Constraining computational models of brightness perception: what's the right psychophysical data?

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In brightness perception†, the common standard to psychophysically measure a perceptual response is brightness matching. The observer adjusts the physical luminance of a test patch so that it matches the brightness of a target patch. When target and test are presented in different contexts of interest (such as White's effect, see Fig. 2) it is assumed that there are unique transfer functions which relate luminance to brightness, i.e. physical to perceptual response, in each context (Fig. 1). Target and test elicit some perceptual (brightness) responses, and the observer adjusts the test luminance so as to equate both perceptual responses. Unfortunately matching data do not reveal the underlying transfer functions, because the transformation is through two transfer functions: one for the target, and one for the test patch (Fig. 1, upper). Thus, matches across a range of luminances (Fig. 1, lower) gives us the difference between these two transfer functions, but not their individual shapes. Any two functions that have the same difference between them can account for the matches (Fig. 1, compare columns).

Contemporary image-computable models of brightness perception on the other hand produce output in arbitrary/non-physical units, which need to be scaled to convert them to comparable physical units. The scaling factor is a degree of freedom that can allow perfect accounting of the psychophysical data, at least when matches are set for (repeats of) only a single target luminance. As a matter of fact matches are often only measured for limited, intermediate luminances (light green data points in Fig. 1). A partial solution would be to collect matches across the range of reference luminances as this additionally constrains the model comparison. However it still does not allow to constrain the transfer functions in different contexts.

Here we propose to use perceptual scaling paradigms in order to estimate transfer functions, because those would allow to constrain mechanistic brightness models. Using Maximum-Likelihood Conjoint Measurement (MLCM), we estimate two perceptual scales, one for each patch in White's effect (Fig. 2 left panel). The scales were nonlinear, and so was the difference between them. We compare them with model output from brightness models of the ODOG family. The transfer functions of the models are best characterized as linear functions with a fixed offset, whereas the empirical were not (Fig. 2 lower panels). Introducing a simple non-linearity at the model's output (e.g. divisive normalization) did not improve the situation, as the experimental scales were different in shape.

Thus, the present scaling data provides a new way to further constrain image-computable models of brightness perception, and current models fail to account for this data. Whether additional changes in the non-linearities of these models can better capture perceptual scales of brightness, remains an open question.

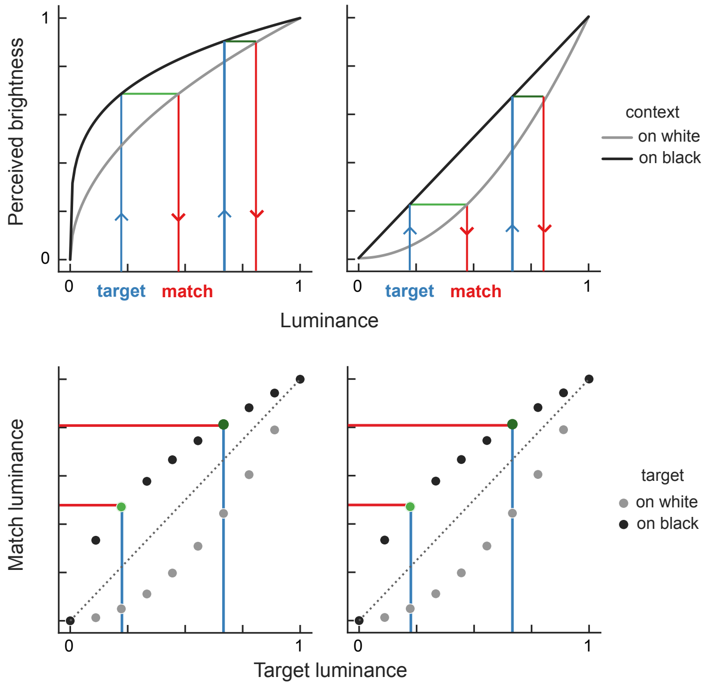

Figure 1: Matching data cannot reveal the shapes of the underlying transfer functions – matches are determined only by difference between transfer functions. Upper row: hypothetical transfer functions from physical luminance to perceived brightness, for target (black line) and match (gray line) patch. The target patch elicits some brightness response (blue arrow), participants matches the response internally (green line), which produces some different matched luminance (red arrow). Bottom row: (hypothetical) matched luminances for a variety of target luminances; green points correspond to upper panels.

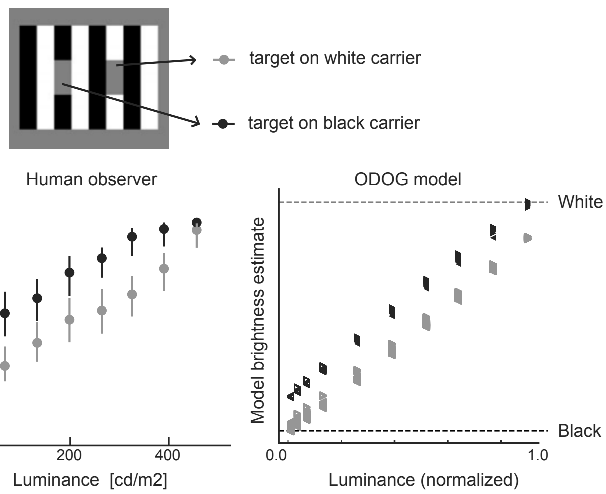

Figure 2: (Top) Stereotypical version of White's stimulus. (Bottom left) Perceptual scales obtained with MLCM from one observer. Targets varied their luminance and carrier placement. (Bottom right) Model output from the ODOG model for the same stimuli.

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†We use brightness and lightness as synonymous, as no distinction can be made for the stimulus here considered.