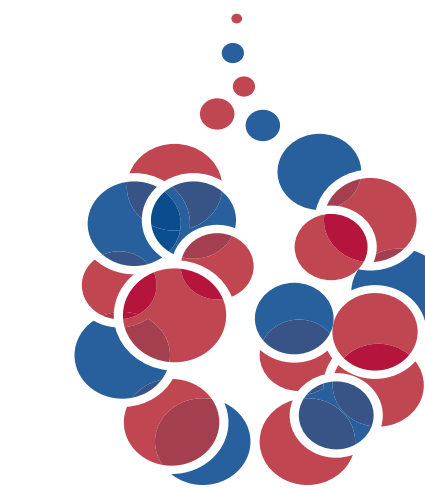


Revealing Visual Statistical Learning with Implicit Measures



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Visual statistical learning (VSL):

an unconscious process by which observers extract the co-occurrences between visual stimuli in continuous environments, based solely on transitional probabilities between items.

This phenomenon can occur:

- for both spatial and temporal regularities (Fiser & Aslin, 2001)
- during an orthogonal task (Turk-Browne, Junge, & Scholl, 2005)
- despite interleaved noise (Junge, Turk-Browne, & Scholl, 2005)

Is VSL modulated by selective attention?

Does it require top-down attention to select the relevant population of stimuli, or does VSL occur automatically as a product of mere exposure?

