Modality Differences in Timing: Testing the Pacemaker Speed Explanation

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Background: Stimulus Modality & Type

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.

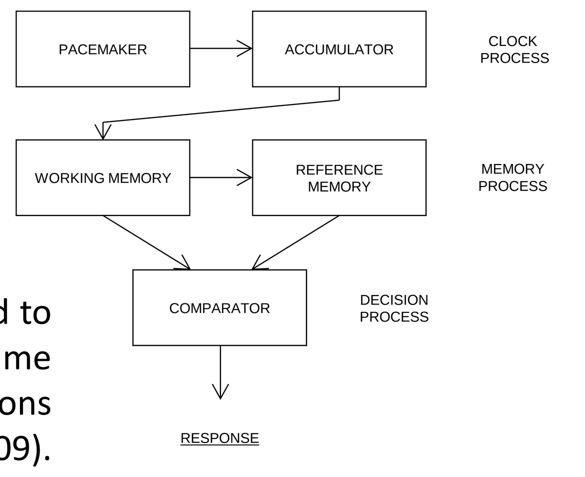

Figure 1. Scalar Expectancy Theory model (Gibbon et al.,1984, p. 54).

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).

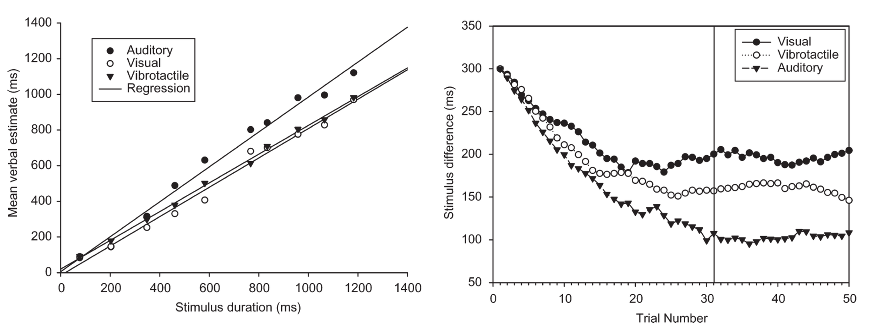

Figure 2. Estimates and thresholds for auditory, visual and tactile stimuli (Jones et al., 2009, p.2179).

This discrepancy between the senses has been explained by Scalar Expectancy Theory as the pacemaker ticking 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-unfilled illusion, where solid tones are judged as multiplicatively longer than a silent interval delineated by beeps.

Research Questions

According to Scalar Expectancy Theory, verbal estimation slopes and temporal difference thresholds are both determined by pacemaker speed. If this is true, we would expect correlations between slopes and thresholds for each:

1. Stimulus Modality: auditory, tactile and visual
2. Stimulus Type: filled and unfilled

In addition, Research Question 3 will investigate how pervasive the differences in timing performance are.

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. Slopes were significantly lower for visual stimuli than auditory and tactile stimuli. SSEs (inaccuracy of estimates) were lowest for auditory stimuli and highest for visual stimuli. (1 participant excluded).

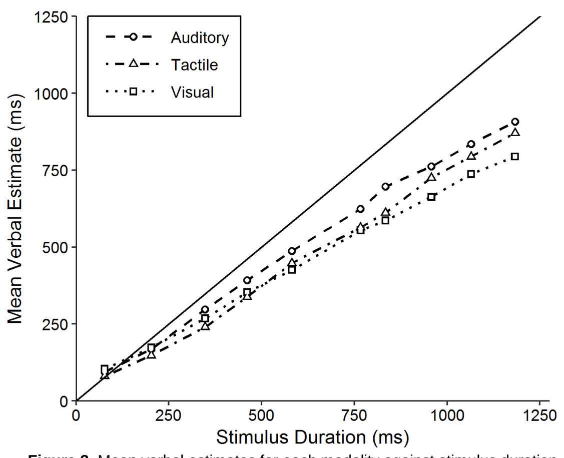

Figure 3. Mean verbal estimates for each modality against stimulus duration.

