Seeing light vs dark lines: Psychophysical performance is based on separate channels, limited by noise and uncertainty

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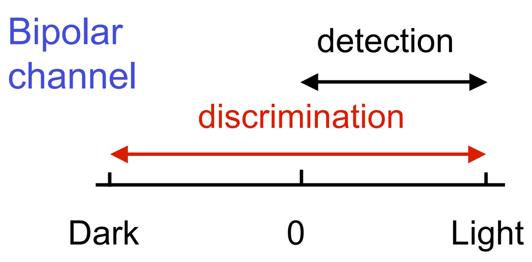
1. Introduction: Two research questions

Question 1: bipolar or monopolar channels?

Opponent processes are common in sensory systems. Is there a single, opponent ('bipolar') channel [1] for dark and light targets ?

ON & OFF cells are well known in vision. Detection of luminance increments or decrements was selectively impaired by adaptation to a temporal sawtooth [2]. Are there *independent* channels for dark and light ?

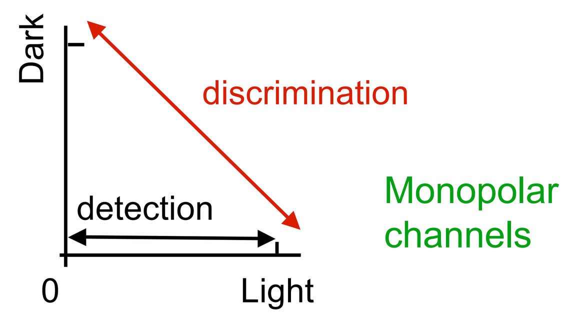
discrimination = 2 x detection



Signal detection theory predictions for d':

We tested these predictions empirically

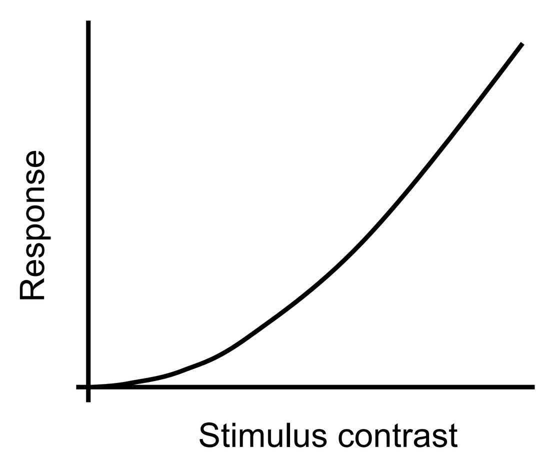
discrimination = √2 x detection

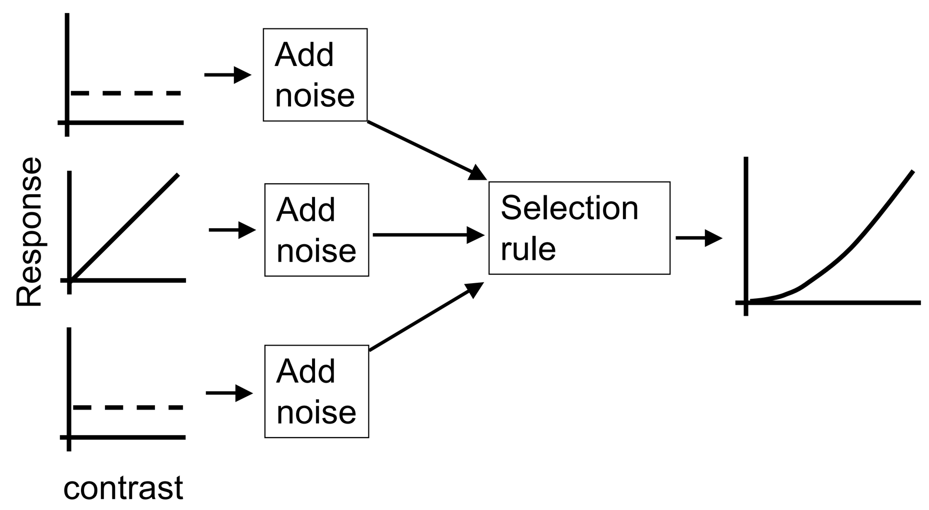


Question 2: nonlinear transducer or intrinsic uncertainty?

