Examining Modality Differences in Timing to Test the Pacemaker Explanation

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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 pulses per second. An accumulator counts the number of these pulses, and time judgements are based on the number of pulses accumulated.

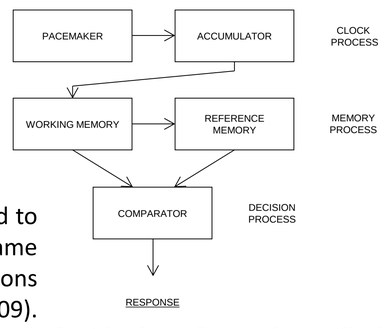
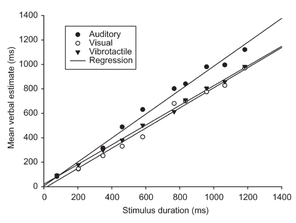


Figure 1. Scalar Expectancy Theory model (Gibbon et al.,1984, p. 54).

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

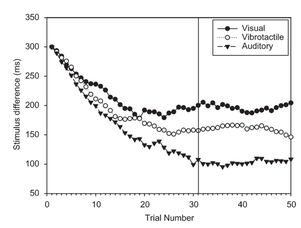


Figure 2. Estimates and thresholds for auditory, visual and tactile stimuli (Jones et al., 2009, p.2179).

This discrepancy between the senses has been explained by Scalar Expectancy Theory as the pacemaker pulsing at a faster rate for sounds, followed by vibrations, and at a slower rate for lights. This explanation has also been applied to the filled-duration illusion, where solid tones are judged as multiplicatively longer than a silent interval delineated by beeps.

Research Aims

1) Closely replicate the threshold and estimation tasks of Jones et al. (2009).
2) Correlate slopes and thresholds within each modality or stimulus type. Both are said to be largely determined by pacemaker speed, so we expect the two tasks to correlate.
3) Investigate intra-individual differences: Is each participant's highest performance in the same condition across tasks? Should be the case for most if largely determined by pacemaker speed.

Experiment 1: Stimulus Modality (Aud, Tac, Vis)

Task A – 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: Estimates for auditory stimuli were significantly and multiplicatively higher than visual stimuli. We regressed estimates against stimulus duration to calculate slope coefficients for each participant. Slopes were significantly lower for visual stimuli than auditory and tactile stimuli. (1 participant excluded).

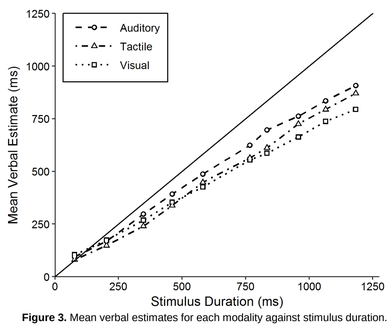


Figure 3. Mean verbal estimates for each modality against stimulus duration.

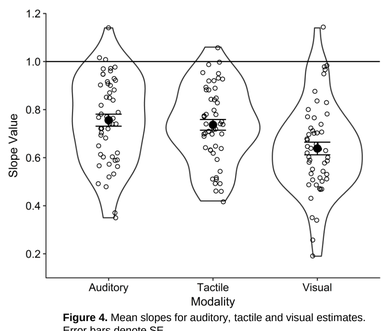


Figure 4. Mean slopes for auditory, tactile and visual estimates. Error bars denote SE.

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.

Task B – Temporal Difference Thresholds

Method: The same 52 participants were presented with two durations and decided which was longer. One duration was always 700 ms, while the other varied according to a 3-up, 1-down staircase, with a starting duration of 1000 ms. Average difference in these two durations over the last 20 trials = threshold.