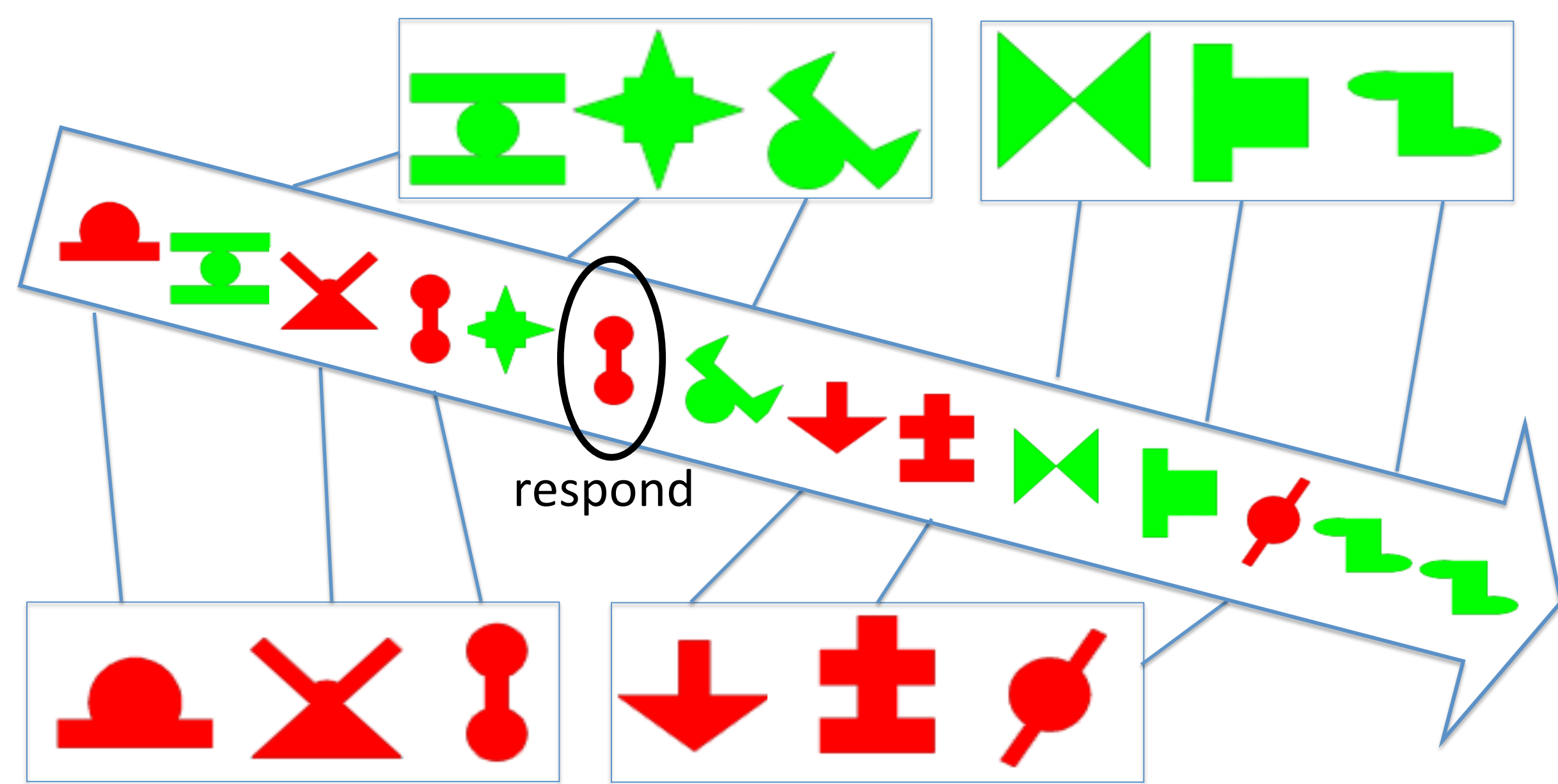
Methods

Stimuli

One red and one green shape set, each with 12 unique shapes. Each shape set was further divided into four "triplets," a trio of shapes.

Temporal Sequences

- Within shape sets, each triplet repeated 24 times. The triplets were then randomly intermixed, but their within-triplet order was always maintained.
- Repetitions of the first and third shapes in a triplet were randomly inserted sequences, to allow for cover task
- The two shape sets were then randomly interleaved into a single long shape stream for temporally-segmented stimulus presentation.



Familiarization Procedure

- Observer randomly assigned either red or green shape set as attended stimulus stream
- Observers were unaware of the underlying sequence structures
- Shapes presented individually for 800ms with a 200ms ISI
- 1-back WM task: respond to shape repetitions

Observers were instructed to only respond to repetitions for shapes in their assigned stimulus set, and to ignore the shapes from the other color stream.

Implicit Test Procedure

- All shapes presented in black; 200ms display and 200ms ISI
- The 24 shapes each served as a "target" shape four times, for 96 total trials
- Trial sequence consisted of the four triplets from the target shape's original shape set. There were 24 shapes per trial: each triplet was presented twice; triplets were randomly intermixed
- RSVP shape detection task: target shape shown, then the trial sequence was rapidly displayed; observer responded as soon as they detected the trial's target shape

VSL would result in speeded responses for detecting target shapes from the third triplet position in particular, since these appearances could be primed by the two shapes that consistently precede them in the triplet sequence.

Does learning occur for both shape sets?

Data analysis

- Trials split according to target shape's original color assignment
- Within shape set: split by target shape's intratriplet position
- Yields a 2 (color stream: attended vs. unattended) x 3 (intratriplet item position: first, second, or third) design

References

- Fiser, J. Z., & Aslin, R. N. (2001). Unsupervised statistical learning of higher-order spatial structures from visual scenes. *Psychological Science*, 12, 499-504.
- Junge, J. A., Turk-Browne, N. B., & Scholl, B. J. (2005). Visual statistical learning through intervening noise. *Journal of Vision*, 5(8), 421.
- Turk-Browne, N.B., Junge, J. A., & Scholl, B.J. (2005). The automaticity of visual statistical learning. *Journal of Experimental Psychology: General*, 134(4), 552-564.