Transducer model
Studies of detection and discrimination with low-contrast gratings usually show a nonlinear relation between d' and contrast. This could imply a nonlinear transducer - an accelerating sensory response to contrast [4].

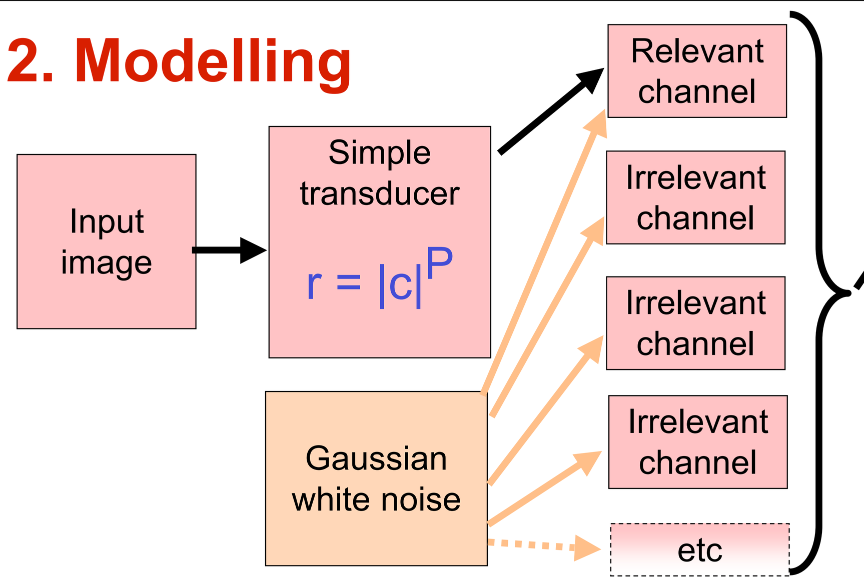
Uncertainty model
Alternatively, the transducer(s) might be linear, but with uncertainty about which of many noisy inputs is relevant to the task. As contrast is raised, fewer irrelevant channels are monitored, leading to progressively improved performance [5].

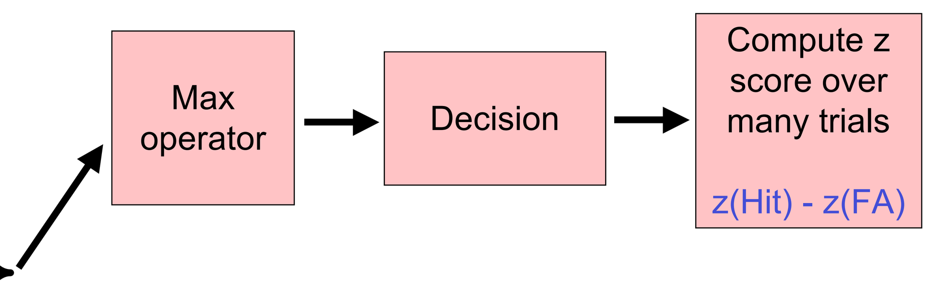




We address these questions in an intensive, high-precision study of psychometric functions for detection and discrimination of light *vs* dark bars.

2. Modelling





Model has 2 versions:

Uncertainty model
2 free parameters: no. of irrelevant channels, and noise.
1 fixed parameter: transducer exponent, P = 1

Transducer model
2 free parameters: transducer exponent (P), and noise.
1 fixed parameter: no. of irrelevant channels = 0

Each run simulates 50,000 trials per contrast level.
Models are run repeatedly to find best-fitting parameter values.

3. Methods

Stimuli
- A single dark or light vertical Gaussian bar (σ=12 min arc) on mid-grey background.
- Image size 256x256 pixels (4.3 deg) surrounded by a full screen of mid-grey.
- Variable contrast, defined as Weber contrast : $(L_{max} - L_{background}) / L_{background}$

Four tasks

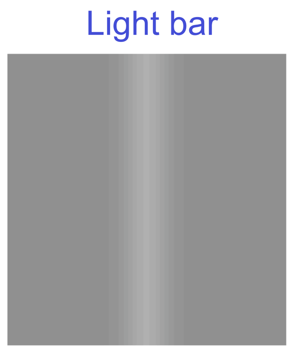
1. **Single interval polarity discrimination**
Stimulus: light or dark bar.
Task: was it light or dark?

