

# Evaluation of Cognitive Processing in Redundant Audio–Visual Signals

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# Need for Research

## **Growth in need for task efficiency**

- Sensory integration
  - Speed up RTs
  - Increase accuracy

## **Limits of optimality<sup>1</sup>**

- Conflicting cognitive pathways
  - Increase cognitive workload
  - Harm performance

# Brief Overview

## **Hone in on specific sensory integration**

- audio & visual information

**Redundant signals:** Each modality supplies single target, prompting one response

- often result from same cause

**Redundant signals effect:** Faster reaction time with redundant signals than either stimulus alone<sup>2,3</sup>

# Past Research

## Naïve Assumption

- Redundant signals effect means facilitation between perceptual processes

## But...

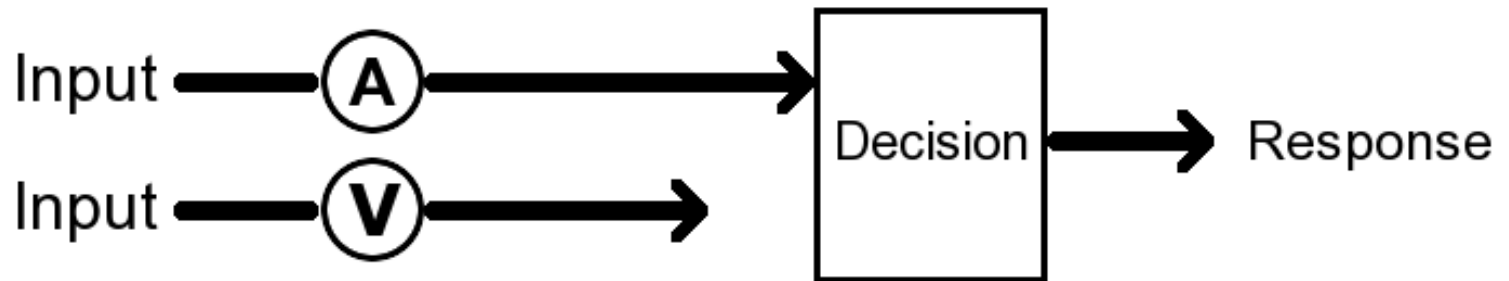
- Raab (1962) demonstrated independent, parallel, race model predicts redundant signals effect

# Possible Explanations

## Possible causes for redundant signals effect:

- **Perceptual facilitation:** Perception of redundant targets is interactive and coactive
- **Statistical facilitation:** Perception of redundant targets is independent and parallel

