Supplementary material

Prior to undertaking Experiment 3 of the paper, we conducted two additional experiments and a reanalysis of old data to investigate the effects of intensity on the internal clock when stimuli are presented against low-intensity backgrounds. These are described here.

Experiment S1: Visual Stimuli

Method

Participants. Forty participants took part. Each was paid £3.

Materials. The stimuli were squares of different luminances shown against a black (c. 0.27 cd/m^2) background. The squares measured 150 x 150 pixels (subtending approximately 3.9 degrees of visual angle) and were displayed on a 19” CRT monitor (1280 x 1024 pixels) with a refresh rate of 85 Hz, viewed from approximately 60 cm. One square was dim (c. 0.58 cd/m^2) and the other was bright (c. 134 cd/m^2); both were clearly visible against the background. The stimuli were shown for 10 different durations similar to those in Wearden et al. (2007): 82, 200, 353, 459, 576, 706, 835, 953, 1071, 1176 ms.

Design and procedure. The procedure was like that for Experiment 3 in the paper. There were 7 blocks of 20 trials; each block comprised one presentation of the dim and bright squares at each of the 10 durations, in a random order. Trials on which the participant failed to enter a response, or entered a response less than 50 ms or greater than 1500 ms, were assumed to indicate typing errors and were discarded (Wearden et al., 1998; 2007). One participant was excluded because more than 10% of trials were discarded; only a handful of trials were excluded from the remaining participants (<1%).

Results

The results are plotted on the left of Figure S1. The top left panel shows the mean judgments for dim and bright stimuli of each duration. Judgments increase with increasing stimulus duration. More importantly, bright stimuli are judged to last longer than dim ones, and this effect becomes more pronounced as stimulus duration increases. These impressions are supported by a 2 x 10 within-subjects ANOVA. There was a main effect of duration, $F(1.7, 65.7) = 246.49$, $p < .001$, $\eta^2_p = .87$, a main effect of brightness, $F(1,38) = 24.98$, $p < .001$, $\eta^2_p = .40$, and an interaction $F(7.0, 267.6) = 8.43$, $p < .001$, $\eta^2_p = .18$.

To probe the effects of stimulus intensity on the slope and intercept, we regressed judged duration on true duration separately for the dim and bright conditions separately for each participant, and used paired-sample *t* tests to compare the coefficients for the two types of stimuli (Wearden et al., 1998; 2007). The mean slope in the bright condition ($M = 0.78$, $SD = 0.25$) was steeper than that in the dim condition ($M = 0.66$, $SD = 0.26$), $t(38) = 6.53$, $p < .001$, $d = 1.05$. However, the average intercept in the bright condition ($M = 57.81$, $SD = 156.63$) was smaller than that from the dim condition ($M = 91.66$, $SD = 154.70$), $t(38) = 4.02$, $p < .001$, $d = 0.64$.

The standard deviations of judgments are shown in the middle of Figure S1. Standard deviations increased with increasing stimulus duration, $F(6.5, 246.2) = 54.37$, $p < .001$, $\eta^2_p = .59$. There was no effect of brightness, $F(1,38) = .87$, $p = .356$, $\eta^2_p = .02$, and no interaction, $F(8.3, 314.0) = 1.83$, $p = .068$, $\eta^2_p = .05$. The bottom of Figure S1 shows the coefficients of variation. The coefficient of variation decreased with increasing stimulus duration (with the exception of the two shortest stimuli), $F(4.2, 159.3) = 7.98$, $p < .001$, $\eta^2_p = .17$, and were higher for dim stimuli than for bright ones, $F(1,38) = 6.53$, $p < .015$, $\eta^2_p = .15$. There was no interaction, $F(5.1, 194.0) = 1.53$, $p = .180$, $\eta^2_p = .04$. These results are consistent with the idea that stimulus intensity influences the pacemaker component of the internal clock.

Experiment S2: Auditory Stimuli

Experiment S2 was very similar to Experiment S1, but with auditory stimuli.

Method

Participants. Twenty nine participants completed the experiment. Each was paid £3.

