Components of visual prior entry

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Introduction

The theory of prior entry states that attention accelerates sensory processing, thereby reducing the time necessary for a stimulus to be perceived. Previous experiments have employed methodologies insufficient to distinguish prior entry from other mechanisms that could also cause the effects. The purpose of this series of experiments is to determine the contributions from the action of attention upon sensory mechanisms relative to those upon cognitive mechanisms such as criterion shifts and response biases, as well as non-attentional sensory facilitation produced by the attentional cues.

Methods

In each experiment, two targets one red and one green, were presented at a fixed eccentricity from a fixation point, with a variable stimulus onset asynchrony (SOA) between them. The task of the observer was to determine, in separate sessions, either which target appeared first (temporal order judgment, TOJ), or whether the two targets appeared simultaneously or not (simultaneity judgment, SJ). Attention was directed to one of the two targets by a different type of attentional cue in each experiment.

Decision models

The behavioral responses were modeled based variations of the models in Sternberg and Knoll (in Attention & Performance IV, 1973). The decision about the order or simultaneity of the two targets is assumed to be based only upon the difference of arrival times between the stimuli at a central mechanism. The arrival times are delayed and dispersed by neural transmission relative to the stimuli onset times. All of the models include a parameter α that specifies the amount by which attention speeds up the transmission of the attended stimulus relative to the unattended stimulus,and a parameter σ that specifies the standard deviation of the distribution of the difference in arrival times.

<u>Simultaneity judgment</u>: There are two main theories. In the *triggered-moment model*, two stimuli are judged simultaneous if they arrive at the central decision mechanism within criterion time τ. The probability of responding that the targets were simultaneous is $\Phi(\tau, \Delta t+\alpha, \sigma) - \Phi(-\tau, \Delta t+\alpha, \sigma)$, where Φ is the cumulative normal function and Δt are the SOAs between the targets. In the *perceptual-moment model*, there are discrete moments of perceptual time that are not necessarily aligned with the stimuli, and the two targets are judged simultaneous if they happen to both arrive within the same moment of time.

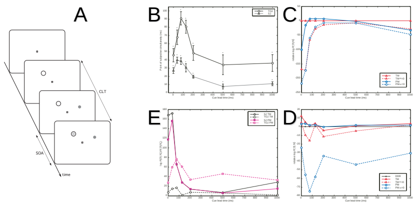
<u>Order judgment:</u> The simplest model is the *deterministic decision rule*, which is modeled as a cumulative normal function, $\Phi(\tau, \Delta t+\alpha, \sigma)$. However, in this case, the decision criterion τ and the attentional acceleration α act in parallel and cannot be distinguished. Another class of models analogous to the triggered-moment and perceptual-moment simultaneity decisions may be derived, assuming that the perception of non-simultaneity is necessary for the discrimination of the order. In these models, if the targets are judged simultaneous, then the observer must make a forced choice and responds with probability β that the attended target appeared first. For the *triggered-moment* model, the probability of responding that the cued target occurred first is $1 + (\beta-1)\,\Phi(\tau, \Delta t+\alpha, \sigma) - \beta\Phi(-\tau, \Delta t+\alpha, \sigma)$.

Model comparison

The various models $\mathcal{H}$ of the decision mechanism were evaluated through Bayesian inference (MacKay, *Neural Computation* **4**:415–447, 1992) by directly evaluating the evidence, $P(\mathcal{D}|\mathcal{H}) = \int P(\mathcal{D}|\mathbf{w},\mathcal{H})\, P(\mathbf{w}|\mathcal{H})d\mathbf{w}$, where $\mathcal{D}$ is the experimental data and $\mathbf{w}$ is the vector of parameters for the model. The integration ranges over the entire parameter space for $\mathbf{w}$, and the prior distribution of the parameters, $P(\mathbf{w}|\mathcal{H})$, is assumed to be uniform within a specified range. Since the integral is typically dominated by a strong peak in the likelihood function, $P(\mathcal{D}|\mathbf{w},\mathcal{H})$, near the optimal parameter values, the evidence is insensitive to the choice of priors.