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

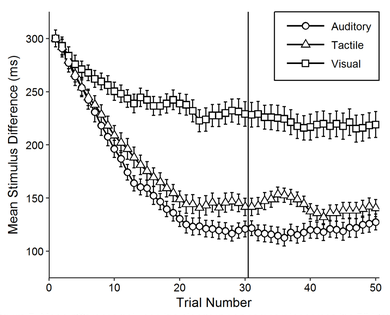


Figure 5. Mean difference between the standard and comparator across the 50 trials.

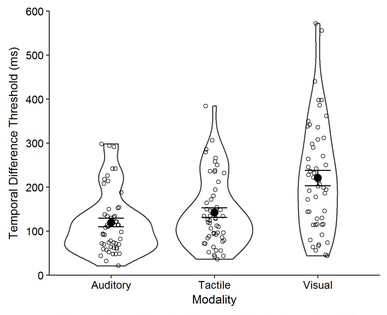


Figure 6. Mean temporal difference thresholds for each modality.

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

Research Aim 2 – Correlations

Results: No significant correlations were found between thresholds and estimation slopes or predicted estimates of 700 ms.

Table 1. Correlations between temporal difference thresholds and (i) estimation slopes, (ii) predicted estimates of 700 ms,. N.B.: α = .025.

Threshold	Estimation Slope				Predicted Estimate of 700 ms			
	n	*r*	*p*	BF_{0-}	*n*	*r*	*p*	BF_{0-}
Auditory	52	-.017	.907	5.26	52	-.077	.590	3.58
Tactile	52	-.207	.142	1.09	52	-.093	.511	3.16
Visual	51	-.237	.094	0.77	51	-.098	.494	3.05

Conclusion: The idea that slopes (or predicted estimates of 700ms) and thresholds are both strongly determined by pacemaker speed is not supported. Perhaps performance on one/both of these tasks is instead determined by other factors (amount of sensory input, memory decay, or the previous response).

Experiment 2: Stimulus Type (Filled & Empty)

Task A – Verbal Estimation

Method: Thirty-two participants completed the same estimation task as Exp 1A using filled (solid tones) and empty (silent interval delineated by beeps) stimuli. No participants had taken part in Experiment 1.

Results: Estimates for filled stimuli were significantly and multiplicatively higher than empty stimuli. Slopes were significantly lower for empty stimuli than filled stimuli. (2 participants excluded).

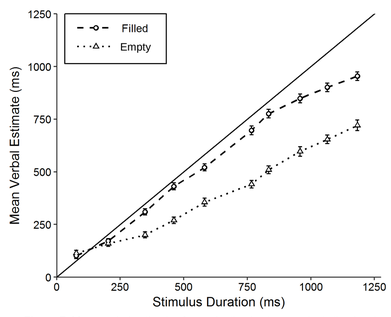


Figure 7. Mean verbal estimates for each stimulus type against stimulus duration.

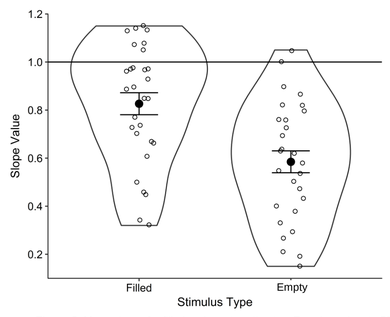


Figure 8. Mean slopes for filled and empty estimates. Error bars denote SE.

Conclusion: Participants generally underestimated durations of both stimulus types, but this effect was greatest for empty stimuli, with estimates relatively higher for filled stimuli.

Task B – Temporal Difference Thresholds

Method: The same 32 participants completed the same threshold task as Exp 1B using filled (solid tones) and empty (silent interval delineated by beeps) stimuli.

Results: Thresholds for filled stimuli were significantly lower than those for empty stimuli. (2 excluded).

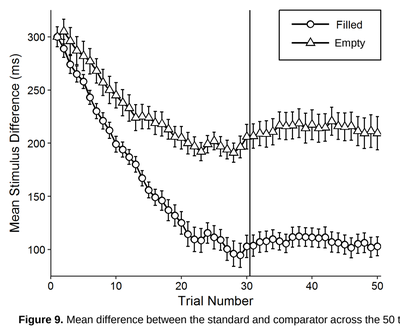


Figure 9. Mean difference between the standard and comparator across the 50 trials.