Stimuli. The stimuli were 500 Hz pure tones presented for 10 durations: 77, 203, 348, 461, 582, 767, 834, 958, 1065, 1183 ms. Two versions of each tone were used, a quiet version (c. 59 dBA) and a loud version (c. 80 dBA). The stimuli were recorded as pre-prepared wav files sampled at 44.1 kHz and were presented diotically over Sennheiser HD265 headphones.

Design and procedure. The procedure was like that for Experiment S1, except that the stimuli were tones. After entering each response there was a pause of 1.25 - 2.25 s before the next stimulus. There were 5 blocks of 20 trials (one presentation of all 10 durations at each of the two intensities, in random order). Data treatment was as for Experiment S1. Two participants were excluded because more than 10% of their judgments were discarded. (Less than 1% of trials were discarded for the remaining 27 participants.)

Results

The results are shown in the right of Figure S1. The top panel shows the mean verbal estimates against the true stimulus durations for the quiet and loud stimuli. Longer tones elicited higher judgments, $F(2.9, 74.4) = 398.85$, $p < .001$, $\eta_p^2 = .94$. Moreover, loud tones elicited higher judgments, $F(1,26) = 20.57$, $p < .001$, $\eta_p^2 = .44$, and this effect depended upon the duration of the tone, $F(9,234) = 3.24$, $p = .001$, $\eta_p^2 = .11$.

As before, we regressed judgment on true duration separately for the loud and quiet tones, and examined the intercept and slope coefficients for each participant. The mean slope was significantly higher for the loud tones ($M = 0.97$, $SD = 0.18$) than for the quiet tones ($M = 0.89$, $SD = 0.20$), $t(26) = 3.75$, $p = .001$, $d = 0.72$. However, the intercept for quiet tones ($M = 164.54$, $SD = 189.41$) did not differ from that for loud tones ($M = 164.55$, $SD = 188.92$), $t(26) = 0.00$, $p = .999$.

The middle panel of Figure S1 shows the judgment standard deviations. Longer stimuli produced more variable judgments, $F(7.2, 186.9) = 14.07$, $p < .001$, $\eta_p^2 = .35$. However, there was no effect of loudness, $F(1,26) = 0.85$, $p = .366$, $\eta_p^2 = .03$, and no interaction, $F(6.5, 167.8) = 0.74$, $p = .629$, $\eta_p^2 = .03$.

The coefficients of variation are shown at the bottom of Figure S1. The coefficients of variation are smaller for longer tones, $F(4.1, 106.9) = 13.45$, $p < .001$, $\eta_p^2 = .34$ (although this does not seem to hold for the two shortest durations), and are larger for quiet tones, $F(1,26) = 6.52$, $p = .017$, $\eta_p^2 = .20$. There was no interaction between duration and loudness, $F(7.2, 188.1) = .50$, $p = .839$, $\eta_p^2 = .02$.

In short, apart from the lack of an effect of loudness on intercept, the results mirrored those found with visual stimuli in Experiment S1. Zelkind (1973) has similarly reported that the effects of tone intensity on perceived time increase as the stimulus duration becomes longer, although he provided very few details of his results.

Intensity of Electrical Stimulation (Ekman et al., 1966)

Most previous studies of the effects of intensity on subjective duration have only used a very narrow range of temporal intervals. An exception is the study of electrical stimulation by Ekman et al. (1966). We reanalyzed their data to test for slope and intercept effects of increased stimulus intensity.

Ekman et al. (1966) tested 15 participants in a magnitude estimation task. Two fingers (from the same hand) were each placed in a cup of sodium chloride solution and an alternating current applied to electrodes in the saline. The sensation threshold was measured separately for each participant and a set of five intensities 1.5 - 3.5 times the threshold was determined. In the main experiment, each intensity was presented for six durations, 180, 330, 560, 850, 1070, and 1720 ms, to give 30 stimuli. A 720-ms presentation of stimulus intensity 2.25 served as a standard and was presented on every trial, followed after an interval of 9 s by one of the 30 test stimuli. Participants were told that the standard stimulus should be denoted “10”, and to assign appropriate numbers to the subjective durations of the comparison stimuli. Each test stimulus was presented four times in random order.