2. **2AFC polarity discrimination**
Stimulus: light in one interval and dark in other
Task: which interval was light?

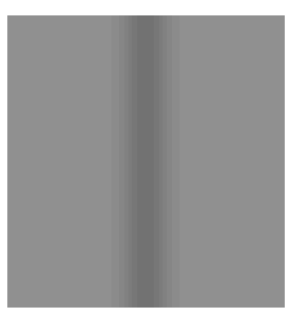
3. **Single interval detection**
Polarity blocked or interleaved
Stimulus: bar or blank.
Task: was bar present?

4. **2AFC detection**
Polarity blocked or interleaved
Stimulus: bar in one interval and blank in other
Task: which interval contained bar?

Light bar



Dark bar



- 9 to 11 contrast levels per polarity.
- Central fixation dot (2 by 2 pixels) replaced by stimuli for 300ms
- 600ms between intervals, if 2AFC
- 1 sec minimum between trials
- Feedback after every trial

2 subjects:
SAW:
- Highly practised with these stimuli
- 240 trials per contrast level
- Performed all 4 procedures in order 1:4

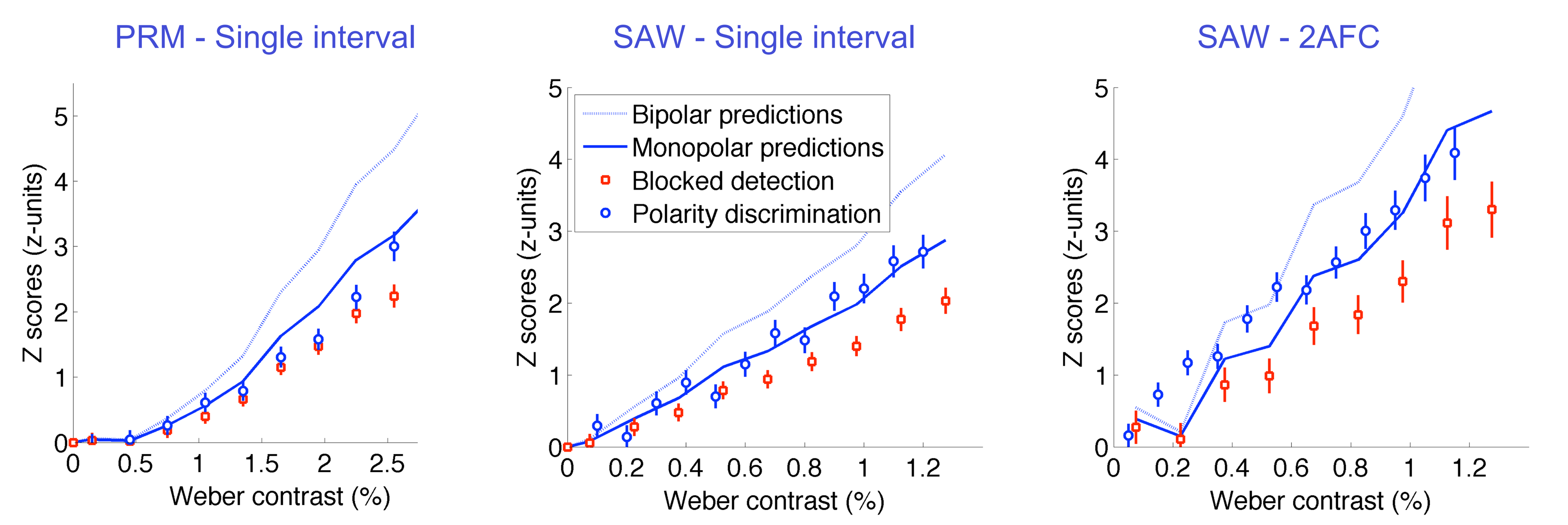
PRM:
- No prior practice in psychophysics
- 300 trials per contrast level
- Performed first 3 procedures interleaved

