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Polarity Correspondence as a General Compatibility Principle

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Abstract

Proctor and Cho (2006) proposed that, when making binary decisions, people code the stimulus and response alternatives asymmetrically (positive and negative polarities), with performance being best when the codes of the corresponding polarities are paired. They presented evidence that polarity correspondence could explain many results associated with orthogonal compatibility, the Implicit Association Test, and numerical judgments. We review and evaluate literature on these topics and on polarity coding in the context of metaphorical relations published during the ensuing 10 years. Our conclusion is that the results have supported polarity correspondence as a contributor to binary decisions. We consider issues concerning the principle and topics in need of research.

Keywords

Implicit Association Test, SNARC effect, stimulus-response compatibility

Many naturalistic and laboratory tasks require binary decisions. One factor influencing the rapidity with which such decisions are made is stimulus-response compatibility (SRC; Proctor & Vu, 2006). If stimulus and response dimensions overlap (are similar; e.g., left and right stimulus locations and left and right key presses), responses are faster and more accurate when the values on those dimensions correspond than when they do not (Kornblum, Hasbroucq, & Osman, 1990). SRC affects performance even when the overlap applies to a stimulus dimension irrelevant to the response, an effect known as *the Simon effect* (Simon, 1990). Emphasis has been placed on perceptual or conceptual overlap as the basis of SRC effects, the former illustrated by the prior example and the latter by location words *left* and *right* to which left and right key presses are made. However, structural correspondence without perceptual/conceptual overlap is sufficient to produce SRC effects (Kornblum & Lee, 1995). For example, a left-to-right mapping of four stimulus locations to the alphabetical order of four spoken letter-name responses yields shorter reaction times than other mappings.

Proctor and Cho (2006) provided evidence for a type of structural-SRC effect for binary tasks called *polarity correspondence*: The stimulus and response alternatives are coded as having positive and negative polarity, and performance is best when the mapping maintains polarity correspondence. They developed their arguments from studies of word-picture verifications (Seymour, 1974) and showed that many results regarding orthogonal SRC, numerical judgments, and the Implicit Association Test (IAT) conform to the principle. The point of the polarity principle, in the words of Proctor and Cho, is that "perceptual or conceptual similarity is not necessary to obtain mapping effects; a type of structural similarity is sufficient" (p. 416).

Ten years have passed since Proctor and Cho (2006) made the case that polarity coding is a key factor in various compatibility effects. In this article, we assess the status of the principle in the domains targeted by Proctor and Cho and that of metaphorical spatial relations.

Orthogonal SRC Effects

When up/down stimulus locations are mapped to left/right responses, an up-right/down-left mapping advantage is often evident (Weeks & Proctor, 1990). This advantage is based in response selection and can be attributed to up and right being the unmarked, or positive polarity, members of stimulus and response sets, relative to which down and left are marked, or coded as negative polarity. This mapping advantage is affected by response eccentricity

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(increasing when the response device is to the right and reversing when it is to the left), responding hand, and prone or supine hand position. Cho and Proctor (2003) summarized evidence that many orthogonal-SRC results can be explained by the polarity-correspondence account, according to which coding relative to multiple reference frames determines the direction and size of the SRC effect.

Subsequent studies have examined the Simon effect for orthogonal dimensions. Nishimura and Yokosawa (2006) found an up-right/down-left Simon effect for left/right key-press responses with a centered response device to the color of stimuli in up/down locations, but Cho, Proctor, and Yamaguchi (2008) and Iani, Milanese, and Rubichi (2014) found only nonsignificant trends. However, Iani et al. found a reversed up-left/down-right advantage for left-handers, from which they concluded, "This result supports the existence of asymmetries in spatial coding in both the vertical and horizontal dimension, which can be represented as polarity differences" (p. 5).

In contrast to the mixed evidence for orthogonal Simon effects with centered response sets, evidence of an influence of response eccentricity similar to that for SRC is strong. Nishimura and Yokosawa (2006) and Cho et al. (2008) found an up-right/down-left Simon effect when the response device was positioned to the right but an up-left/down-right effect when it was positioned to the left. Cho et al. also showed that prone/supine hand posture had a qualitatively similar impact on orthogonal Simon and SRC effects.

For the left/right Simon task, practice with an incompatible mapping of stimulus-response locations prior to the Simon task reverses the Simon effect (Proctor & Lu, 1999). Bae, Cho, and Proctor (2009) demonstrated similar results for the orthogonal Simon task. Participants who practiced with an up-right/down-left mapping prior to performing a Simon task showed a 26-ms orthogonal Simon effect, whereas those who practiced with an up-left/down-right mapping showed a −11-ms reversed effect. Iani et al. (2014) found that this transfer effect was comparable for left- and right-handers.