Acknowledgments

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Experiment 1: Turk-Browne et al. (2005)

Familiarization performance

94% repetition detection accuracy for assigned color set ($SD = 6.3\%$)

Implicit test performance:

- Main effect of intratriplet position: $F(2,80) = 8.9, p = 0.02$.
- No main effect of stream, $F(1,25) < 1$; no interaction, $F(2,50) < 1$
- For both shape streams: third position shape RTs were significantly faster than for first position shapes (*within-stream, position 1 RT versus position 3 RT paired t-tests listed above graphs*)

Observers did not exclusively extract the structure of the selected population— they learned the co-occurrences of the irrelevant stimuli as well.

Experiment 2: Shape insertion task

The working memory load of the 1-back task of the task may have inordinately heightened the salience and task-relevance of shape identity, resulting in VSL even for the unattended stream.

Same stimuli and sequences, but a new orthogonal task during familiarization to reduce the WM load and attention on shape identity

- All previous shape repetitions replaced by insertions of a 25th shape
- This shape appeared in both color sets and was shown to observer before the task starts
- Task: Observers were instructed to respond whenever the 25th shape appeared in their assigned stimulus set

Implicit test performance:

- Main effect of intratriplet position: $F(2,24) = 24.0, p = 1.9e-06$
- Main effect of stream: $F(1,12) = 9.11, p = 0.01$; no interaction
- Faster RTs for third position unattended (466ms) than third position attended (485 ms): $t(12) = 2.95, p = 0.01$

Experiment 3: Weaker co-occurrence statistics

Although observers seem to learn regularities for the irrelevant stimuli, is this knowledge more sensitive to decreases in the strength of the statistical co-occurrences?

Identical to Experiment 1, but prior to interleaving and added repetitions, $P(\text{shape2}|\text{shape1})$ & $P(\text{shape3}|\text{shape2})$ reduced from 100% to 75%

Implicit test performance:

- Main effect of intratriplet position: $F(2,48) = 11.2, p = 0.02$
- No main effect of stream, $F(1,24) < 1$; no interaction

Experiment 4: Explicit test of learning

Are these consistent effects a consequence of a more sensitive, implicit testing measure?

Familiarization procedure identical to Experiment 1, but followed by an explicit, two-interval forced-choice task instead

Explicit Test Procedure (Turk-Browne et al., 2005)

- Observers viewed two triplet sequences per trial
- Each shape appeared for 800ms with a 200ms ISI, with a 1000ms pause between the two triplets.
- One triplet was the "true" triplet from the familiarization sequence; the other was a "foil" triplet made from shapes from the same original shape set as the true triplet
- Task: identify which three-shape sequence seemed more familiar, based on the familiarization sequences
- Unspeeded responses; no feedback given

Explicit task performance:

- Learning metric: accuracy for discriminating between true triplets and from their foils
- Calculated separately for each color stream
- For each stream, a single-sample t-test versus 50% (chance) yielded significant accuracy.
- No performance difference between streams, $t(23) < 2$.