4. Results

Answer 1: monopolar channels

- Z-scores for blocked detection (red symbols) were averaged across polarity
- Values multiplied by √2 (monopolar) or 2 (bipolar) gave predictions for polarity discrimination
- Monopolar channel predictions (solid lines) are close to the data (blue) for both observers
- Bipolar channel predictions (dotted lines) fit poorly for both observers

Conclusion
Human observers use independent, monopolar channels to detect & discriminate light *vs* dark lines



5. Results (continued)

Answer 2: Transducer and Uncertainty models both fit data well

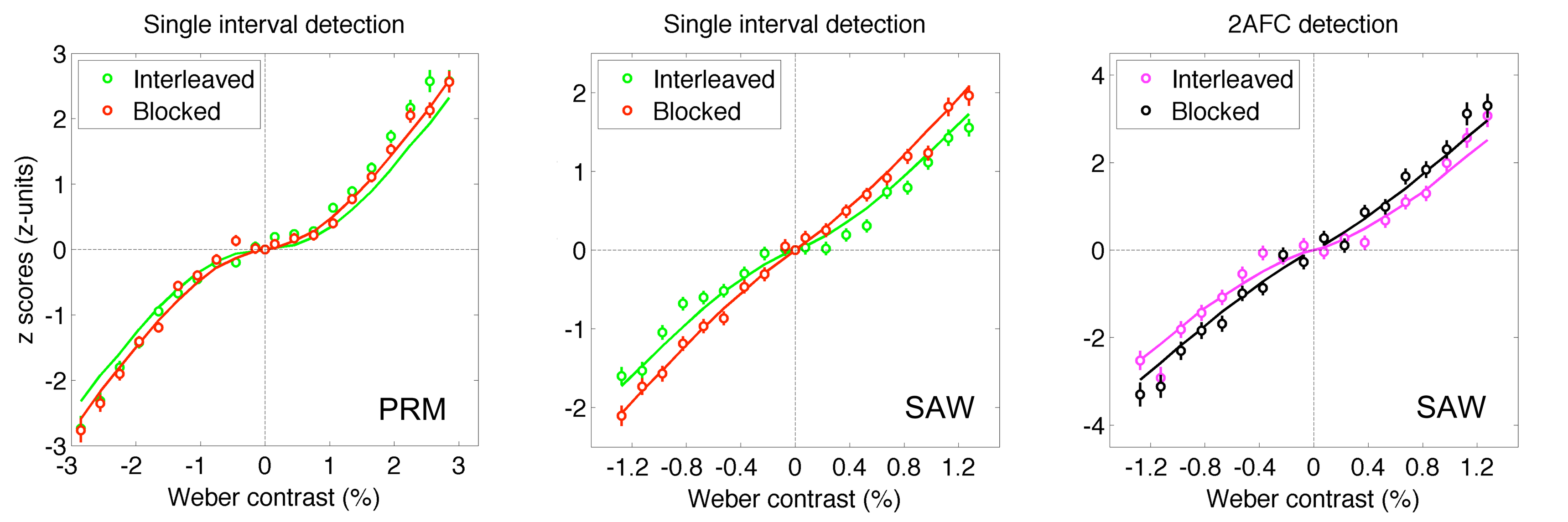
- Both versions of the *monopolar* model were fitted to data from each subject.
- Details of best fits are shown in this table.
- Plots for the uncertainty model are shown below.

Observer	SAW	SAW	PRM	PRM
Model version	Transducer	Uncertainty	Transducer	Uncertainty
Error score	37	36	31	31
No. of irrelevant channels	[0]	1	[0]	15
Transducer exponent (P)	1.2	[1]	1.7	[1]
Noise amplitude (%)	1.3	1.05	4.45	1.45

