Voak, 1995). However, the most common manipulation to increase the clock speed is a rapid sequence of stimuli (clicks or flicker), presented along with or before the signal to be timed (Droit-Volet and Wearden, 2002; Grondin, 2001; Penton-Voak et al., 1996). This manipulation was developed by Treisman and colleagues, who presented visual stimuli along with auditory clicks or presented visual flickers in verbal time estimation tasks (Treisman et al., 1990; Treisman and Brogan, 1992), finding that certain frequencies increased verbal estimates. He suggested that both kinds of stimulations presented at certain frequencies, increased the activation of a temporal oscillator component of an internal clock. This idea was adapted to SET, suggesting that clicks and flickers raise SET's internal clock's arousal level which, in turn, increases the number of pulses released by the pacemaker and stored in the accumulator.

In general, human and animal studies have suggested that increasing the speed of the internal clock produces leftward displacements of the psychophysical functions, because the

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manipulations are usually presented only when subjects respond to durations, not when they learn them (Droit-Volet and Wearden, 2002; Maricq et al., 1981; Meck, 1983). This is in part because if the manipulations are administered in continued training (i.e., in trials when subjects learn the referent durations) and also in the testing phase (i.e., in trials when subjects classify durations), the memory representations of the durations would be in the same scale, and the displacements will disappear (Meck, 1996). In addition, in human timing it is not common to obtain right displacements because if the hypothesis of the arousal level holds, it is hard to find stimuli that reduce the clocks arousal level. However, right displacements of the functions could be obtained if the clock is accelerated only when learning the durations (i.e., the opposite condition of the usual presentation of the manipulation). Therefore, to evaluate the previous possibility, a timing procedure that presents two separated phases is necessary: one in which the subjects are required to learn the durations and a second one in which they are required to respond to them. Under these conditions, manipulations such as flickering stimuli could be independently presented during either phase.

One possible temporal task is the bisection method (Allan and Gibbon, 1991; Church and Deluty, 1977; Wearden, 1991; Wearden and Ferrara, 1995). Two versions of the task have been developed for human subjects, the partition and the similarity one. In the partition version, no referent trials are identified, therefore subjects classify at their discretion the durations that are presented. In contrast, the similarity version consists of two phases: training and testing. In the training phase, short (S) and long (L) referents are presented separately and subjects are indicated only to attend to the durations. Next, on the testing phase, subjects classify as "short" or "long" a range of durations (which include both, the standard S and L durations, and intermediate durations) based on their similarity to the referents. Therefore, the present study explored in a similarity version of the bisection task the effects of visual flicker presentation on subjective time estimation to the case in which a duration is learned (training phase) or when it is classified according to its similarity to previous learned durations (testing phase).

As in the study by Droit-Volet and Wearden (2002), to evaluate SET's proposals, different measures derived from the psychometric function, which relates the proportion of "long" responses to stimulus duration were obtained. The first measure is the bisection point, which is the stimulus giving rise to 50% of the "long" (or "short") responses (i.e., the duration at which subjects are indifferent). The second measure is the superimposition that results from normalizing the psychometric functions by its correspondent bisection point. This superposition implies the scalar property, that is, that the mean of the estimated time grows linearly with the objective time and that the standard deviation of the mean of estimations for different durations varies as a constant fraction of their mean, as the timed durations vary (Gibbon and Church, 1990). This constant fraction implies that the standard deviation increases proportionally with the mean of the distribution. Finally, difference limen and Weber fraction were obtained. Difference limen is a measure of absolute sensitivity, which indicates the smallest duration difference that can be discriminated. Weber fraction is a measure of relative sensitivity, i.e., the just noticeable difference expressed as ratio of a measure of the timed duration, the bisection point in the temporal bisection task. If scalar timing holds, difference limen should increase with longer durations indicating that absolute temporal discrimination decreases as duration range increases but Weber fraction should remain constant with different duration ranges indicating that relative temporal sensitivity remains constant.