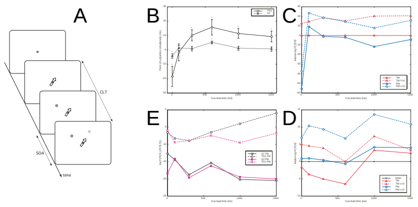
Experiment 1

<u>Purpose:</u> Replicate previous results with exogenous cues and test the task-dependence of the results. <u>Results</u>: PSSs follow the expected attentional time course. The models suggest that a non-zero attentional acceleration is required. <u>Discussion</u>: The difference between the SJ and TOJ is likely due to response bias or criterion shifts. Non-attentional sensory factors might be responsible for the effects at zero cue lead time.



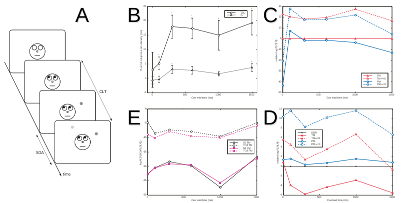
Experiment 2

<u>Purpose:</u> Employ endogenous cues to eliminate the cue stimulus at the target location. <u>Results:</u> The models suggest that no attentional acceleration is necessary. <u>Discussion:</u> Endogenous cues are inefficient and require volitional effort. Observers may ignore the cue and distribute their attention.



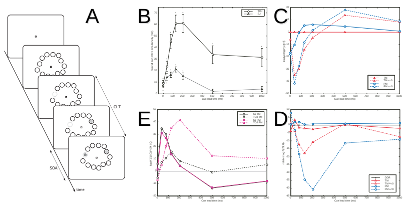
Experiment 3

<u>Purpose:</u> Employ gaze-directed cues. These have been shown to orient attention automatically but do not directly stimulate the target location. <u>Results:</u> The PSS shifts for the TOJ are larger and follow the attentional time course expected for this type of cue, but the the models suggest that no attentional acceleration is necessary. <u>Conclusion:</u> A cue stimulus at the target location seems to be required to cause a prior entry effect.



Experiment 4

<u>Purpose:</u> Test the type of stimulus necessary to cause prior entry effects. Cues are isoluminant color changes in existing objects rather than new luminance-defined objects. <u>Results:</u> Attentional acceleration is necessary for short but not long cue lead times. <u>Conclusion:</u> New objects are not necessary to cause prior entry effects.



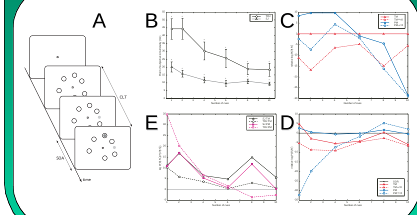
Key to experiment diagrams. In each experiment box there are five diagrams:

A. A cartoon of the stimulus time course.
B. The experimentally measured point of subjective simultaneity (PSS) for the simultaneity (SJ) and temporal order judgments (TOJ).
C. The relative evidence calculated from the data for the triggered-moment (TM) and perceptual-moment (PM) models of the SJ with or without the attentional acceleration parameter(α) set to zero.
D. The evidence for the TOJ models relative to the deterministic decision rule (DRR).
E. A test of the prior entry hypothesis ($\alpha \neq 0$) using the TM and PM models for both the SJ and TOJ.

Each graph shows the calculations for the models combined over all subjects at each different cue lead time (CLT) tested.

Experiment 5

<u>Purpose:</u> Dissociate sensory effects and attention. Employ a large number of cues to overwhelm attention but retain a cue stimulus at the target location <u>Results:</u> Attentional acceleration is necessary for all numbers of cues, but the PSS decreases with an increasing number of cues. <u>Conclusion:</u> Exogenous cues produce a significant non-attentional effect.



Conclusions

Attentional cues affect judgments of perceptual latency. However, the locus of action is largely upon cognitive factors such as response bias and criterion shifts, and the sensory effects of attention are only produced by exogenous cues that also have a significant attention-independent sensory effect.