This experiment is therefore different from ours (and, e.g., Wearden et al., 1998) in that the magnitude estimation task involved assigning numbers relative to a specific stimulus standard rather than in milliseconds (which is presumably based on an internal subjective notion of 1 s), and the standard was presented on every trial. Nonetheless, the data are adequate to ask how intensity influenced subjective duration.

We conducted a multiple regression with magnitude estimate as the dependent variable and stimulus duration, stimulus intensity, and the product of duration and intensity as predictors. Overall, the predictors accounted for a large proportion of the variance in magnitude estimates, $F(3,26) = 476.69$, $p < .001$, $R^2 = .98$. The (unstandardized) coefficients revealed a significant positive effect of duration ($\beta = 4.48$, $SE = 1.05$, $p < .001$). More importantly, the coefficient for intensity was significantly above zero ($\beta = 0.80$, $SE = 0.38$, $p = .046$), as was the interaction term ($\beta = 2.25$, $SE = 0.40$, $p < .001$). In other words, increasing stimulus intensity increased both the slope and the intercept of the regression line relating subjective duration to stimulus duration.

Summary and Comments

Pacemaker effects

The results suggest that, across three sensory modalities, stimulus intensity influences the rate of the pacemaker. In every case, the effects of stimulus intensity become more pronounced as duration increased.

Switch effects

The effects on the intercept were mixed: Experiment S2 found no difference in intercept for tones; the data from Ekman et al. show a greater intercept for high intensity electrical stimulations; Experiment S1 found that the intercept was smaller for bright lights than for dim ones, even though the slope was greater for the more intense stimulus, suggesting that the difference between switch opening and closing latencies (i.e., $l_o - l_c$) was greater for the dim stimulus. This last result is surprising, and we suspect that it is spurious: The effect was not replicated in Experiment 3 of the paper, despite the fact that the stimuli and procedure were very similar. It seems likely that the rather abrupt jump in apparent intensity at c. 700 ms (see Figure S1) may have caused the estimate of the intercept for the bright stimuli to undershoot. (The abrupt jump does, of course, raise some questions about the applicability of the regression analysis and the idea that the effects of stimulus intensity become progressively more pronounced as duration lengthens in the way assumed by SET.)

Judgment variability

The results concerning judgment variability match those seen in previous studies: Judgment standard deviations increased with increasing duration, but were not affected by stimulus intensity; coefficients of variation broadly declined with increasing duration, and were smaller for the condition with the slower pacemaker (Wearden et al., 1998; 2007). It is not clear why the effect of intensity on coefficient of variation was not also found in Experiment 3 of the paper, but given the relatively small effect size an explanation in terms of statistical power seems likely.

Wearden et al. (1998) attributed the effects of stimulus modality on coefficient of variation to variability in the operation of the switch component, and this could explain the results of Experiments S1 and S2: The time taken to detect stimulus onset or offset will probably not be any longer for a weak stimulus, but it might be more variable. However, the fact that the absolute variability (standard deviation) of judgments does not differ for low and high intensity stimuli of the same objective duration may argue against this account. A thorough discussion of the interplay between stimulus duration and the means, standard deviations, and coefficients of variation of temporal judgments can be found in Wearden et al. (2007).

References

Ekman, G., Frankenhaeuser, M., Levander, S., & Mellis, I. (1966). The influence of intensity and duration of electrical stimulation on subjective variables. *Scandinavian Journal of Psychology*, *7*, 58-64.