In the present study we will test if an increase of the speed of the internal clock can be induced by flickering timed stimuli and the flicker effects on subjective timing when learning durations or when responding to them. To evaluate if the results obtained are due to an increase of the clock speed or due to the effect of other SET components, we will evaluate psychophysical function displacements and bisection point values in two duration ranges. Psychophysical function superposition, Weber fractions and difference limen will be used to test if increases in the internal clock speed affect temporal sensitivity.

2. Materials and methods

2.1. Participants

Sixty undergraduate students from the Universidad Nacional Autonoma de Mexico (48 females and 12 males, mean age = 19.67 years, S.D. = 1.37), were randomly allocated to six groups. Participants received course credit for participating.

2.2. Materials and apparatus

Participants were tested individually in either of two similar quiet rooms with diminished light. Each room was equipped with a PC computer and a SVGA monitor screen. The computer controlled the experimental task and recorded data with Super Lab Pro 2.0 for Windows (Cedrus Corporation). Two alphanumeric keys (1 and 2) from the keyboard were selected as response keys. The stimulus was a blue circle (4.5 cm in diameter), presented at the centre of the monitor screen on a white background.

2.3. Procedure

Participants were randomly assigned to one of six groups resulting from the combination of two duration conditions and three flicker conditions (see Table 1). The duration conditions were a 200/800-ms duration range and a 400/1600-ms duration range. In the 200/800-ms condition the stimulus duration was 200 ms for S and 800 for L and during the test phase stimulus durations of 300, 400, 500, 600, and 700 ms were presented in addition to the referent durations. In the 400/1600-ms condition the stimulus duration was 400 ms for S and 1600 for L and during the test phase stimulus durations of 600, 800, 1000, 1200, and 1400 ms were presented in addition to the referents. The flicker conditions were as follows: In the NoFlicker–NoFlicker (NF–NF) condition, filled stimuli were presented in both phases of the bisection task. In the Flicker–NoFlicker (F–NF) condition, flickering stimuli were presented in the training blocks and filled stimuli in the test blocks. Finally, in the NoFlicker–Flicker

Table 1
Experimental design

Group	Duration range (ms)	Stimuli	
		Training	Test
NF–F 200/800	200–800	Filled	Flicker
NF–NF 200/800	200–800	Filled	Filled
F–NF 200/800	200–800	Flicker	Filled
NF–F 400/1600	400–1600	Filled	Flicker
NF–NF 400/1600	400–1600	Filled	Filled
F–NF 400/1600	400–1600	Flicker	Filled

Groups were formed by combining two duration range conditions and three flicker conditions.

condition (NF–F), filled stimuli were presented in the training and flickering stimuli in the test blocks. On flickering stimuli, the blue circle flickered at a frequency of 50 Hz throughout the duration in effect, i.e. flickering stimuli were sequences of a 10 ms blue circle followed by a 10 ms white display. For example, a 200 ms stimulus was marked by 10 blue circle-white sequences.

Training and testing phases were presented as nine sequences of Training and Test blocks. Training blocks consisted of three sequential presentations of the S and the L referent durations (SLSLSL) and participants were instructed only to attend to them. The referents were identified before presentation by a 4 s display (e.g. "THIS IS A SHORT STIMULUS"). Then, a 1 s white screen was introduced and then the duration was presented. After a training block completion, a display indicated that the block was over and participants had to press the spacebar to initiate the Test block. Test blocks consisted of seven test durations (S and L intermixed with five intermediate durations) randomly presented. After the stimulus, the participants responded at their discretion. The participants were instructed to classify each trial stimulus according to their judged similarity to the standard S or the standard L durations. If the duration was judged as short, the participant pressed button 1 on the alphanumeric keyboard. If the duration was judged as long, the participant pressed button 2 on the alphanumeric keyboard. Responses to any other key were recorded as key errors, and the next trial was not presented until the current duration was classified with one of the selected keys. There were no correction trials, since there were not correct or incorrect classifications. One second after the response, the next trial was presented and the sequence continued until all seven test durations were classified. After each Test block completion, a display indicated that S and L would be presented again in a Training block. At the completion of the third and the sixth Test blocks, 10 s resting periods were introduced.