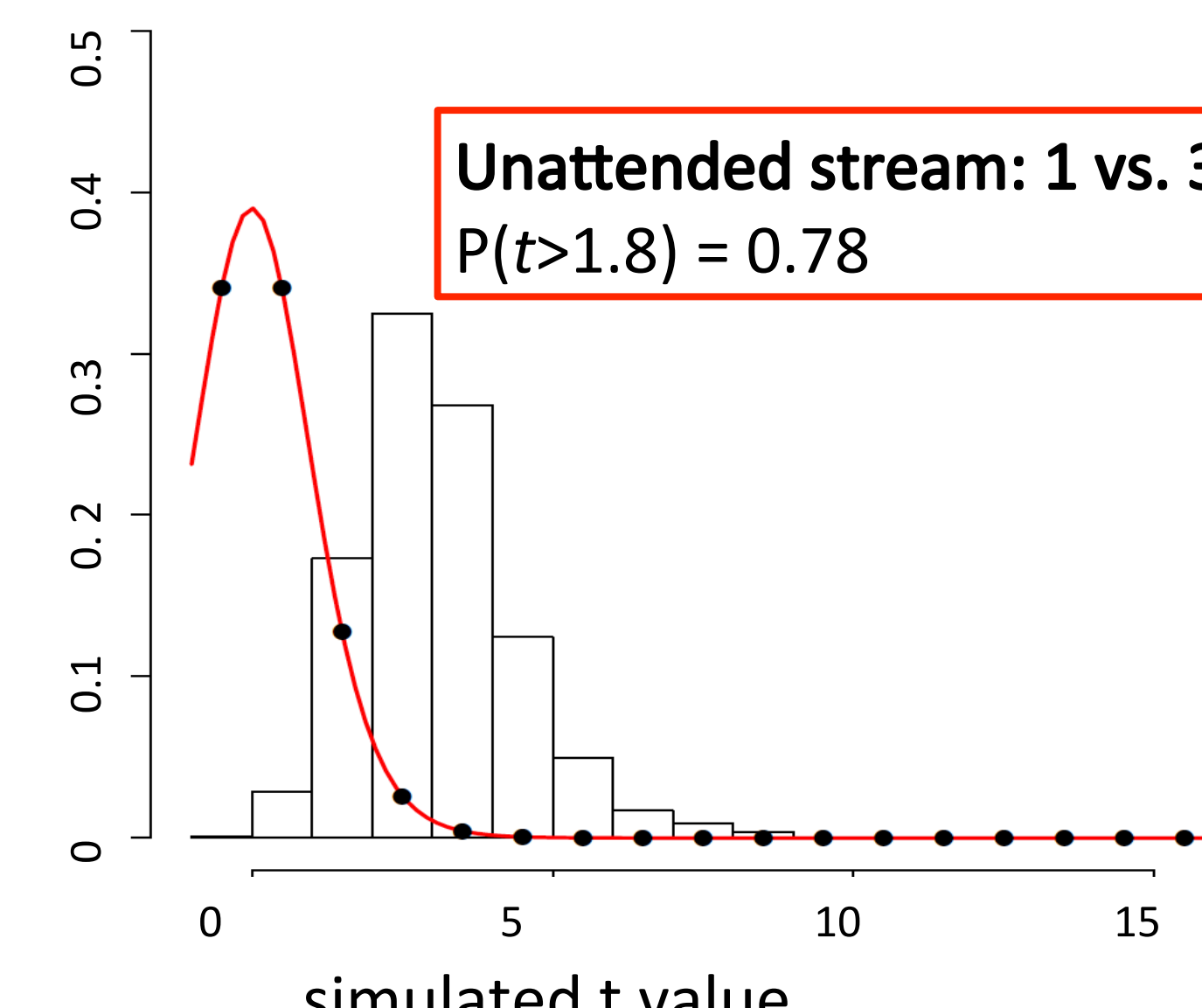
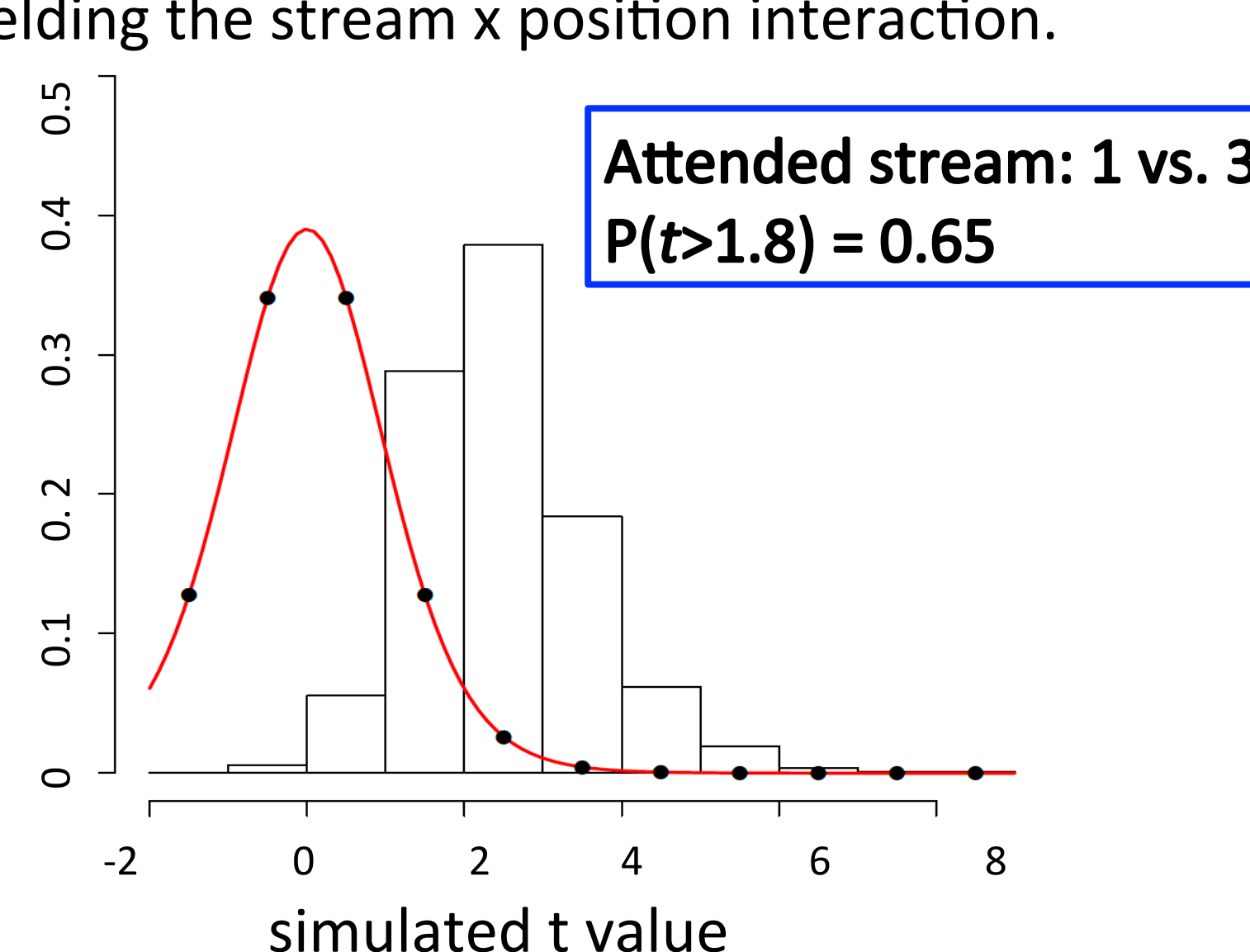
✧ VSL occurs for **both** stimulus streams, not just the attended population set. The learning effects for each stream are small but nearly equivalent in size, and are apparent regardless of testing modality.