Bae, Cho, and Proctor (2009) reported a similar pattern of transfer results when practice was with a mapping of low/high pitch tones to left/right key presses, as would be expected if part of the transfer effect involved abstract, asymmetric codes. Likewise, Nishimura and Yokosawa (2009) found a correspondence effect for pitch of an irrelevant tone in the left or right ear when participants responded to the color of a centered visual stimulus. Responses were faster when the low pitch was paired with the left response and the high pitch with the right response than when the low pitch was paired with the right response and the high pitch with the left response. The authors concluded, "These effects of nonhorizontal stimulus features on horizontal responses may be explained within a single theoretical framework (see Proctor & Cho, 2006), at least to a large extent" (p. 670).

Numerical-Judgment Effects

Proctor and Cho's (2006) analysis of numerical judgments focused on *linguistic markedness of response codes* (*MARC*) and *spatial-numerical association of response codes* (*SNARC*) effects. The MARC effect—better performance when odd numbers are paired with a left response and even numbers with a right response—has been attributed to asymmetric coding, with odd being marked relative to even (Nuerk, Iversen, & Willmes, 2004). Consequently, there is little disagreement that something like polarity correspondence produces it. Cho and Proctor (2007) provided evidence that the classification defined by the task rule is critical in determining polarity. Participants made key presses to the digits 3, 4, 8, and 9 or the corresponding number words, using an odd/even or multiple-of-3 rule, which resulted in the same key-press response to each stimulus. For both stimulus modes, the MARC effect was obtained with the odd/even rule but tended to reverse with the multiple-of-3 rule. Huber et al. (2015) found a MARC effect for right-handers, but strong left-handers showed a reversed effect, suggesting that handedness may be a factor in polarity coding.

The SNARC effect—better performance when small numbers are paired with a left response and large numbers with a right response—is usually attributed to a mental number-line representation. However, behavioral data have provided evidence consistent with a basis in polarity correspondence. Gevers, Verguts, Reynvoet, Caessens, and Fias (2006) showed that the SNARC effect for magnitude judgments is categorical (i.e., how much larger than 5 a digit is does not matter), whereas the SNARC effect for parity judgments is continuous. Analogous to Cho and Proctor's (2007) finding for the MARC effect, Santens and Gevers (2008) showed that the SNARC effect is task dependent: When participants indicated whether a digit was greater or less than 5 by moving a finger from a start key to a near or far key (both located either to the left or to the right), the small-close/large-far mapping yielded better performance than the opposite mapping, even when the close key was to the right of the far key. The researchers noted that these findings argued "in favor of an intermediate categorization of numbers as relatively small (− polarity) or large (+ polarity)" (p. 269). Bae, Choi, Cho, and Proctor (2009) found that polarity mappings can transfer from the orthogonal SRC task to numerical judgments. Practice with an orthogonal incompatible mapping (up-left/down-right) reduced the SNARC effect in a subsequent parity-judgment session, whereas practice with a horizontal incompatible mapping did not.

Based on a meta-analysis of the SNARC literature, Wood, Willmes, Nuerk, and Fischer (2008) concluded, "The polarity-correspondence account offers a parsimonious explanation for the SNARC effect in speeded binary classification tasks" (p. 490). However, they indicated that findings from patients with left-hemispatial neglect pointed toward a mental number line. Umiltà, Priftis, and Zorzi (2009) similarly concluded, "The most compelling evidence of the spatial nature of the representation of number magnitude comes from neuropsychological studies of neglect patients" (p. 567). This evidence is that when asked to bisect the interval between two digits, left-neglect patients report a value that is closer to the larger digit. But this bisection task is not a binary decision and therefore not directly relevant to the polarity-correspondence principle.

Implicit Association Test

In a standard IAT (Greenwald, McGhee, & Schwartz, 1998), left/right key presses are assigned to stimuli of two target-concept categories (e.g., flower vs. insect) and two evaluative attribute categories (e.g., pleasant vs. unpleasant). One category from each set is assigned to one response and the other category to the alternative response. The *IAT effect* refers to better performance when the mapping of two categories to responses is compatible (flower-pleasant vs. insects-unpleasant) than incompatible (insect-pleasant vs. flower-unpleasant).

