Modality Differences in Timing: Testing the Pacemaker Speed Explanation

Emily A. Williams, Andrew J. Stewart & Luke A. Jones | The University of Manchester

Emily.A.Williams@Manchester.ac.uk | @EA_Will | TimeLabManchester.com

Background

The timing of stimulus duration by humans has historically been under-researched compared to other perceptual domains. One reason is that, although humans possess a very sensitive discrimination for duration (as low as 0.01 seconds), there is no sensory organ for time. This forces explanations to draw on hidden processes more heavily than for other sensory systems, such as vision and hearing.

Models often centre around an 'internal clock' (e.g. Scalar Expectancy Theory; Gibbon et al., 1984), which comprises of a pacemaker that emits a certain number of 'ticks' per second. An accumulator counts the number of these ticks, and time judgements are based on the number of ticks accumulated.

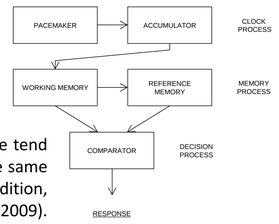
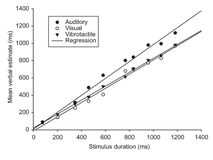


Figure 1. Scalar Expectancy Theory model (Gibbon et al.,1984, p. 54).

However, despite the apparent accuracy of our internal clock, we tend to judge sounds to be longer than lights, even when they are the same duration (Goldstone, Boardman & Lhamon, 1959). In addition, vibrations are judged somewhere between the two (Jones et al., 2009).

'Verbal' Estimates



Difference Thresholds

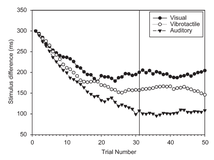


Figure 2. Estimates and thresholds for auditory, visual and tactile stimuli (Jones et al., 2009, p.2179).

This discrepancy between the senses has been found on several tasks, and has been explained by Scalar Expectancy Theory as the pacemaker ticking at a faster rate for sounds, followed by vibrations, and at a slower rate for lights. The current work aims to test this explanation.

Research Questions

1. Do the accuracy of 'verbal' duration estimates correlate with temporal difference thresholds?
2. Can modality differences be alternatively explained by differences in sensory bias?

Experiment 1a: Verbal Estimation

Method: Fifty-two participants estimated durations of 77, 203, 348, 461, 582, 767, 834, 958, 1065, and 1183 ms, presented as auditory, tactile and visual stimuli. Estimates were typed into a keyboard.

Results: Significant main effects of stimulus duration and modality, and a significant interaction. Linear regressions were conducted to extract each participant's slope and intercept values, since Scalar Expectancy Theory argues the slope is a measure of pacemaker speed. (1 participant excluded).

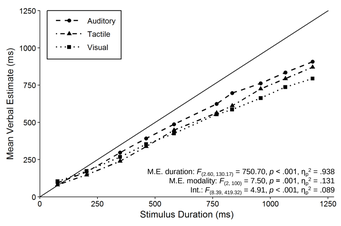


Figure 3. Mean verbal estimates for each modality against stimulus duration.

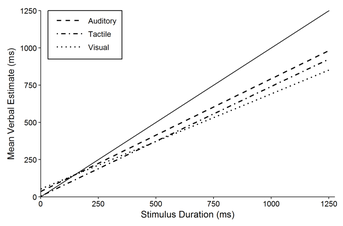


Figure 4. Linear regressions for each modality against stimulus duration.

Significant difference(s) in slopes →
($F_{(2, 100)} = 12.76$, $p < .001$, $\eta_p^2 = .203$)

Post hoc analyses ($\alpha = .017$):
- Visual > Auditory ($p < .001$, $BF_{-0} = 548.740$)
- Visual > Tactile ($p < .001$, $BF_{-0} = 193.124$)
- Tactile ≈ Auditory ($p = .392$, $BF_{0+} = 2.956$)

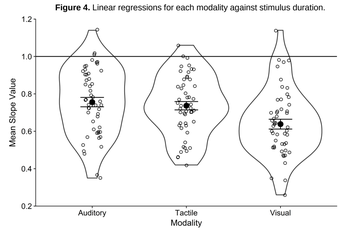


Figure 5. Mean slopes for auditory, tactile and visual estimates. Error bars denote SE.

Experiment 1a (cont.)

Results (cont.):

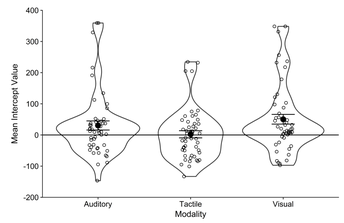


Figure 5. Mean intercepts for auditory, tactile and visual estimates. Error bars denote SE.

← Significant difference(s) in intercepts
($F_{(1.67, 83.30)} = 7.55$, $p = .002$, $\eta_p^2 = .131$)

Post hoc analyses ($\alpha = .017$):
- Tactile < Visual ($p = .001$, $BF_{01} = 0.040$)
- Tactile < Auditory ($p = .004$, $BF_{01} = 0.113$)
- Visual ≈ Auditory ($p = .149$, $BF_{01} = 2.410$)

Conclusion: Participants generally underestimated durations in all modalities, but this effect was greatest for visual stimuli, with estimates relatively higher for tactile and auditory stimuli.

Experiment 1b: Temporal Difference Thresholds

Method: Fifty-two participants were presented with two durations and decided which was longer. One duration (the standard) was always 700 ms, while the other duration (the comparator) changed in a 3-up, 1-down staircase, with a starting duration of 1000 ms. Average of last 20 trials = threshold.

Results: Thresholds for auditory stimuli were significantly lower than for tactile and visual stimuli.