✧ This robust form of unconscious visual processing might be more strongly modulated by bottom-up attention than by top-down selection.

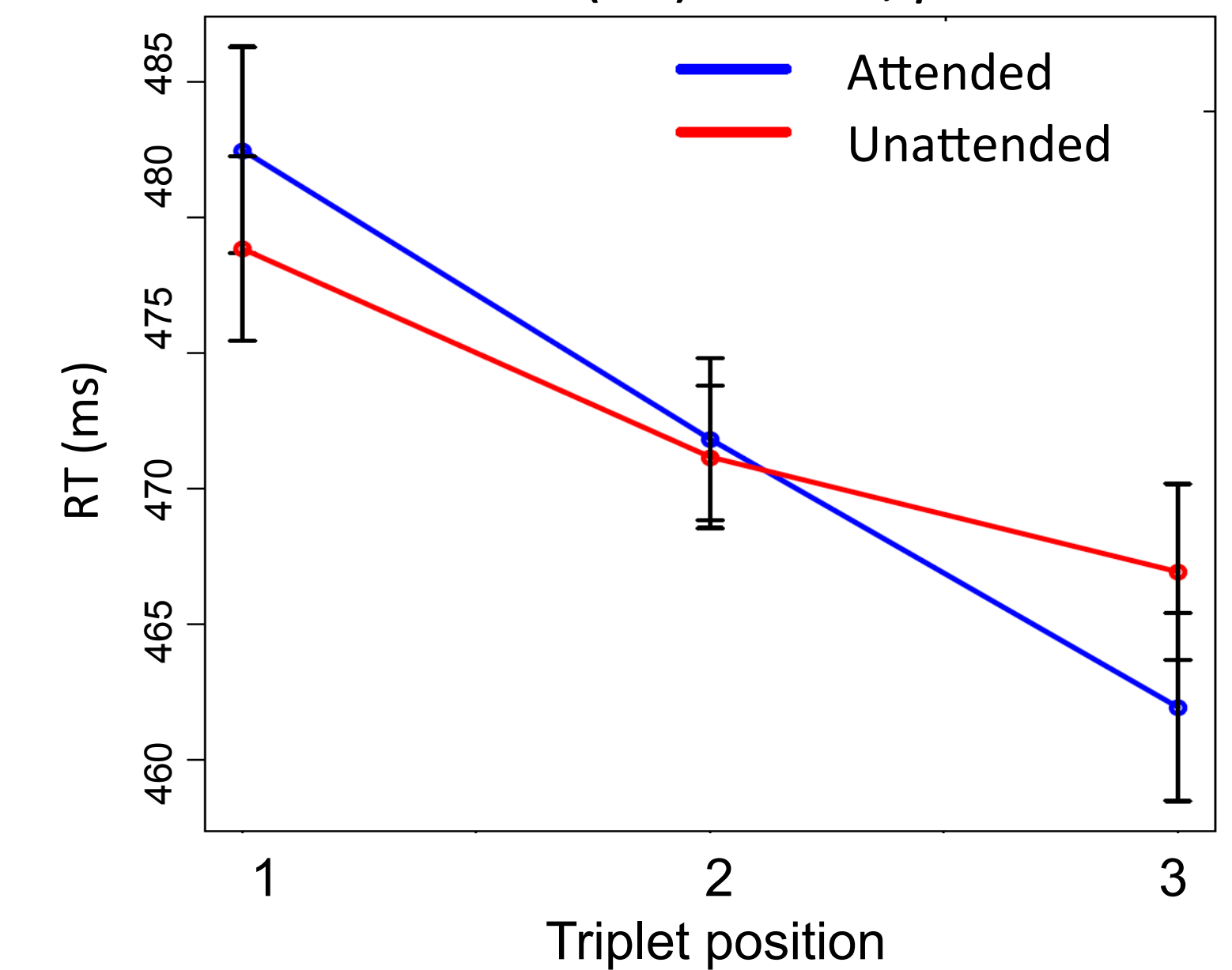
Aggregating results across tasks: simulated statistical results, sampling $n = 12$ from $n = 136$

- 2000 simulations randomly sampled from combined data sets, sample size matched to Experiment 3 in Turk-Browne et al. (2005)
- Histograms depict frequency of simulated result, measured by the likelihood that the sample yields the test value required for $p = 0.05$
- Red lines depict null distribution