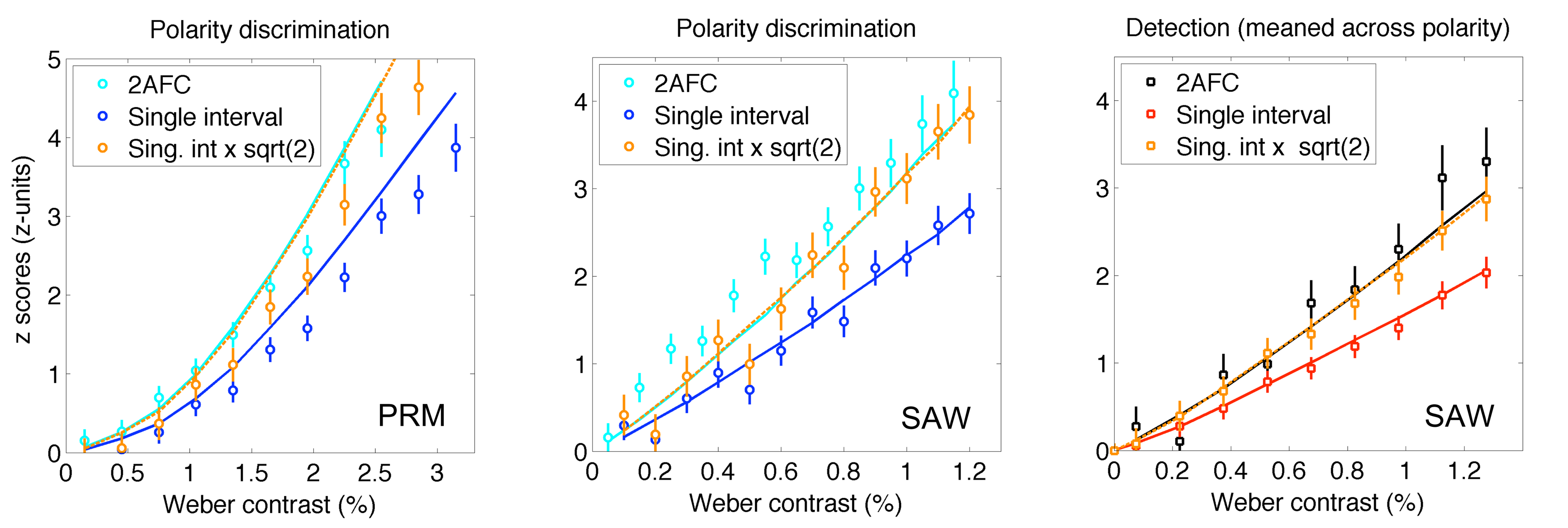
[ ] fixed parameter

Both models fit equally well, so neither can be rejected. But the uncertainty model may be seen as more parsimonious. Differences in uncertainty between subjects (SAW=1, PRM=15) and between stimulus conditions explain the variations in sensitivity & in degree of nonlinearity in a unified fashion, as shown below.

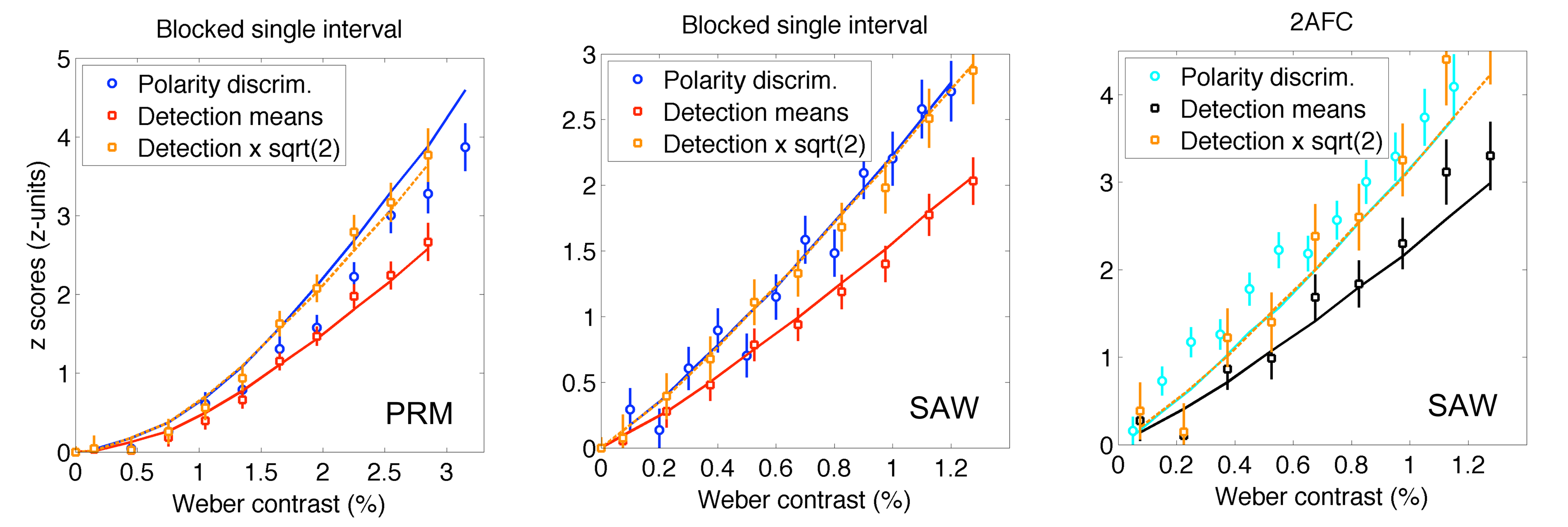
Uncertainty model predictions (lines) and experimental data (symbols)