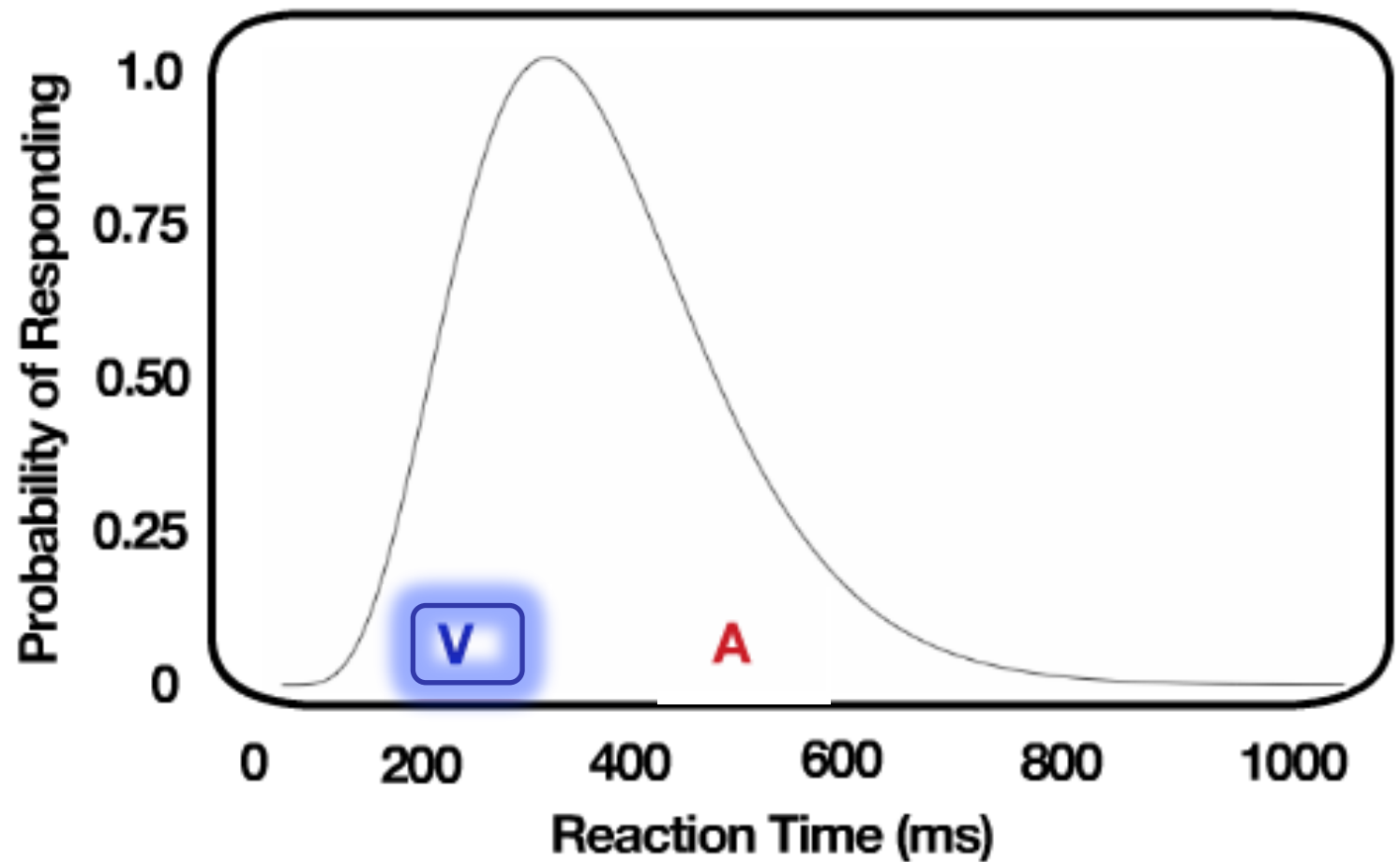
# Race Model

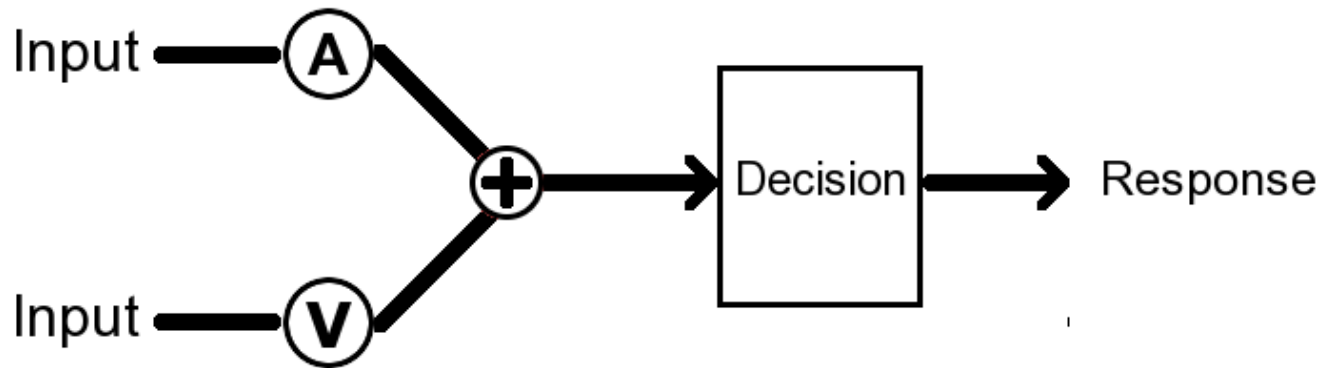


## Assumptions:

- Independent
- Parallel
- First-Terminating

## Statistical Facilitation





**Coactive Model:** Perceptual processes pool information from each modality to make a single decision



# Race Model Inequality (RMI)

**Miller<sup>4</sup> derived:**

$$P(\text{RT} < t | S_A \text{ and } S_V) \leq P(\text{RT} < t | S_A) + P(\text{RT} < t | S_V)$$

- If redundant signal RTs are faster than bound, we reject independent, parallel model and assume coactive cognitive processing
- Analyzes performance as more sources are added
  - Examines question of workload
  - Not directly parallel versus coactive

# Capacity Coefficient

## Determinations:

— Workload capacity & stochastic dependence.