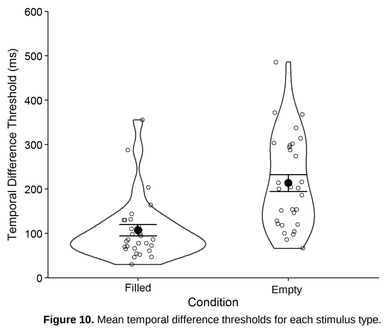


Figure 10. Mean temporal difference thresholds for each stimulus type.

Conclusion: Participants had greater sensitivity to the durations of filled stimuli than for empty stimuli. This is the same stimulus pattern found as verbal estimation slopes.

Research Question 2 – Correlations

Results: No significant correlations were found between thresholds and slopes or predicted estimates of 700 ms for filled stimuli. A significant correlation was found between empty slopes and thresholds.

Table 2. Correlations between temporal difference thresholds and (i) estimation slopes, (ii) predicted estimates of 700 ms. N.B.: α = .025.

Threshold	Estimation Slope				Predicted Estimate of 700 ms			
	n	*r*	*p*	BF_{-0}	*n*	*r*	*p*	BF_{-0}
Filled	31	-.377	.037	3.51	31	-.306	.094	1.62
Empty	29	-.431	.020	6.12	29	-.087	.655	0.34

Conclusion: It appears as though slopes and thresholds are related for empty stimuli but not for filled stimuli. This suggests that participants may rely on the pacemaker more when the task is more difficult.

Research Aim 3 – Intra-Individual Differences

If both tasks are strongly determined by pacemaker speed, the condition which gives rise to the highest speed should be the same in each task. In other words, participants should achieve their best performance in the same condition across tasks. We will also examine intermediate and worst.

Results: A minority of participants achieved their best (or intermediate) slopes and thresholds in the same stimulus modality. However, more than half obtained their worst slopes and thresholds in the same modality. The majority of participants achieved their lowest threshold and steepest slope for filled stimuli.

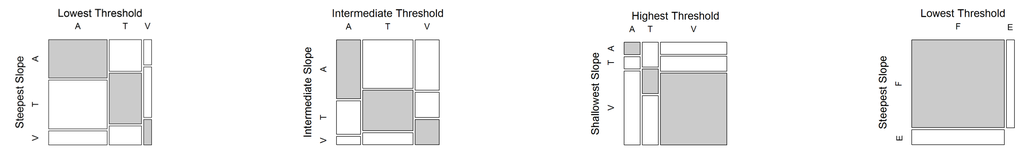


Figure 11. Mosaic plots representing the frequency of each modality or stimulus type for best, intermediate, or worst performance on the two tasks. The area of each tile indicates the number of participants who fall into each of the slope-threshold combinations. Shading represents the tiles where slopes and thresholds lie in the same modality. *Note:* A = Auditory, T = Tactile, V = Visual, F = Filled and E = empty stimuli.

Conclusion: Though the same pattern of performance in stimulus modalities and types may emerge in both tasks, it is not always the case that these patterns pervade for most participants.

Discussion

- Sounds are judged as longer than lights, and filled intervals are judged as longer than empty intervals.
- Scalar Expectancy Theory explains these effects as differences in pacemaker speed, which is said to determine both thresholds and estimation slopes.
- However, slopes and thresholds were found not to correlate for auditory, tactile or visual stimuli.
- Correlations between slopes and thresholds were found for empty but not filled stimuli.
- This suggests that when less sensory information is given, participants may depend more on the pacemaker to complete the tasks. This may be because the task becomes harder with empty stimuli.
- In addition, conditions leading to best performance were not always consistent across tasks.

References

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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.

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