

**TEMPORAL ASYMMETRY AND “MAGNET EFFECT”
IN SIMILARITY AND DISCRIMINATION OF
PROTOTYPICAL AND NONPROTOTYPICAL STIMULI:
CONSEQUENCES OF DIFFERENTIAL SENSATION WEIGHTING**

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Abstract

The judged similarity between two successive stimuli is higher when the less prototypical stimulus is the first in the pair than when it is the last. Also, the rated similarity between a scalar and a nonscalar melody is greater when the nonscalar melody comes first rather than last in the pair, and a change from a mistuned to a tuned musical interval is harder to detect than when the order is reversed. Such time-order asymmetries can be accounted for by a generalization of Hellström’s sensation-weighting model, with a lower weight for the first stimulus as is usual when two successive stimuli are compared. This would result in assimilation of a first-presented nonprototypical stimulus toward the prototype, increasing its similarity to a more prototypical last-presented stimulus. Also, fewer “different” judgments, but not worse discrimination from variants, occur for prototypical than for nonprototypical stimuli; the so-called perceptual magnet effect appears to be a methodology-based artifact.

Systematic change or drift of estimates of a memorized stimulus toward a prototype or category mean have been known for a long time, under various names such as law of sense memory (Leuba, 1892) and central tendency of judgment (Hollingworth, 1910). Huttenlocher and her associates have explored systematic changes in estimation from memory (Huttenlocher, Hedges, & Duncan, 1991; Huttenlocher, Hedges, & Vevea, 2000), arguing that people use category information in a Bayesian manner to increase precision of estimates.

Asymmetries of Discrimination and Similarity

A number of studies show similar asymmetries for different kinds of paired stimuli: Better discrimination, or a lower similarity judgment, is obtained when the stimulus that is more central in the set, or closer to a prototype, ideal, or norm, is presented first rather than second.

Vowels: Perceived Position in Vowel Space

Repp and Crowder (1990) had their listeners judge whether paired successive vowels were the same or different. The ordering of the vowels in the pairs caused clear asymmetry effects regarding the number of “different” responses, and the authors summarized their results by stating that “the first vowel in a pair seems to drift toward the interior of the stimulus range employed in a given test” (p. 2080). This view modifies the “neutralization hypothesis” of Cowan and Morse (1986), who explained this type of asymmetry by a drift of the first vowel in the direction of the neutral *schwa*. In line with Repp and Crowder’s results, Polka and Bohn (2003) concluded, from a review of research on asymmetries in infants’ detection of changes from one vowel sound to another, that “vowel discrimination is easier for infants when they

were presented a change from a less peripheral to a more peripheral vowel (closer to the limits or corner of the vowel space)” (p. 224). Ikeda et al. (2002), in a study of preattentive perception of vowels using an oddball paradigm, found larger mismatch negativities (MMNs) when the standard was prototypical and the deviant nonprototypical, than in the reverse case.

Geometrical Shapes: Prototypicality and Nonprototypicality

Op de Beeck, Wagemans, and Vogels (2003) had human participants rate the similarity between geometrical shapes, presented successively in pairs, while monkeys learned to discriminate the same shapes. Similarities were lower, and discrimination better, when the stimulus more prototypical of the set was presented first in the pair than when the order was reversed.

Musical Chords and Intervals: Harmonical Stability and Consonance

Bharucha and Krumhansl (1983) found it to be easier to discriminate between a harmonically stable and an unstable musical chord when the stable chord was presented first in the pair rather than second. Analogous results were found by Bartlett and Dowling (1988) for pairs of a stable and an unstable melody, and by Schellenberg and Trehub (1994) for pairs of a consonant and a dissonant musical interval. Discrimination between successively presented musical intervals has been found to be better when the first interval is consonant and the second interval dissonant than when the order is reversed (Schellenberg & Trehub, 1996; Trainor, 1997).

Order and Disorder

Bharucha and Pryor (1986) found that discrimination performance (same/different judgments) between two successive tone sequences was better when the rhythm of the first sequence was regular and the second sequence disrupted, than in the reverse case. Chait et al. (2007) found that auditory cortical responses in humans to transitions from “order” (a constant tone) to “disorder” (a sequence of random frequency tone pips) were faster than to the reverse transitions. Likewise, responses to the disappearance of interaural coherence were faster than responses to its appearance (Chait et al., 2005) and similar results in the visual domain were reported by Julesz and Tyler (1976). Bharucha, Olney, and Schnurr (1985) found that it was easier to detect changes in texts when the changes made a coherent text anomalous than vice versa.