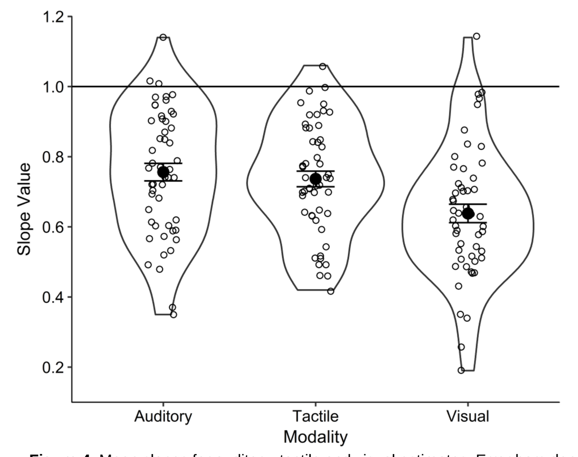

Figure 4. Mean slopes for auditory, tactile and visual estimates. Error bars denote SE.

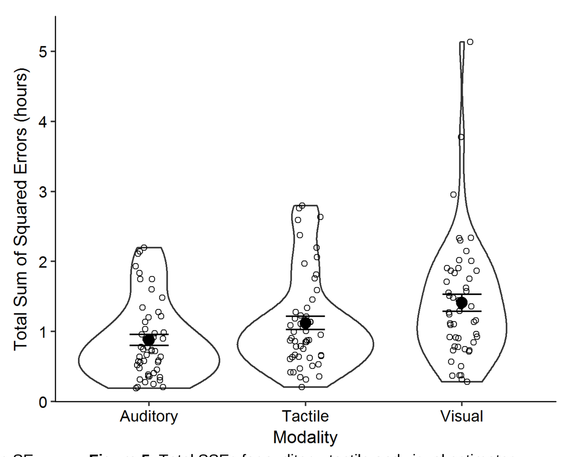

Figure 5. Total SSEs for auditory, tactile and visual estimates.

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 (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 those for tactile and visual stimuli.

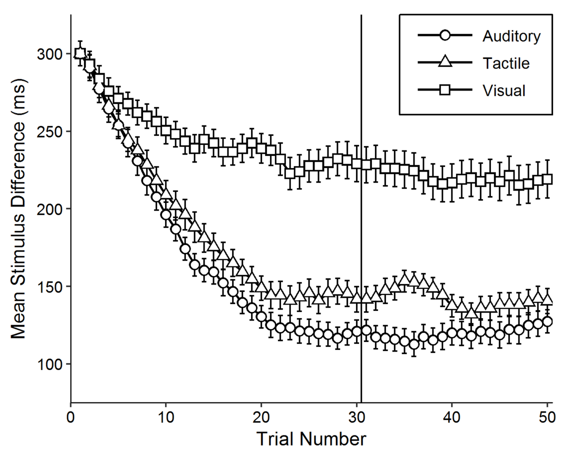

Figure 6. Mean difference between the standard and comparator across the 50 trials.

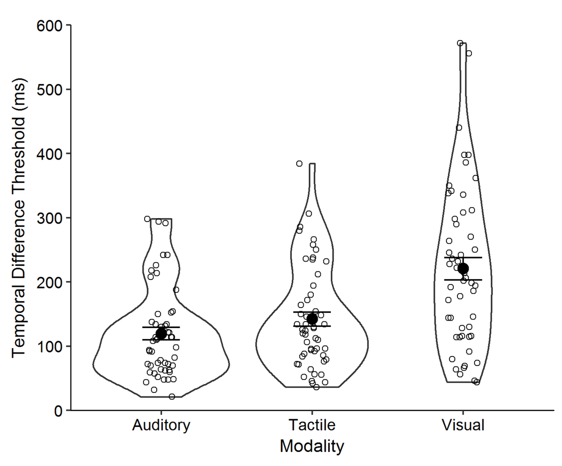

Figure 7. Mean temporal difference thresholds for each modality.

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. The distributions for SSEs and thresholds appear quite similar.

Research Question 1 - Slope, SSE and Threshold Correlations

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

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

Threshold	Estimation Slope				SSE of Estimates			
	n	r	p	BF_{-0}	n	r	p	BF_{+0}
Auditory	52	-.017	.907	5.264	52	.167	.238	1.675
Tactile	52	-.207	.142	1.092	52	.269	.053	0.485
Visual	51	-.237	.094	0.771	51	.171	.229	1.607

Conclusion: The idea that slopes (or SSEs) and thresholds are both strongly determined by pacemaker speed is not supported in this instance. Perhaps performance on one/both of these tasks is instead determined by other factors, e.g. the amount of sensory input, their memory, or the previous response.