3. Results

Fig. 1 shows the mean proportion of "long" responses plotted against stimulus duration for each group. Inspection of the psychophysical functions suggests that in all groups the proportion of long responses increased with the stimulus duration. However, compared to the NF–NF condition, the psychophysical functions appear to be systematically shifted to the left in the NF–F condition and to the right in the F–NF condition at both the 200/800 and 400/1600-ms duration ranges.

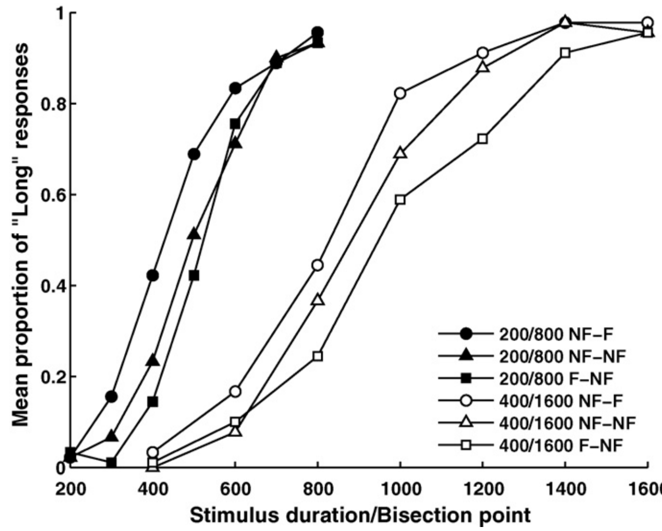

Fig. 1. Proportion of "long" responses plotted against stimulus duration presented separately for the 200/800 and 400/1600 duration ranges (in ms). Data are shown for each range with flicker in the training phase (F–NF); flicker in the test phase (NF–F) and without flicker (NF–NF).

To further evaluate the observed differences between the psychophysical functions, the bisection point was calculated for each subject. The bisection point, or point of subjective equality, is the comparison stimulus value producing 50% of long responses. Two methods were used to calculate the bisection point: least squares (Maricq et al., 1981) and a logistic function (Morrisey et al., 1993). Due to the fact that there were no differences between the values obtained by both, we present and evaluate only the values obtained with the least squares method (Table 2).

To correct the heterogeneity of variance of bisection point distributions, a log transformation was performed. A 2×3 ANOVA on the log transformed bisection points, with duration range and flicker as factors yielded significant effects of duration ($F_{(1,54)} = 274.7$; $p < 0.05$) and flicker ($F_{(2,54)} = 7.3$; $p < 0.05$), but no significant interaction between duration range and flicker ($F_{(2,54)} = 0.1$; $p > 0.05$). To evaluate whether bisection points differed among flicker conditions, specific comparisons were conducted. At both duration ranges, the F–NF bisection points were significantly higher than the ones obtained with the

Table 2
Group bisection points (in ms), group difference limens and group Weber fractions for each group

Group	Bisection point		Difference limen		Weber fraction	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
NF–F 200/800	434	18.75	54	3.31	0.12	0.01
NF–NF 200/800	498	15.86	66	7.47	0.12	0.01
F–NF 200/800	515	11.77	51	3.04	0.10	0.01
NF–F 400/1600	816	42.54	100	6.02	0.13	0.02
NF–NF 400/1600	894	44.24	97	6.87	0.11	0.01
F–NF 400/1600	948	45.69	112	9.23	0.12	0.01

Table 3
Confidence intervals for the bisection points of the NF–NF groups and the respective geometric and arithmetic means (in ms) of the duration ranges used

Group	Limit		Mean	
	Lower	Upper	Geometric	Arithmetic
NF–NF 200/800	462	534	400	500
NF–NF 400/1600	793	993	800	1000

NF–NF and the NF–F conditions ($F_{(1,54)} = 7.53$; $p < 0.05$). Moreover, NF–F bisection points were significantly lower than those obtained with the NF–NF condition ($F_{(1,54)} = 7.07$; $p < 0.05$). In addition, a trend ANOVA comparison was performed on the flicker conditions. A significant linear effect was found ($F_{(1,54)} = 13.74$; $p < 0.05$), but not a quadratic one ($F_{(1,54)} = 0.86$; $p > 0.05$).