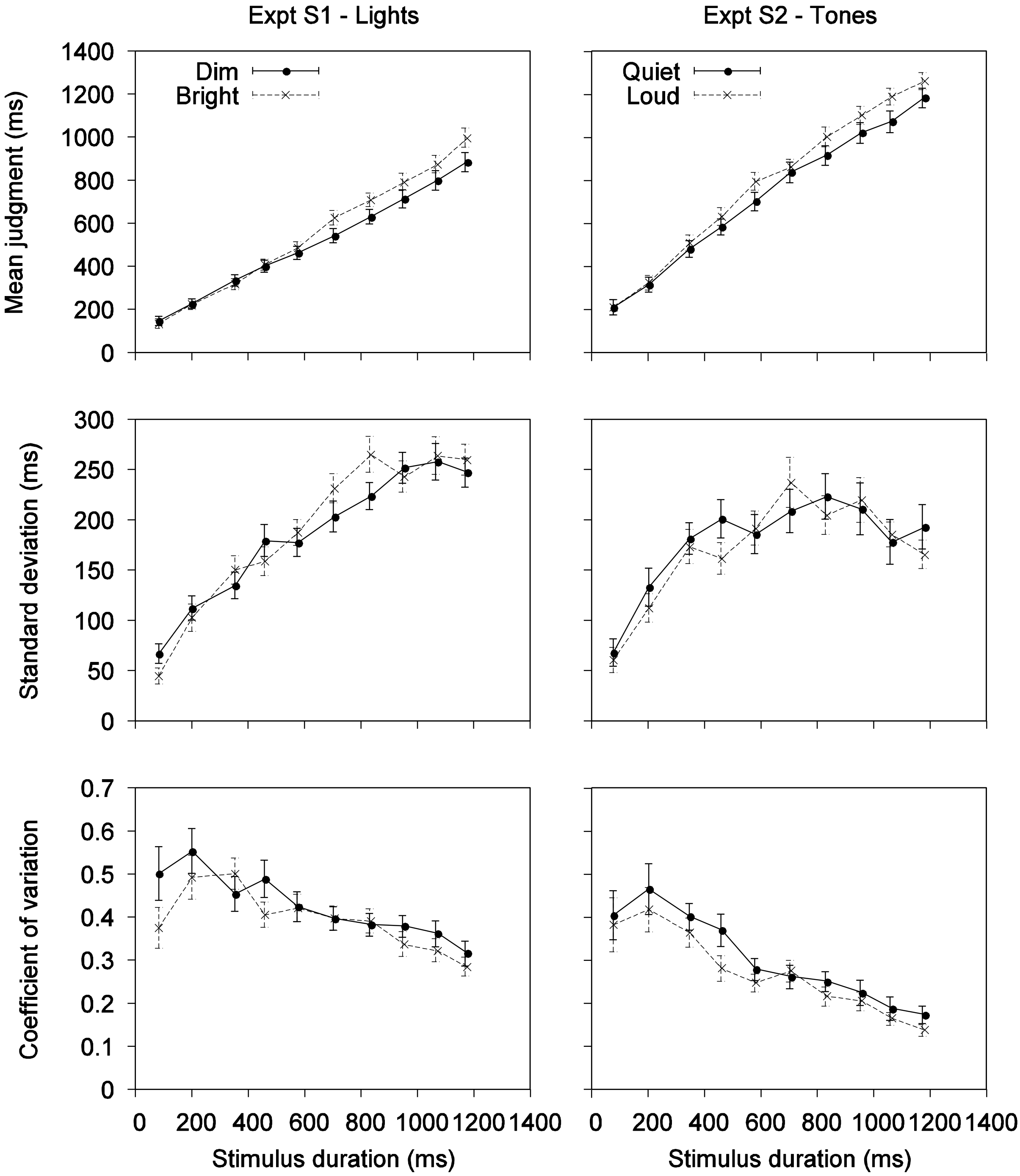
Wearden, J. H., Edwards, H., Fakhri, M., & Percival, A. (1998). Why “sounds are judged longer than lights”: Application of a model of the internal clock in humans. *The Quarterly Journal of Experimental Psychology*, *51B*, 97-120.

Wearden, J. H., Norton, R., Martin, S., & Montford-Bebb, O. (2007). Internal clock processes and the filled-duration illusion. *Journal of Experimental Psychology: Human Perception and Performance*, *33*, 716-729.

Figure Captions

Figure S1. Results for Experiments S1 (left) and S2 (right).

Figure S1.


Expt S1 - Lights
Expt S2 - Tones
Dim
Bright
Quiet
Loud
Mean judgment (ms)
Standard deviation (ms)
Coefficient of variation
Stimulus duration (ms)
Stimulus duration (ms)
0
200
400
600
800
1000
1200
1400
0
50
100
150
200
250
300
0
0.1
0.2
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0.4
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0.6
0.7