Stimulus uncertainty: Moving from interleaved to blocked trials increased and linearised z-scores for SAW. This reflects the reduction of *extrinsic* uncertainty about stimulus polarity. The effect is not seen in PRM's data, because, on this model, she has much higher *intrinsic* uncertainty (irrelevant channels: PRM = 15, SAW = 1).



Method effect - single interval vs 2AFC: Data and model both show a √2 increase in z-scores, when the method changes from single interval to 2AFC. This is correctly predicted by signal detection theory [3], and is now seen to hold even when uncertainty is included. It implies that sensitivity (d') is the same for both methods.



Task effect - detection vs polarity discrimination: Data and model both show a √2 increase in z-scores, from detection to polarity discrimination. This confirms the assumption of independent, monopolar channels for light & dark (see box 4).

Inter-subject variation: PRM was much more non-linear than SAW. The uncertainty model explains this mainly by increasing the number of irrelevant channels from 1 (SAW) to 15 (PRM).

Conclusions

1. **Transducer and uncertainty models fit the data equally well, with only 2 free parameters**
2. **This provides new experimental support for Pelli's (1985) uncertainty model as a viable alternative to the more familiar transducer model.**
3. **The uncertainty model accounts for the effects of stimulus uncertainty, method, task and variation between subjects in a unified fashion.**

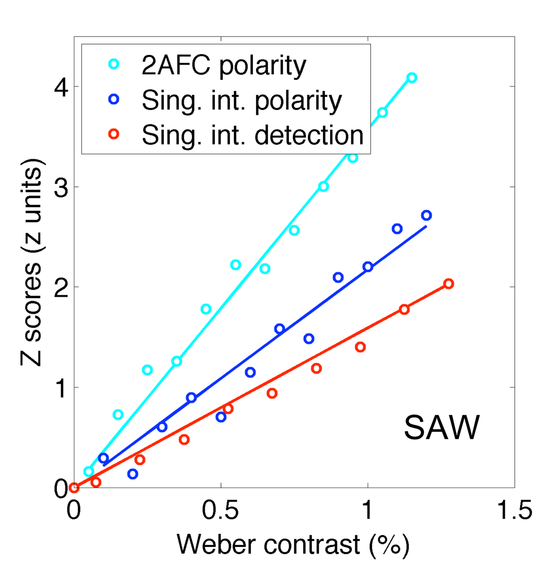
6. Discussion

Convergence of models
A special case: The transducer and uncertainty models are the same when the transducer exponent is 1 and the number of irrelevant channels is zero. SAW is very close to this ideal model (P = 1.2 *or* irrelevant channels = 1).

A new phenomenon - linear performance at low contrast
A transducer exponent of about 2 is often reported in detection and contrast discrimination experiments [5]. Here SAW shows **linear** performance for blocked single interval detection, and 2AFC and single interval polarity discriminations.

Practice reduces uncertainty ?
SAW had many more hours of practice than PRM and his data were fitted with only 1 irrelevant channel (PRM = 15). Perhaps intensive practice decreases the number of irrelevant channels monitored.

Data and best linear fits



Future work
- increase the number of subjects
- interleave all 4 methods
- examine practice effects more closely
- use stimuli that contain light and dark components.

References
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