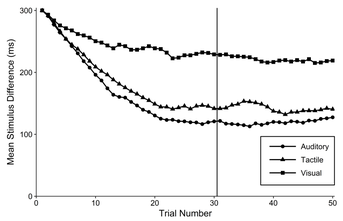


Figure 7. Mean difference between the standard and comparator across the 50 trials.

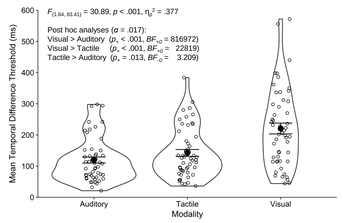


Figure 8. Mean temporal difference thresholds for each modality. Error bars denote SE.

Conclusion: Participants had greater sensitivity to the durations of auditory and tactile stimuli than for visual stimuli. This is the same modality pattern found in slopes from the verbal estimation task.

Research Question 1

Rationale: If estimates and thresholds are both determined by pacemaker speed, we would expect a negative correlation, since a faster pacemaker would lead to higher estimates and lower thresholds.

Results: No significant correlations were found between thresholds and slopes, SSEs or deviations.

Table 1. Correlations between thresholds and (i) slopes, (ii) SSEs of estimates, and (iii) deviations in estimates for 767 ms. N.B.: $\alpha = .017$.

Threshold	Estimation Slope			SSE of Estimates			Estimate of 767 ms Deviations		
	r	p_{-}	BF_{0-}	r	p_{+}	BF_{0+}	r	p_{+}	BF_{0+}
Auditory	-.018	.449	5.218	.167	.119	1.669	.153	.140	1.917
Tactile	-.197	.081	1.221	.252	.036	0.616	.148	.147	1.999
Visual	-.171	.112	1.596	.106	.227	2.859	-.148	.853	11.164

Conclusion: The idea that slopes and thresholds are strongly determined by pacemaker speed is not supported in this instance, as the two measures do not appear to be related.

Experiment 2: Temporal Order Judgements

Rationale: An alternative explanation for the differences between modalities in estimates and thresholds could be sensory bias. This will be measured as the Point of Subjective Simultaneity (PSS) on a cross-modal Temporal Order Judgement task.

Method: Fifty-two participants completed aud-vis, tac-aud and vis-tac order judgements. Stimuli were 15 ms, presented with stimulus onset asynchronies (SOAs) of ± 20, 55, 90, 200 and 400 ms.

Results: No significant bias was found for auditory-visual comparisons, but significant biases were found in favour of auditory stimuli when compared with tactile stimuli (30 ms), and in favour of tactile stimuli when compared with visual stimuli (49 ms).

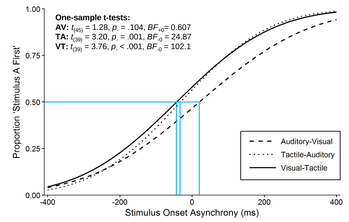


Figure 9. Psychometric functions for each cross-modal comparison in the TOJ task.

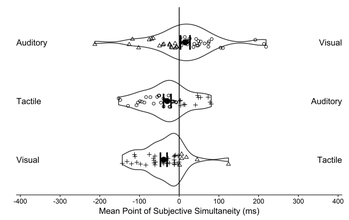


Figure 10. Mean Points of Subjective Simultaneity for each cross-modal comparison.

Conclusion: The large aud-vis bias expected from previous studies was not found. Participants required tactile to lead auditory stimuli, and visual to lead tactile stimuli, to perceive simultaneity.

Research Question 2

Rationale: If the differences between modalities (as measured by estimates and thresholds) could be alternatively explained by sensory bias, there should be positive correlations between PSSs and these differences.

Results: Only one of the six correlations was significant, suggesting little relationship between PSSs and the modality differences in estimation slopes and temporal difference thresholds.

Table 2. Correlations between cross-modal PSSs and differences in (i) slopes, and (ii) thresholds, for each comparison. N.B.: $\alpha = .025$.

Point of Subjective Simultaneity	Difference in Slopes				Difference in Thresholds			
	n	r	p_{+}	BF_{0+}	n	r	p_{-}	BF_{0-}
Auditory-Visual	42	-0.273	.960	13.56	43	-0.241	.940	12.72
Tactile-Auditory	39	-0.019	.547	5.691	39	0.332	.016	0.284
Visual-Tactile	38	0.110	.255	2.719	39	0.240	.070	0.951

Conclusion: Sensory bias, as measured by the Point of Subjective Simultaneity, appears not to be an alternative to the pacemaker speed explanation for modality differences in estimates and thresholds.

Discussion

We generally perceive sounds to be longer than lights, even when the two are of equal duration. Scalar Expectancy Theory explains this as a difference in pacemaker speed, and this assertion was tested in two ways. Firstly, temporal estimates and thresholds were found not to correlate, despite both tasks arguably depending on the pacemaker. Secondly, sensory bias was investigated as an alternative explanation, but was again found not to correlate with modality differences in these tasks.

References

Gibbon, J., Church, R. M., & Meck, W. H. (1984). Scalar timing in memory. *Annals of the New York Academy of sciences*, *423*(1), 52-77.

Goldstone, S., Boardman, W. K., & Lhamon, W. T. (1959). Intersensory comparisons of temporal judgments. *Journal of Experimental Psychology*, *57*(4), 243.

Jones, L. A., Poliakoff, E., & Wells, J. (2009). Good vibrations: Human interval timing in the vibrotactile modality. *The Quarterly Journal of Experimental Psychology*, *62* (11), 2171-2186.

Digital Copies

tinyurl.com/CogSci-EAW