**Limited Workload Capacity ( $C < 1$ ):** Decrease in performance Ratio of: source as number of sources increases.

**Unlimited Workload Capacity ( $C = 1$ ):** Performance of each source and stays consistent with baseline performance as number of sources increases

**Baseline Performance:** Performance total of individual

**Super Workload Capacity ( $C > 1$ ):** Increase in performance in each source as the number of sources increases.

— Assumed that audio and visual stimuli have UCIP design  
 Predicted by coactive processing models

$$C_{OR}(t) = \frac{H_{AV}(t)}{H_A(t) + H_V(t)} \approx 1$$

# Capacity Coefficient cont.

**UCIP model is more constrained than the general class of race models tested by RMI**

- Evidence for unlimited capacity is evidence against violations of the RMI

**Violations of race model inequality imply capacity above 1 (super capacity) for at least some time<sup>6</sup>**

- Therefore, if capacity coefficient is never above one, there is no violation of race model inequality.

# Hypotheses

## Replication of Miller (1982)

1. Will find a violation of race model inequality
  - Response times not attributed from independent race model<sup>4,7</sup>

## Capacity coefficient

2. Will find super workload capacity
  - Reject independent parallel race model

# Methods

**Group 1:** 119 undergraduate students receiving class credit for participation

**Group 2:** 26 students receiving paid compensation

- Used for comparing Miller (1982) analyses to additional SFT measures (for full analysis see Fox, Glavan, Houpt, under review)

	Visual	$\emptyset_{\text{visual}}$
Audio	AV	A $\emptyset$
$\emptyset_{\text{Audio}}$	$\emptyset$ V	$\emptyset\emptyset$

**Audio:** 780 Hz tone

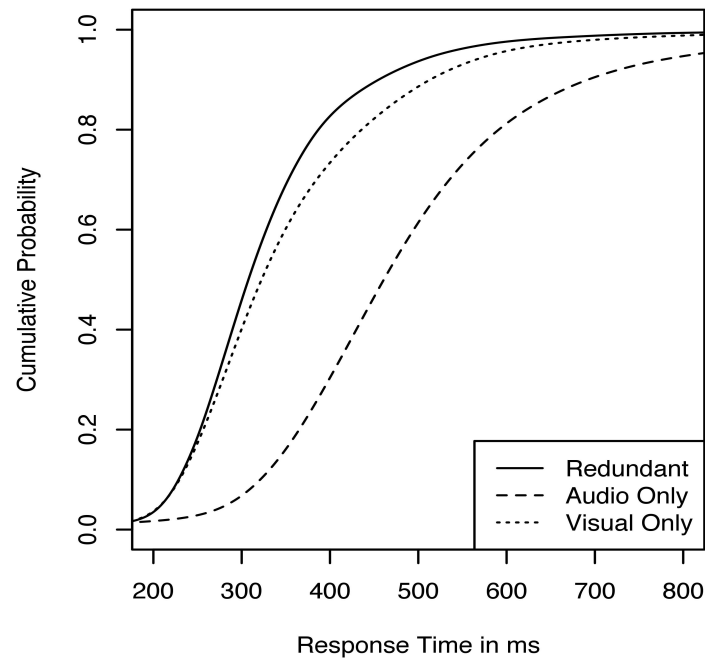
**Visual:** white asterisk (1.85°)

# Results: Group 1

**27 of 119 participants exceeded 90% accuracy**

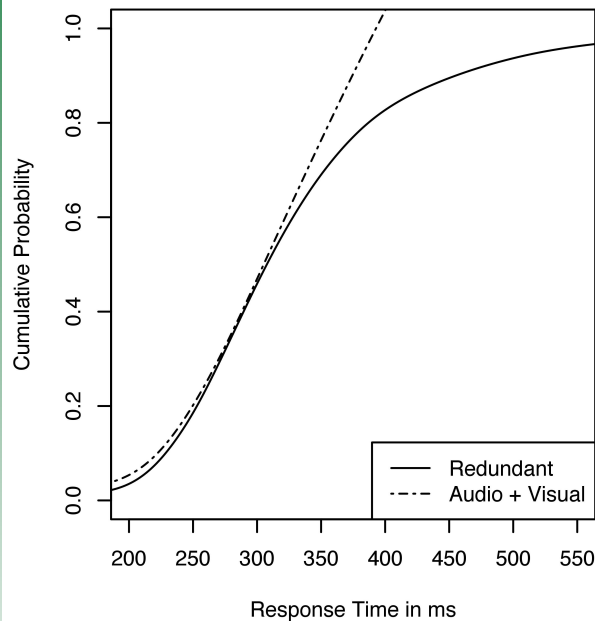
**Decisive evidence of redundant-target advantage:**