Presentation Frequency

Polk et al. (2002), using pairs of colors (simultaneous but numbered as 1 and 2), found that rated similarities (e.g. “How similar is Blue₁ to Blue₂?”) were asymmetric and could be manipulated by training, presenting some stimuli ten times more often than the others. After training, asymmetry increased; the rated similarity was greatest when the low-frequent color was in the “1” position and the high-frequent in the “2” position.

Explanations for Asymmetric Similarity

Feature Matching

One influential theory of asymmetries in similarity judgments is Tversky’s (1977) set-theoretical *feature-matching theory*. With the task defined as “how similar is X to Y?” this theory makes the distinction between subject (X) and referent (Y), and accounts for the judged similarity as being a weighted function of the number of features shared by X and Y and those present in X but not in Y and in Y but not in X.

In the kind of task discussed here, the stimuli are presented successively, and the instruction is neutral: “How similar are X and Y?” or “Are X and Y same or different?” Tversky applied his model also to asymmetries between the two presentation orders. However, a dimensional approach seems more adequate for stimuli that are better described as points in multidimensional space than as collections of binary features. Also, this approach makes the study of similarities and same/different data continuous with that of ordinal comparisons.

Sensation Weighting

One approach for unidimensional stimuli is to interpret the judged similarity as being a monotonous function of the absolute magnitude of the subjective difference between the stimuli. For pairwise successive stimuli, the subjective difference is well described by Hellström’s (1979, 1985, 1989, 2003) *sensation-weighting* (SW) model. According to this model the subjective difference, d , is the difference between two weighted compounds,

$$d = [s_1 \psi_1 + (1 - s_1) \psi_{r1}] - [s_2 \psi_2 + (1 - s_2) \psi_{r2}], \quad (1)$$

where ψ_1 and ψ_2 are the sensation magnitudes of the stimuli, and ψ_{r1} and ψ_{r2} are the *reference levels* (ReLs). For $\psi_{r1} = \psi_{r2} = \psi_r$ the model reduces to

$$d = s_1 (\psi_1 - \psi_r) - s_2 (\psi_2 - \psi_r). \quad (2)$$

The SW model, which was developed to account for time-order errors (TOEs), also predicts asymmetries in similarity judgments of unidimensional stimuli presented in the two possible orders. In particular, $s_1 < s_2$, as is most often found, means that a difference between the first stimulus and the ReL becomes less important than the same difference between the second stimulus and the ReL. Defining prototypicality as closeness to the ReL, and assuming judged similarity to be a decreasing function of $|d|$, a prototypical (Pr) and a nonprototypical (NPr) stimulus should be judged as more dissimilar (and their discrimination, as measured by “different” judgments, better) when the stimuli are presented in the order Pr-NPr than in the order NPr-Pr. It is also predicted that, as was noted by Schellenberg (2002, p. 243), “asymmetric distortions in similarity space increase as one moves away from the category center.”

Numerical Example for Asymmetric Similarity

Assume $\psi_r = 5$; $\psi_{Pr} = 6$; $\psi_{NPr} = 10$; $s_1 = 0.5$; $s_2 = 0.8$. We abbreviate $s_1 (\psi_1 - \psi_{r1})$ and $s_2 (\psi_2 - \psi_{r2})$ by D_1 and D_2 . In the order Pr-NPr, $D_1 = 0.5 (6-5) = 0.5$, $D_2 = 0.8 (10-5) = 4.0$, and $d = |4.0-0.5| = 3.5$. In the order NPr-Pr, $D_1 = 0.5 (10-5) = 2.5$, $D_2 = 0.8 (6-5) = 0.8$, and $d = |2.5-0.8| = 1.7$. Thus similarity is lower in the order Pr-NPr than in the order NPr-Pr.

Stimuli as Points in Multidimensional Space

We now conceive stimuli as lying in a multidimensional subjective space, where stimuli that are, or by adaptation come to be experienced as, “normal,” “prototypical,” “regular,” “orderly,” etc., occupy central locations, and those “unusual,” “nonprototypical,” “irregular,” “disorderly,” etc. are located more peripherally. This is the result of a continuous process of adaptation in Helson’s (1964) sense, which builds up an adaptation level (AL), or reference level

(ReL). In stimulus comparison, the subjective stimulus magnitudes are modified by the sensation-weighting mechanism, which helps improve edge- or change-detection by increasing the signal-to-noise ratio (S/N) of potentially informative stimulus changes (Hellström, 1989).