The IAT is typically interpreted as a measure of relative association strength between target categories and positive/negative attitudes. However, without association (perceptual/conceptual overlap), structural overlap for categories coded as having positive or negative polarity along different dimensions could also underlie the IAT effect (Proctor & Cho, 2006). Rothermund and Wentura (2004) and Kinoshita and Peek-O'Leary (2005, 2006) made similar arguments and offered evidence of IAT effects that could be attributed to correspondence of a salience asymmetry for the target categories (unrelated to pleasant/unpleasant) with that of the attribute categories. One striking finding was that of Brendl, Markman, and Messner (2001): For an insect/nonword IAT, the "incompatible" mapping of insect-pleasant and nonword-unpleasant led to better performance than the "compatible" mapping.

Recently, Meissner and Rothermund (2013) developed a model that allowed them to dissociate contributions of recoding the IAT into a simpler task from those of evaluative associations. Their logic was that recoding should have a similar benefit for target and attribute categories, whereas associative processes should affect responses only to the target categories. Of importance, Meissner and Rothermund (2015) showed that recoding was responsible for the reversed insect-nonword IAT effect—a difference that cannot be attributed to conceptual overlap with the pleasant-unpleasant categories—although the associative process showed evidence that the insect category also activated the unpleasant category. Their study again suggested that conceptual overlap between the target and attribute dimensions is not necessary to obtain an IAT effect.

Metaphorical Spatial Relations

Judgments about concepts with metaphorical relations to vertical space are faster when the to-be-judged word is presented in the corresponding vertical position. Pecher, Van Dantzig, Boot, Zanolie, and Huber (2010) had participants judge whether entities associated with the sky (e.g., *helicopter*) or ocean (e.g., *whale*) could be found in the sky or the ocean. Responses were faster when words were presented at the position congruent with the task (up for sky, down for ocean), which Pecher et al. interpreted as counter to the polarity principle and consistent with a mental-simulation explanation. Lakens (2011) indicated that this task dependency could be attributed to different reference frames being adopted for the tasks and concluded, "The results of Pecher and colleagues provide little evidence against a polarity explanation" (p. 1). Van Dantzig and Pecher (2011) responded that the view of polarity as relative "is inconsistent with prior explanations of polarity effects" (p. 2). But Lakens's position is closer to that of Cho and Proctor (2007), who interpreted their similar demonstration of task framing's role in the MARC effect in terms of polarity correspondence.

Lakens (2012) performed a meta-analysis of studies that examined the vertical representation of valence, divinity, morality, and power, from which he concluded, "A polarity account provides a better explanation of reaction-time patterns in previous studies than an interference explanation [in terms of spatial conflict]" (p. 726). Lakens also reported an experiment in which participants first categorized moral and immoral words for one task and positive- and negative-affect words for another, with words presented in the center of a screen and the negative-polarity words occurring on 75% of trials for the condition of interest. In a subsequent task in which the positive- and negative-polarity words occurred equally often in the top and bottom positions, the metaphor-congruency effect was eliminated, which Lakens interpreted as supporting the polarity principle.

Recently, Santiago and Lakens (2015) obtained results they construed as counter to the polarity principle. Response eccentricity, which has a strong influence on orthogonal SRC, did not have a significant influence on a task that involved categorizing words as referring to the past or the future. Although nonsignificant, the past-left/future-right mapping advantage was numerically larger for the right keyboard location (65 ms) than the left location (40 ms), a difference that we have recently found to be significant in a replication conducted with a larger number of participants (Proctor & Xiong, 2015), consistent with the orthogonal SRC results. The SNARC effect also showed little influence of response eccentricity. For parity judgments, this would not be surprising, given that they yield a continuous function of numerical distance (Gevers et al., 2006). For magnitude judgments, the SNARC effect was again numerically larger for the right keyboard location (32 ms) than for the left location (17 ms). So, whether the response-eccentricity effect is limited to the orthogonal SRC task is unclear.

Conclusion

Table 1 summarizes the polarity-correspondence accounts, and their current status, for the four reviewed domains. The polarity principle has fared relatively well over the past decade: It still provides the only viable account for the range of orthogonal SRC effects; binary coding has

Table 1. Summary of Primary Effect for Each Domain, Along With the Polarity-Correspondence Account, Influential Factors, and Current Status of the Account

