Sensory Integration Across Modalities: How Kinaesthesia Integrates with Vision in Visual Orientation Discrimination

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Abstract
Stimuli in one modality can affect the appearance and discriminability of stimuli in another, but how they do so is not well understood. Here we propose a theory of the integration of sensory information across modalities. This is based on criterion setting theory (CST; Treisman and Williams, 1984), an extension of signal detection theory which models the setting and adjustment of decision criteria. The theory of sensory integration based on CST (CST-SI) offers an account of cross-modal effects on sensory decision-making; here we consider its application to orientation anisotropy. In this case, CST-SI postulates that the postural senses are concerned with the relations between momentary body posture and the cardinal dimensions of space, vertical and horizontal, and that they also contribute to stabilizing perception of the cardinal orientations in vision through actions on the corresponding visual decision criteria, but that they have little effect on perception of diagonal orientations.

Predictions from CST-SI are tested by experimentally separating the contributions that different information sources make to stabilizing the visual criteria. It is shown that reducing relevant kinaesthetic input may increase the variance for discrimination of the visual cardinal axes but not the obliques. Predictions that shift in the location of the psychometric function would be induced by varying the distribution of the test stimuli, and that this effect would be greater for oblique than cardinal axes were confirmed. In addition, peripheral visual stimuli were shown to affect the discrimination of cardinal but not oblique orientations at the focus of vision. These results support the present account of anisotropies.

Keywords
Sensory integration, orientation anisotropy, oblique effect, context, decision criterion, criterion setting theory

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1. Introduction

Sensory discrimination may be enhanced at certain points on a sensory dimension. An example is orientation anisotropy or the oblique effect (Appelle, 1972; Essock, 1980; Howard and Templeton, 1966), the superior discrimination of the vertical or horizontal (‘cardinal’ or ‘principal’) axes as compared with oblique and other orientations. Lages and Treisman (2010) have presented a theory of sensory decision-making and discrimination learning which provides an account of anisotropies, for stimuli within a single modality. But their fuller understanding requires that we also consider cross-modal contributions. Below we extend the theory of discrimination learning to provide an account of cross-modal sensory integration and of its role in orientation and other anisotropies, and test it experimentally.

In Fechner’s seminal model of discrimination (Fechner, 1860/1966), a standard or reference stimulus was presented, together with or followed by a test stimulus, and the subject either did or did not ‘notice’ a difference between them; the measure of discrimination was the ‘just noticeable difference’ (jnd). This assumed that a perception of the test stimulus was compared with that of the reference stimulus when they were simultaneous, or with a representation or copy, a unique memory trace of it, when they were not. To explain orientation anisotropy on the basis of such a model would require that the cardinal axes produce particularly strong long-lasting representations or fixed memory traces (FMTs) to define them. The greater stability of these memory traces would give them a special resistance to forgetting and to external sources of noise and interference, such as adaptation and contextual effects, resulting in improved discrimination.

An alternative to the Fechnerian approach was provided by signal detection theory (SDT; Green and Swets, 1966; Macmillan and Creelman, 1991; Tanner and Swets, 1954; Thurstone, 1927) which introduced a more sophisticated account of the role of noise, and replaced the concept of a fixed threshold with that of an adjustable decision criterion, to which the assumption of criterion variability was added by Wickelgren (1968). This approach was taken further by criterion setting theory (CST; Treisman, 1984a, b, 1985, 1987; Treisman and Faulkner, 1984a, b, 1985, 1987; Treisman and Williams, 1984) which offers an account of the setting of criteria and their modification from trial to trial. Lages and Treisman (this issue) have presented a theory of discrimination learning based on criterion setting theory (CST-DL) which also models contextual effects and anisotropies.

While Lages and Treisman (2010) have successfully tested predictions derived from this model, for both orientation and depth discrimination, CST-DL has a major limitation: it is restricted to test and contextual stimuli in the same modality. But information from more than one sensory modality may be used in judging orientation in visual space: vision may be supplemented by information from other postural senses, the vestibular system, proprioceptive sensation from muscles, ligaments and joints, and somaesthetic sensation from touch and pressure; we use the term ‘kinaesthesia’ to cover these senses. For example, in Mittelstaedt’s (1983) study of the effect of posture on recognition of the visual vertical, when observers