- audio-alone (BF =  $1.11 \times 10^{42}$ )
- visual-alone (BF =  $3.92 \times 10^{13}$ )



# Results: Group 1 cont.

**Only marginal evidence of a violation of the race model inequality**



Quantile	<i>t</i>	<i>p</i> -value	<i>BF</i>	Miller (1982)
5%	10.90	1.000	$< 1.0 \times 10^{-16}$	$p = .10$
15%	5.98	0.999	$3.33 \times 10^{-16}$	$p < .05$
25%	3.11	0.994	$1.60 \times 10^{-3}$	$p < .05$
35%	0.15	0.147	0.79	$p < .05$
45%	-0.38	0.088	1.81	$p = .10$
55%	-0.18	0.126	1.31	
65%	1.62	0.749	$6.40 \times 10^{-2}$	
75%	3.59	0.999	$3.28 \times 10^{-4}$	
85%	6.54	1.000	$< 1.0 \times 10^{-16}$	
95%	9.97	1.000	$< 1.0 \times 10^{-16}$	

*Note.  $H_0$ : No violation of race model inequality.*

# Results: Group 1 cont.

## Capacity Coefficient:

- **Super Capacity ( $C > 1$ ):** 5 participants
- **Limited capacity ( $C = 1$ ):** 12 participants
- **Group level:** substantial evidence indicating limited capacity z-score ( $BF = 4.34$ )



# Results: Group 2

**12 of 26 participants exceeded 90% accuracy**

**Decisive evidence of redundant-target advantage:**

- audio-alone (BF =  $2.71 \times 10^{215}$ )
- visual-alone (BF =  $1.17 \times 10^8$ )

Table 3: Sequential t-test of the race model inequality.

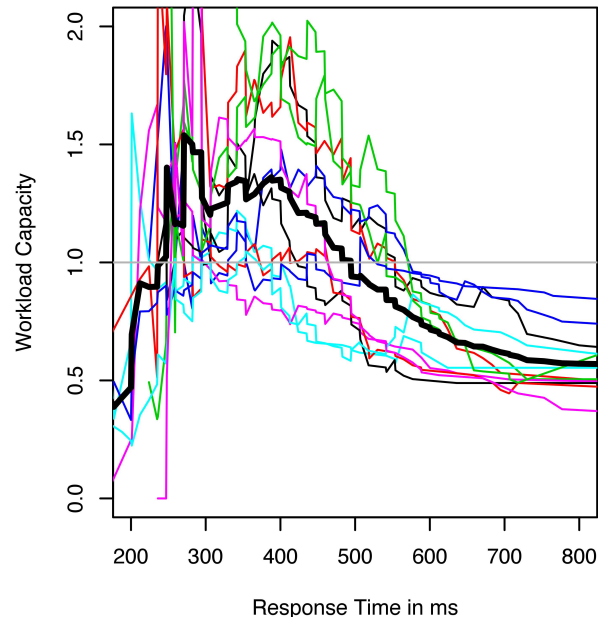
Quantile	<i>t</i>	<i>p</i> -value	<i>BF</i>	Miller (1982)
5%	2.36	0.981	0.04	$p = .10$
15%	0.78	0.775	0.34	$p < .05$
25%	-0.29	0.389	1.48	$p < .05$
35%	-1.70	0.058	10.70	$p < .05$
45%	-1.59	0.070	9.12	$p = .10$
55%	-1.24	0.121	5.49	
65%	-1.06	0.156	4.28	
75%	-0.40	0.350	1.71	
85%	1.29	0.888	0.17	
95%	3.35	0.997	$8.26 \times 10^{-3}$	

*Note.  $H_0$ : No violation of race model inequality.*

# Results: Group 2 cont.

## Capacity Coefficient:

- **Super Capacity ( $C > 1$ ):** 3 participants
- **Limited capacity ( $C = 1$ ):** 1 participants
- **Group level:** slight evidence indicating limited capacity  
z-score ( $BF = 2.27$ )



# Conclusions

## **No violation of the race model inequality**

- Difficult to examine individual influence in group level analysis

## **Biased toward responding**

- Both group indicate lower false alarm rates and higher miss rates than Miller (1982)

## **Cognitive processing with audio-visual stimuli vary across individuals**

- Evidence indicating a limited capacity at the group level
- researchers should be wary of conclusions about cognitive workload based solely on group analysis