Experiment 2: Stimulus Type (Filled & Unfilled)

Task A – Verbal Estimation

Method: Thirty-two participants completed the same estimation task as Exp. 1 using filled (solid tones) and unfilled (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 unfilled stimuli. Slopes were significantly lower for unfilled stimuli than filled stimuli. SSEs (inaccuracy of estimates) were lowest for auditory stimuli and highest for visual stimuli. (2 participants excluded).

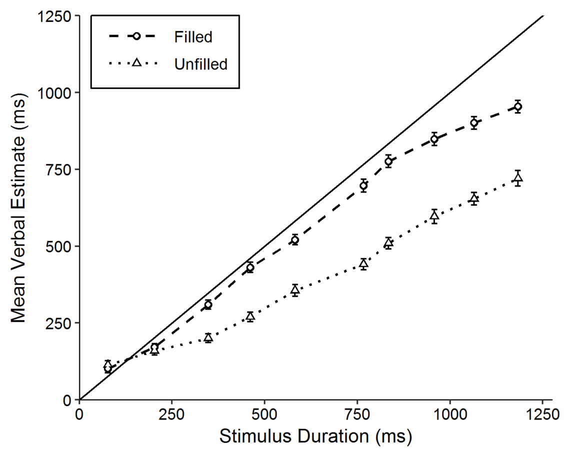

Figure 8. Mean verbal estimates for each stimulus type against stimulus duration.

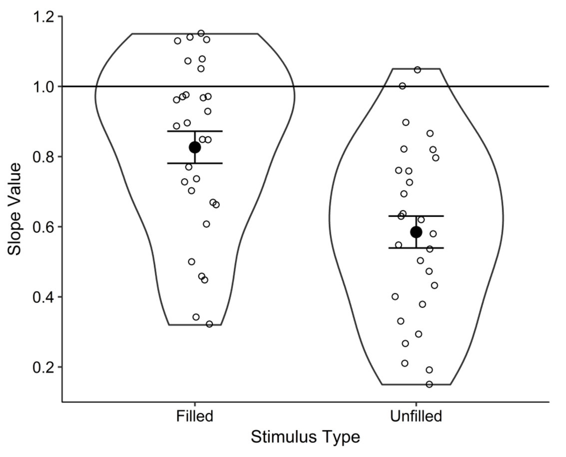

Figure 9. Mean slopes for filled and unfilled estimates. Error bars denote SE.

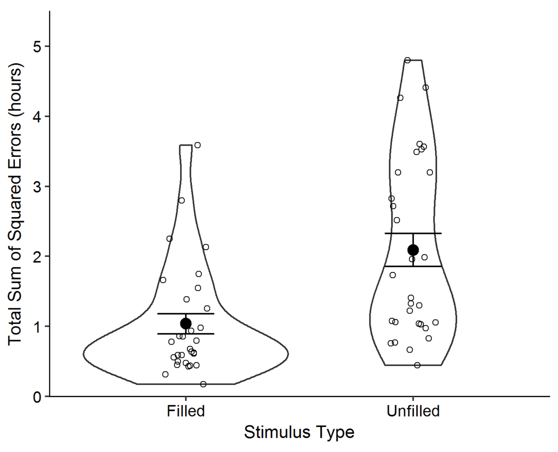

Figure 10. Total SSEs for filled and unfilled estimates.

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

Task B – Temporal Difference Thresholds

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

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

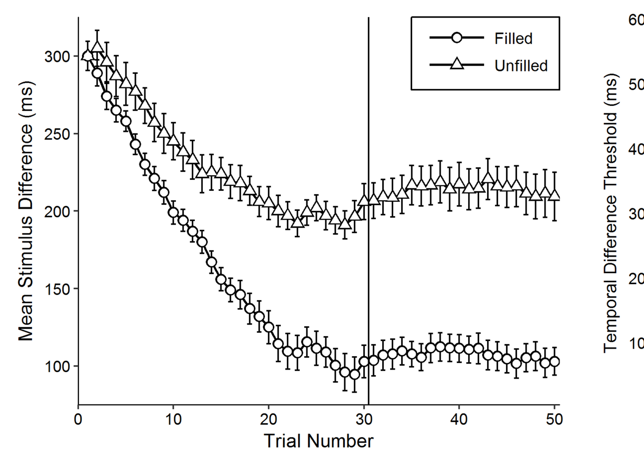

Figure 11. Mean difference between the standard and comparator across the 50 trials.