Domain	Primary effect	Polarity-correspondence account	Influential factors	Current status
Orthogonal stimulus-response-compatibility (SRC) effect	An up-right/down-left mapping advantage when up/down stimulus locations are mapped to left/right responses.	Up and right are coded as positive polarity, whereas left and down are coded as negative polarity; coding relative to multiple frames of reference determines the direction and size of the SRC effect.	Response eccentricity; responding hand; hand position; transfer.	Majority of evidence is consistent with the polarity-correspondence account.
Numerical-judgment effects				
Markedness of response codes (MARC)	Better performance when odd numbers are paired with a left response and even numbers with a right response.	Asymmetry coding: Odd is marked as negative polarity relative to even, positive polarity.	Task dependency; handedness.	The polarity-correspondence account provides the only offered explanation.
Spatial-numerical association of response codes (SNARC)	Better performance when small numbers are paired with a left response and large numbers with a right response.	Numbers categorized as small are coded as negative polarity and numbers categorized as large are coded as positive polarity (magnitude judgment).	Task dependency; transfer.	Recent behavioral evidence points toward a categorical basis.
Implicit Association Task (IAT)	Left/right key presses assigned to stimuli of two target categories (e.g., flower-insect) and two attribute categories (e.g., pleasant-unpleasant). One category from each set is assigned to one response and the other to the alternative response. Performance is better when the mapping of target and attribute categories is compatible (e.g., "flower"-"pleasant" vs. "insect"-"unpleasant") rather than incompatible (e.g., "insect"-"positive" vs. "flower"-"negative").	Asymmetries in salience: Unpleasant categories are "figure" (marked) relative to the pleasant categories as "ground" (unmarked); better performance is evident when each category dimension's salience is mapped correspondingly. Recoding: When asymmetries in salience within categories of the target and attribute dimensions are mapped compatibly, a binary discrimination of the stimuli rather than the four nominal categorizations is applied.	Block design; category-valence manipulation.	Evidence suggests that recoding based on salience asymmetries plays a major role in the IAT effect.
Metaphorical spatial relations	Concepts with metaphorical relations to vertical space are judged faster when the to-be-judged word is presented in the corresponding vertical position (e.g., *helicopter-sky; whale-ocean*).	Task framing in terms of polarity correspondence: Polarity of words (e.g., *helicopter-sky, whale-ocean*) is based on task-dependent frames of reference.	Transfer; response eccentricity.	Results are consistent with the polarity-correspondence account, allowing for task-dependent reference frames. Response eccentricity may not show the expected effect.

emerged as a feasible explanation of numerical-judgment data; coding asymmetries seem to account for the largest part of the IAT effect; and polarity coding provides a reasonable explanation for correspondence effects obtained in tasks with metaphorical spatial relations. The most basic point of the principle—that SRC effects do not necessarily imply association, or overlap, of the perceptual/conceptual content—has been borne out. In binary tasks, participants tend to code the stimulus and response alternatives in a relational manner, and the mapping of these relations influences performance. An intuitive rationale for the pervasiveness of polarity coding in laboratory tasks is that choices among alternative courses of action in daily life are often asymmetric (e.g., should I buy a season ticket or not?).

Despite its viability, deriving predictions from the polarity principle for specific task contexts is limited in several respects. One is that additional assumptions about the factors influencing coding must be made. Pecher et al. (2010) interpreted polarity coding as task independent, but that cannot be the case, as their results and those of Cho and Proctor (2007) and Gevers et al. (2006) illustrated. Task dependence is to be expected, if for no other reason than that the weighting of various reference frames or sources of stimulus information will vary (e.g., Yamaguchi & Proctor, 2012). Similarly, how response eccentricity influences response coding needs clarification. Also, although Proctor and Cho (2006) focused on location coding, some studies have suggested a role for handedness (Huber et al., 2015; Iani et al., 2014), and this role remains to be determined. Some authors have emphasized affective correspondence, and the extent to which the asymmetric codes are contentless is an issue that needs to be resolved. Finally, polarity coding is not the only contributor to binary SRC effects, and efforts like those of Rothermund and colleagues to separate the contributions of various factors are imperative.

Recommended Reading

Gevers, W., Verguts, T., Reynvoet, B., Caessens, B., & Fias, W. (2006). (See References). An article that presents a dual-route model of the SNARC effect.

Meissner, F., & Rothermund, K. (2015). (See References). An article providing evidence that the insect-nonword reversed IAT effect is due to recoding based on salience asymmetry.

Proctor, R. W., & Cho, Y. S. (2006). (See References). A comprehensive argument for polarity correspondence as a general principle for binary classification tasks.

Santiago, J., & Lakens, D. (2015). (See References). A study that varied response eccentricity in several tasks to evaluate the polarity principle.

Wood, G., Willmes, K., Nuerk, H.-C., & Fischer, M. H. (2008). (See References). A meta-analysis favoring polarity correspondence as an explanation for the SNARC effect.

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