Confidence intervals of the bisection points obtained in the NF–NF 200/800 and NF–NF 400/1600 groups were computed so as to evaluate whether the arithmetic or the geometric mean of S and L better represented the data. As Table 3 shows, the arithmetic but not the geometric mean fell within the confidence interval in the NF–NF 200/800 group; while the geometric, but not the arithmetic mean fell within the confidence interval in the NF–NF 400/1600.

To test the scalar property, group functions were superposed. The method to superpose the functions was to plot each group proportion of "long" responses against a duration relative scale, which is obtained by dividing each duration stimuli by the correspondent bisection point of each group. As Fig. 2 shows, group data superposed well.

To obtain temporal sensitivity indicators we calculated the difference limens and Weber fractions with the least squares method. The difference limen is half the difference of the duration giving rise to 75% of "long" responses minus the duration giving rise to 25% of the responses. Weber fraction is calculated by dividing the difference limen by the bisection point. Difference limens and Weber fractions obtained

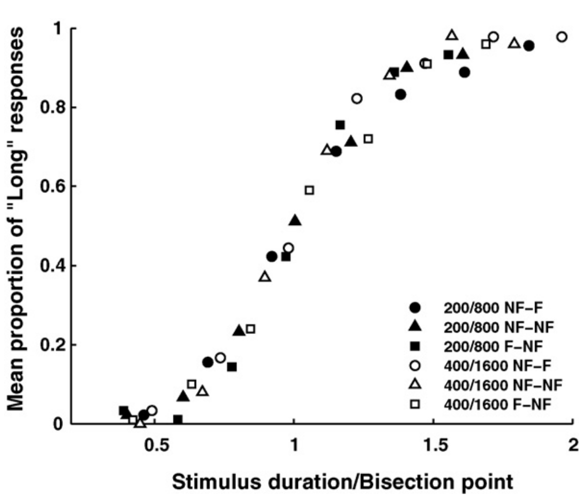

Fig. 2. Proportion of "long" responses, plotted against stimulus duration divided by the appropriate bisection point for the condition (mean least squares bisection points were used).

for each group are presented in Table 2. A 2 × 3 ANOVA on the obtained difference limen values, yielded significant effects of duration range ($F_{(1,54)} = 78.60$; $p < 0.001$), but no effects of flicker ($F_{(2,54)} = 0.32$; $p > 0.05$) nor an interaction effect ($F_{(2,54)} = 0.07$; $p > 0.05$). The corresponding ANOVA on Weber fraction values yielded no significant effects of range ($F_{(1,54)} = 0.27$; $p > 0.05$), flicker ($F_{(2,54)} = 0.001$; $p > 0.05$), nor an interaction one ($F_{(2,54)} = 1.22$; $p > 0.05$).

4. Discussion

The present study explored the effects of the differential presentation of a timed visual flicker on the training or the testing phase in a temporal bisection task. Previous research has shown that a previous flicker or click train during the testing phase displaces the psychophysical bisection function to the left, which is attributed to an assumed increase in the clock speed. A flicker manipulation would be difficult to implement to obtain right displacements because they are supposed to increase the arousal level of the internal clock, not to diminish it. However, we reasoned that, if a visual flicker increases the clock speed, the effects on the psychophysical function would depend on the phase of the bisection task in which they are presented due to the fact that the increased number of pulses would differentially accumulate when learning referent durations than when classifying intermediate durations. Therefore, in one condition of the present experiment flicker was presented only in the testing phase of the task (i.e., when participants classify the intermediate durations as S or L). In this condition, left displacements of the psychophysical function and lower bisection point values were obtained. In addition, we presented a second condition in which the flicker was presented only in the training phase of the task (i.e., when participants learn the referent durations). In this condition, right displacements of the psychophysical function and greater bisection point values were obtained.