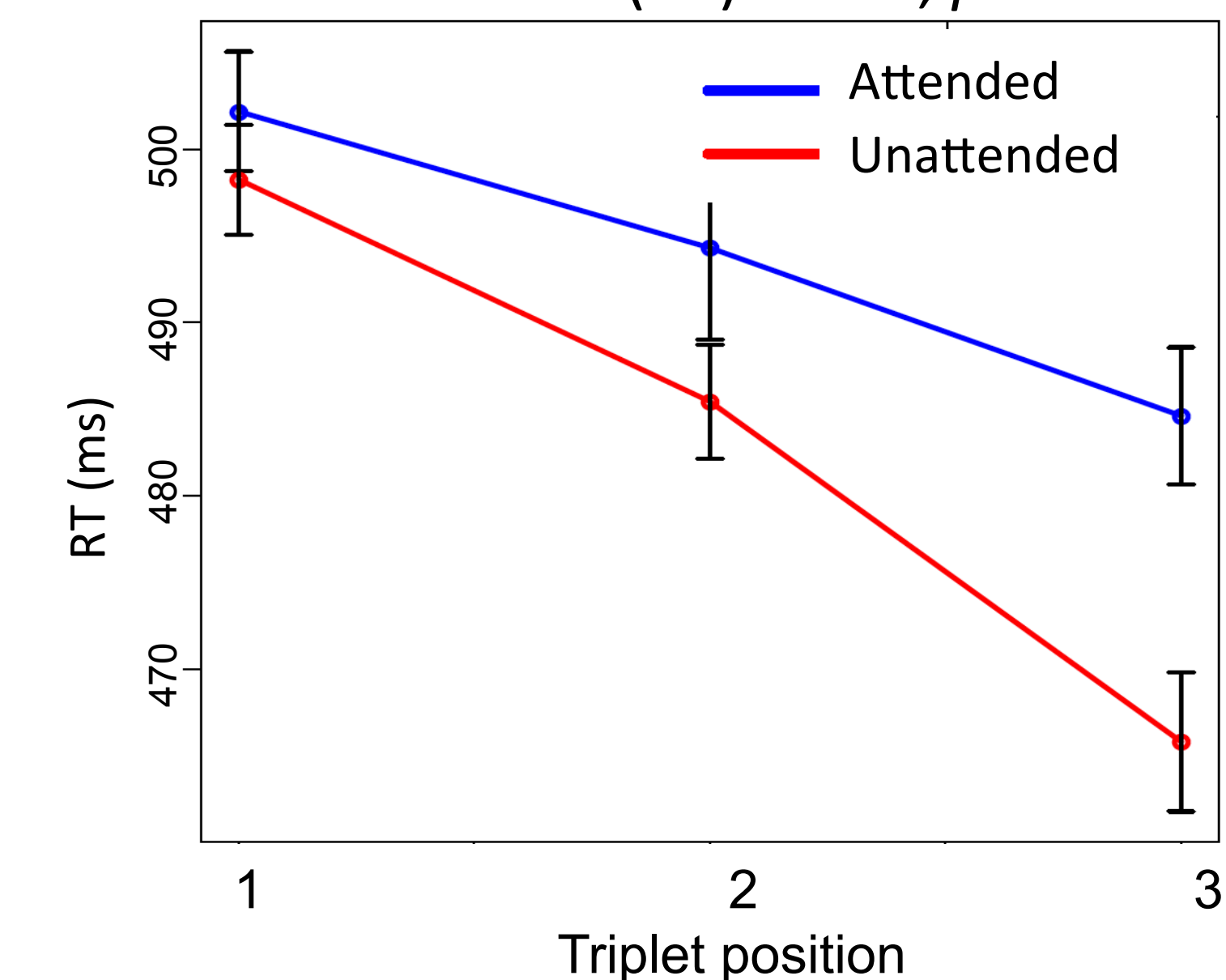
- Regardless of which data comprise the randomly selected sample, results are highly likely to indicate learning for both stimulus streams, and at chance for yielding the stream x position interaction.