Sensation Weighting in the Multidimensional Case

The SW model may be generalized to encompass paired successive multidimensional stimuli. With p dimensions and Minkowski constant m ($= 2$ for Euclidean space), Equation 1 becomes

$$d_{12} = \left\{ \sum_{i=1}^p [s_1 (\psi_{1i} - \psi_{ri}) - s_2 (\psi_{2i} - \psi_{ri})]^m \right\}^{1/m}. \quad (3)$$

Numerical Example for Asymmetry in Two Dimensions

We now extend our numerical example into two dimensions (as is pertinent for, e.g., experiments with synthetic vowels, where usually the two lowest formants are varied), with $p = 2$; $m = 2$; $\psi_r = (5,5)$ $\psi_{Pr} = (6,6)$; $\psi_{NPr} = (10,10)$; $s_1 = 0.5$; $s_2 = 0.8$. Denoting distance by Δ , in the order Pr-NPr, $d = \Delta [(0.5,0.5),(4.0,4.0)] = 4.95$, and in the order NPr-Pr, $d = \Delta [(2.5,2.5), (0.8,0.8)] = 2.41$. Thus, again the order Pr-NPr yields a lower similarity than the order NPr-Pr.

Perceptual Magnet Effect

What happens when both stimuli are made less prototypical by shifting them away from ReL by the amount U ? For the unidimensional case we obtain from Equation 1:

$$d = s_1 (\psi_1 - \psi_r) - s_2 (\psi_2 - \psi_r) + U (s_1 - s_2) \quad (4)$$

Thus a bias term is added, which increases the perceived distance between the two stimuli without improving sensitivity to changes in ψ_1 and ψ_2 . The extension to the multidimensional case is straightforward. In a same-different paradigm, the proportion of “different” judgments should increase (also to objectively equal pairs). This effect is in fact observed in the form of the *perceptual magnet effect* (e.g., Iverson & Kuhl, 1995, 2000; Kuhl, 1991): Deviations from a prototypical speech sound have been reported to be harder to detect than the corresponding deviations from a nonprototypical sound, the prototype acting as a “magnet.” The present explanation (cf. Schellenberg, 2002) suggests that the magnet effect has nothing to do with true discriminability, but is an artifact of the experimental procedure, where judgments from the two presentation orders are pooled, and order bias (akin to TOE) is not taken into account. (Also, Kuhl, 1991, used no true control trials, and Iverson and Kuhl, 1995, ignored the false alarms on 31% of the “same” trials). In an adequate procedure, the effect of a stimulus change on (e.g.) d' should be measured, separately for the first and second stimulus. A minimal requirement is that – contrary to standard practice – data from the two orders are kept separate. Corneille et al. (2006), having participants learn “club membership/non-membership” of faces, found that faces of club members were more likely to be judged “same,” but no better discriminated from each other, than those of nonmembers. Corneille et al. suggest a somewhat similar explanation as the present one: “...the constant reference to the reference [club member] prototype may have resulted in the perception of smaller intra-categorical variations for the reference than for the nonreference category. This, in turn, may have enhanced the probability for *same* decisions for the reference exemplars” (p. 565).

Numerical Example for Perceptual Magnet Effect

Suppose that in the previous example Pr (6,6) and NPr (10,10) are compared, using both presentation orders, with variants that are displaced by a small, equal distance δ in ψ space, to (7,7) and (11,11), respectively. Calculating the subjective distances, for Pr we obtain $d_{Pr,Pr+\delta} = \Delta [(0.5,0.5),(1.6,1.6)] = 1.56$, and $d_{Pr+\delta,Pr} = \Delta [(1.0,1.0),(0.8,0.8)] = 0.28$. The mean subjective distance is 0.92. For NPr, we obtain $d_{NPr,NPr+\delta} = \Delta [(2.5,2.5),(4.8,4.8)] = 3.25$, and $d_{NPr+\delta,NPr} = \Delta [(3.0,3.0),(4.0,4.0)] = 1.41$. The mean distance is 2.33. As we see, the mean subjective distance from the variant is greater for the nonprototype than for the prototype.

Conclusion: Sensitivity Maximization

One way to conceptualize sensitivity maximization for paired stimuli is to think of the stimulus pair as the unit of analysis. We may then consider a “neutral” pair as one consisting of two equal stimuli. This yields equal ReLs for the two stimuli. s_1 and s_2 are adjusted in accordance with the current processing conditions to maximize S/N . The most common result is $s_1 < s_2$, which mirrors the greater degradation of the representation of the first stimulus, that is, the greater amount of usable information on the second stimulus. As a result, it is easier to detect a change or deviation in the second than in the first stimulus. Regarding just noticeable differences and correctness percentages for unidimensional stimuli, this effect has been verified many times (e.g., Hellström, 2003), but it is far from as well-known as it deserves to be. Asymmetric similarity – the phenomenon that a decrease in regularity or prototypicality is more easily detected, or is judged to be greater, than a change in the opposite direction – seems to be just another consequence of the differential sensation weighting. Likewise, the “perceptual magnet effect” seems to be a consequence of shifting the compared stimuli away from the ReL, rather than a genuine detrimental effect of prototypicality on discriminability.

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