This pattern of results agrees and extends previous studies that suggested that the visual flicker increase the rate of pulses emitted by the pacemaker proposed by SET, suggesting a differential effect of the increase of the speed of SET's clock dependent on the memory in which the number of pulses is stored. According to SET, the following processing stages operate in a timing task: the clock process consists of a pacemaker, a switch and an accumulator. Pulses emitted by the pacemaker are gated into the accumulator through the switch when a timing signal is present. Two memories register the clock information: a reference memory and a working memory. Reference memory stores representative values for the pulses accumulated during all the previous relevant trials (reinforced or referents). Working memory is directly loaded from the accumulator and stores the pulses accumulated during the trial just elapsed. In the decision stage a decision whether to respond depends on some sort of comparison between the value in working memory and a sample from reference memory, generally by comparing some function of the difference between these two memory samples with a threshold b.

Therefore, in the present study and according to SET components, when the clock speed is increased on the testing but not in the training phase of the bisection task, the psychophysical function displaces to the left because the number of pulses representing a duration stored in working memory, is larger than the number of pulses obtained with the normal speed of the clock representing the same duration but stored in reference memory. Otherwise, when the clock speed is increased only in the training phase of the bisection task, the psychophysical function displaces to the right, because the number of pulses for the duration stored in reference memory is larger than the number of pulses for the same duration stored in working memory.

These results agree and extend those obtained by Treisman et al. (1990) and Treisman and Brogan (1992) who presented simultaneous auditory clicks or visual flicker stimuli in a verbal time estimation task, and those from Droit-Volet and Wearden (2002) and Wearden et al. (1999) when visual flicker or auditory clicks preceded the standard or the test stimuli presentation. Moreover, because in our study the flicker is the timed stimuli, it rules out completely an assimilation effect that could explain the changes in subjective time when the flicker is presented before the timed stimuli. In addition, the differential effects also suggest that the increases in subjective time estimation are direct effects of flicker, probably at a perceptual level as proposed by Droit-Volet and Wearden (2002).

However, according to SET, there could be other possible explanations for the displacements observed in the present experiment: effects over the latency of the switch or over the memory constant. The latency of the switch is the time the switch takes to close and it is independent of the duration presented. To rule out an effect over the switch, a comparison of the nature of the change obtained in both ranges is done. If the effect were over the latency of the switch closure, an additive shift in bisection points would be expected at both duration ranges because it involves a mechanism that operates before the release of pulses. A proportional change would imply that the flicker increased the number of pulses released, i.e., the clock speed was increased. A significant linear effect, but not a quadratic one, was found for bisection points, which suggests that bisection point shifts were larger for the larger duration range. Furthermore, the data conformed to the scalar property, indicating that the effects in time estimation were proportional to the durations presented (Penney et al., 2000). To distinguish between switch effects over clock effects, the change in bisection points' values in two different duration ranges is generally contrasted. However, to give more support to the proportional change, further investigations should test the nature of this change by contrasting the change in bisection point's values not only in two, but in three duration ranges.

Although the switch/clock effects can be differentiated in the present experiment, its design cannot exclude the possibility that the effects on subjective time were the result of flicker effects on the memory constant, K that transforms the number of pulses in the accumulator to the value stored in memory. In this case, proportional increases in bisection points would also be expected, however this effect would be permanent and produce no rebound effect, because clock speed can be modified on each trial, but the memory constant maintains the remembered durations for the subsequent estimations (Meck, 1983, 1996; Meck et al., 1984). To rule out a memory effect, it is necessary to conduct a within-subject task design in which the participants time both, flicker and filled stimuli within the same session. A memory effect would produce immediate changes in the bisection point and in the psychophysical functions on flicker and on filled trials; otherwise changes would occur only during flicker trials. Indeed, the latter result is obtained in human studies when a participant time flickers (or clicks) and filled stimuli in different blocks within a session (Droit-Volet and Wearden, 2002; Penton-Voak et al., 1996; Wearden et al., 1999). Therefore, although our experimental design cannot rule out a memory effect, the consistency of our data with previous experiments suggests further support to the hypothesis of the increase in the speed of the internal clock.