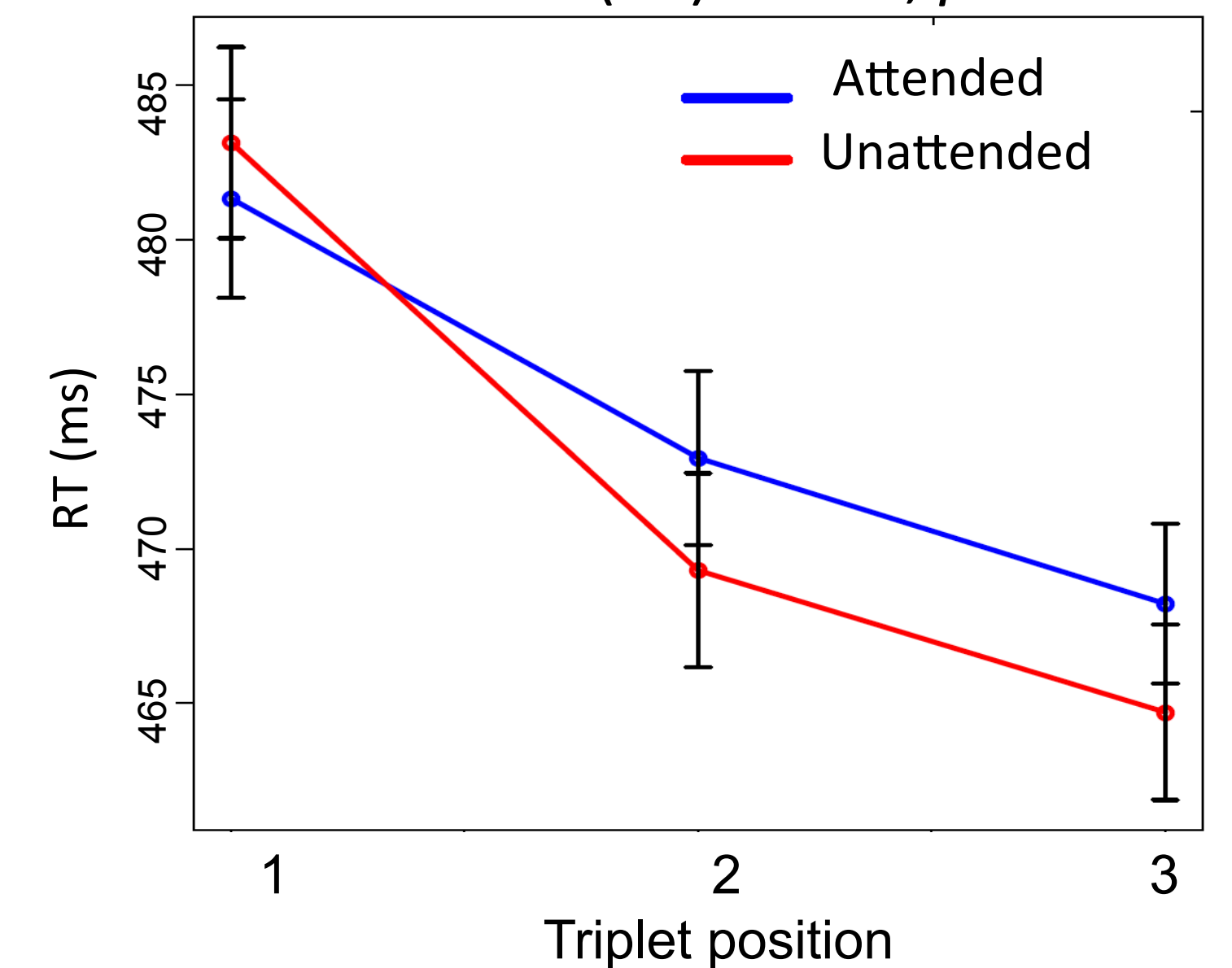
Attended: $t(25) = 3.34, p = 0.003$
Unattended: $t(25) = 2.27, p = 0.03$



Attended: $t(12) = 3.47, p = 0.005$
Unattended: $t(12) = 5.92, p = 0$



Attended: $t(24) = 1.76, p = 0.09$
Unattended: $t(24) = 2.87, p = 0.01$



Attended: $t(23) = 3.03, p = 0.01$
Unattended: $t(23) = 2.1, p = 0.05$