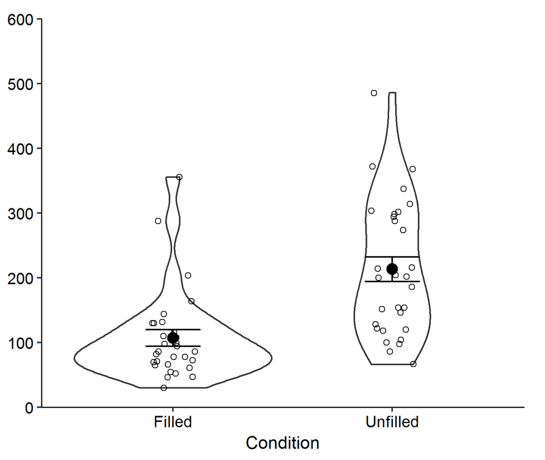

Figure 12. Mean temporal difference thresholds for each stimulus type.

Conclusion: Participants had greater sensitivity to the durations of filled stimuli than for unfilled stimuli. This is the same stimulus pattern found as verbal estimation slopes. The distributions for SSEs and thresholds appear remarkably similar.

Research Question 2 – Slope, SSE and Threshold Correlations

Results: No significant correlations were found between thresholds and slopes, or thresholds and SSEs for filled stimuli. A significant correlation was found between unfilled slopes and thresholds.

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

Threshold	Estimation Slope				SSE of Estimates			
	n	r	p	BF_{-0}	n	r	p	BF_{+0}
Filled	31	-.377	.037	3.512	31	.273	.138	1.182
Unfilled	29	-.431	.020	6.118	29	.407	.028	4.484

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

Research Question 3 – Pervasiveness of Effects (Individual Differences)

If both tasks depend on the pacemaker, participants should obtain their best slopes and thresholds in the same condition. That is, the stimulus modality or stimulus type that their pacemaker runs fastest for, should be the same in each task. We will also examine intermediate and worst slopes and thresholds.

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.

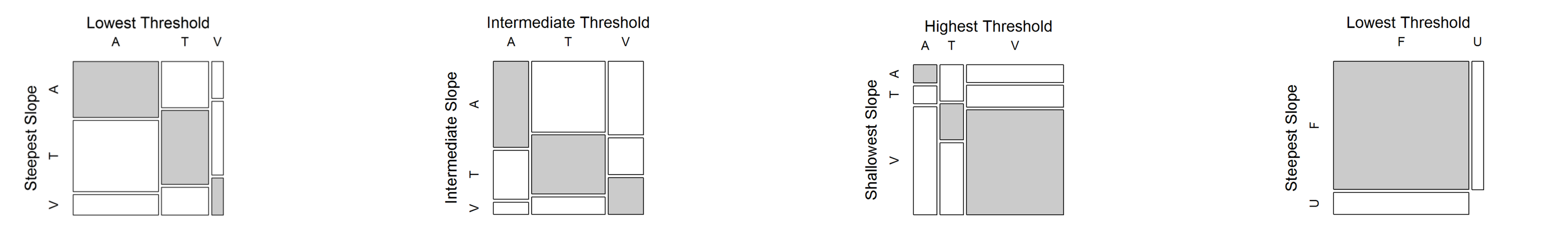

Figure 13. Mosaic plots representing the frequency of each modality or stimulus type for best, intermediate, or worst performance on the two tasks. The area of each tile indicates the number of participants who fall into each of the slope-threshold combinations. Shading represents the tiles where slopes and thresholds lie in the same modality. *Note:* A = Auditory, T = Tactile, V = Visual, F = Filled and U = Unfilled 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

People generally perceive sounds to be longer than lights, even when the two are of equal duration. In addition, we perceive filled intervals to last longer than unfilled intervals. Scalar Expectancy Theory explains these effects as differences in pacemaker speed, which determines thresholds and estimates slopes. However, slopes and thresholds were found not to correlate for filled auditory, tactile or visual stimuli. This suggests that performance for these stimuli does not depend on the pacemaker. Correlations between slopes and thresholds were found for unfilled auditory stimuli, suggesting that when less sensory information is given, participants must depend more on the pacemaker to complete the 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.

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