Another possible explanation for displacements of the psychophysical functions is a change in the rule of the decision processes, mainly in the value of the response threshold b. Previous research indicates that the variables that could change the value of the threshold are: to encourage (or discourage) a specific response from the participants or to increase the difficulty of the decision, which seem to make the participants become stricter in their responses. This has been manipulated experimentally by giving an incentive to increase the appearance of the type of responses (Wearden and Grindrod, 2003), and by making more difficult the comparison between the durations with smaller ranges (Wearden and Ferrara, 1996). The effects of the previous manipulations have been modelled by changing the value of the parameter b (Wearden, 2004). The first variable was kept constant in the present study, so it cannot account for the differences observed. On the other hand, changes in the decision process due to the difficulty of the comparison are reflected in the Weber fraction: Ferrara et al. (1997) reviewed the values of the Weber fraction from different studies and indicated that easy discriminations generate higher values of the fraction, while difficult discriminations generate lower values. In the present study, however, the values of the Weber fraction remained constant throughout the conditions, therefore changes in the decision processes can be ruled out, leaving changes in the clock speed as the most plausible explanation for the displacements of the psychophysical functions.

Other measurements obtained in the present study agree with SET's hypothesis. First, the difference limen increased in the longer duration range groups, indicating that absolute sensitivity decreased with duration. Second, Weber fractions were constant across groups, suggesting that relative timing remained stable. In addition, there were no flicker effects over any of these measures. Altogether, these results indicate that the flicker did not affect neither a participant's absolute or relative temporal sensitivity.

Although bisection measures obtained in the present study support the hypothesis of an increase of the speed of the internal clock and SET's proposals, a question remains with regard to the bisection point location and the relation between subjective and real time (linear or logarithmic) under standard conditions (i.e., without flicker). In animal timing research, this point is located near the geometric mean of the S and L durations (Maricq et al., 1981; Meck, 1983; Meck et al., 1985, 1984; Morrisey et al., 1993), indicating a logarithmic relationship as required by the ratio comparison in the decision stage of SET, but in human timing bisection point location varies between the geometric and the arithmetic means. Several factors have been proposed to affect the bisection point's location, for example, spacing between stimuli (Wearden and Ferrara, 1995), the L/S ratio (Wearden and Ferrara, 1996) or stimulus modality (Grondin et al., 1998; Penney et al., 1998; Wearden et al., 1998). In the present study the obtained values suggest a linear relation in the shorter durations; but a logarithmic one in the larger durations although all the mentioned factors were constant in both ranges; therefore neither of them explains the variations of the location of the bisection points here obtained. Another possibility is the duration values themselves. In general, human timing studies present durations shorter than one second to prevent chronometric counting, because below 1123 ms there is no difference between time estimations with and without simultaneous chronometric counting, but beyond this duration, estimations are more accurate when counting (Grondin et al., 1999, 2004). However, in several studies in which duration ranges less than a second are presented, the bisection points are closer to the arithmetic mean (Allan, 2002; Droit-Volet and Wearden, 2002; Wearden and Ferrara, 1995, 1996), while with duration ranges longer than a second, the bisection points are closer to the geometric mean (Allan and Gibbon, 1991). In addition, on studies where duration ranges shorter and longer to one second were presented, bisection points were located in the middle of both means (Droit-Volet and Wearden, 2002; Allan and Gibbon, 1991). Moreover, two different physiological mechanisms have been suggested to time durations, one for durations shorter than one second and another for durations on the range of several seconds (Hazeltine et al., 1997). These different mechanisms could have contributed to the different locations of the bisection point; closer to the arithmetic mean when in the range shorter than one second and closer to the geometric mean when in the range longer than one second.

In general, the present study supports the hypothesis of an increase on the speed of the internal clock by flickering stimuli and gives some suggestions of how the mechanism of the internal clock works. We suggest that the clock's arousal level can be increased while it runs, so that the clock can be affected by the characteristics of the stimuli that are timed. Therefore, the mechanism of timing is not independent of the environment and it is indeed affected by the physical characteristics of the stimuli it times.

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