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Polarity Correspondence: A General Principle for Performance of Speeded Binary Classification Tasks

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Differences in performance with various stimulus–response mappings are among the most prevalent findings for binary choice reaction tasks. The authors show that perceptual or conceptual similarity is not necessary to obtain mapping effects; a type of structural similarity is sufficient. Specifically, stimulus and response alternatives are coded as positive and negative polarity along several dimensions, and polarity correspondence is sufficient to produce mapping effects. The authors make the case for this polarity correspondence principle using the literature on word–picture verification and then provide evidence that polarity correspondence is a determinant of mapping effects in orthogonal stimulus–response compatibility, numerical judgment, and implicit association tasks. The authors conclude by discussing implications of this principle for interpretation of results from binary choice tasks and future model development.

Keywords: binary decisions, stimulus–response compatibility, Implicit Association Test, MARC effect, SNARC effect

Humans represent spatial information in at least two distinct forms. One, called “perceptual representations” by Logan (1994) and “coordinate spatial relations representations” by Kosslyn (1994), consists of spatial images with metric properties. Logan described such representations as “analog arrays of objects and surfaces” (p. 1015), and Kosslyn indicated that they contain “metric information about location, size, and orientation for both objects and parts” (p. 193). The second form, called “conceptual representations” by Logan and “categorical spatial relations representations” by Kosslyn, specifies discrete relations between objects or properties of single objects. According to Logan, “The conceptual representations are propositions, like *above* (*dash, plus*), that consist of a relation (*above*) and one or more arguments (*dash, plus*)” (p. 1015). Similarly, Kosslyn stated,

> The *categorical spatial relations encoding subsystem* produces a “spatial code” that specifies a categorical relation between two or more objects, parts, or characteristics, or specifies the size or orientation of a single object, part, or characteristic. These spatial codes, unlike the coordinates produced by the coordinate spatial relations encoding subsystem, are propositional representations. (p. 194)

Note, as in the example of *above* (*dash, plus*) used by Logan, a categorical representation is asymmetric in that a target object is coded relative to a reference object.

The distinction between coordinate and categorical forms of spatial representation is supported by considerable behavioral, neuropsychological, and neurophysiological evidence (e.g., Kosslyn, Thompson, Gitelman, & Alpert, 1998; Logan, 1995). Coordinate representations provide the primary basis for tasks requiring absolute judgments of distance and size (e.g., *X* is ____ cm away from a bar), whereas categorical representations provide the primary basis for tasks requiring relative judgments of position and size (e.g., *X* is above or below a bar). Categorical representations are not restricted to spatial configurations but apply as well to other domains such as time (e.g., before or after; Langacker, 1986).

Most research to date on categorical representations has focused on the encoding and identification of linguistic and nonlinguistic stimuli. However, research has suggested that stimuli and responses are coded in a common format at the stage of action selection or response selection (Hommel, Müsseler, Aschersleben, & Prinz, 2001). An implication of this common coding view is that categorical coding of responses is also possible and should be relied on extensively for performing tasks that involve relational judgments, most obviously binary classification tasks for which stimuli must be classified into one of two response categories. This implication is evident in the literature on spatial stimulus–response compatibility (SRC) effects, described later in the introduction, in which such effects are attributed to correspondence of spatial codes, but it has not been appreciated more generally. Moreover, within the compatibility literature, the emphasis has been on the perceptual and conceptual content of the categorical codes rather than their structure. In this article, we make a case for the proposition that the primary structural property of categorical codes, their asymmetric nature, provides a basis for correspondence effects that influence the speed and accuracy of response selection in a variety of binary classification tasks.

Binary Classification Tasks

Binary classification tasks have been widely used in cognitive psychology and related areas since the earliest days of the “cognitive revolution.” Nickerson (1972, 1973) noted the popularity of

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the binary classification task in two reviews published in the early 1970s and attributed this popularity to the fact that "it allows us to manipulate the perceptual or cognitive demands of a situation while keeping the motor component simple and constant" (Nickerson, 1973, p. 450). Use of the binary classification task was sufficiently widespread for Mudd (1983) to conclude that the task had become standard in cognitive research because "it provides an easily controlled situation for the observation of a relatively simple behavior, but a behavior that has been shown to be exquisitely sensitive to a number of meaningful psychological variables" (p. 4).

Since Nickerson's (1972, 1973) reviews and Mudd's (1983) book, the range of issues studied with binary classification tasks has expanded even further. Classifications may be "same"–"different," "yes"–"no," "true"–"false," "old"–"new," or "left"–"right." In many cases, the category of the stimulus presented on a trial is designated by a left or right keypress, but the response can be a unimanual switch or finger movement, a spoken category name, or any other means of distinguishing two categories. The tasks themselves range from simple (e.g., press a left key to a left light or right key to a right light, judge whether two letters match) to complex (e.g., indicate whether the spatial relation described by a sentence is true or false for a picture, judge the lexical status of a letter string) and differ in whether one stimulus (or category) or multiple stimuli are assigned to each response. Binary classification tasks are used to infer properties of representation and process across the full range of human information processing: perception, affective reaction, attention, language, memory, response selection, and motor control. In sum, such tasks are useful tools for assessing many psychological issues.

The processing stages presumed to be involved in the performance of various binary classification tasks vary across models and authors, as does the extent to which transmission of information between stages is characterized as discrete or continuous. However, it is generally agreed that a minimum of three different processing stages must be distinguished for a given task (Proctor & Dutta, 1995): *stimulus identification,* which is affected primarily by stimulus properties; *response selection,* which classifies the stimulus code into a response-category code and is affected by the stimulus–response (S-R) mapping; and *motor programming,* or response execution, which is influenced by physical response properties. For many tasks, additional processing stages such as memory scanning are presumed to intervene between stimulus identification and response selection. The logic for the use of left–right keypress responses in most studies is to keep the contribution of the motor-programming stage constant and minimal across conditions (Nickerson, 1973), allowing effects to be attributed to earlier processing stages.

SRC and Response Selection

A major factor affecting the response-selection stage is SRC, or the mapping of stimuli to responses. Among SRC effects, those involving spatial compatibility are the most widely investigated. Fitts and Deininger (1954) demonstrated that choice reaction time (RT) is shorter when spatial location stimuli are mapped to their corresponding locations in a spatial response array than when they are mapped to noncorresponding locations. Simon and Rudell (1967) found similar spatial SRC effects for tasks in which stimulus location is irrelevant, a phenomenon now known as the Simon effect. Spatial SRC effects are typically attributed to response selection being faster when the spatial stimulus code corresponds with that for the response location than when it does not (see, e.g., Hommel & Prinz, 1997; Proctor & Reeve, 1990). More generally, effects of SRC proper and Simon-type effects occur for stimulus and response sets that have dimensional overlap, which Kornblum (1991) defined as perceptual (physical) or conceptual similarity, regardless of whether the dimensions are spatial or nonspatial.

The well-known fact that SRC effects occur when the stimulus and response dimensions overlap has two consequences regarding how researchers tend to interpret data in the absence of overlap. One tendency is to assume that if there is no perceptual or conceptual similarity between the dimensions of the stimulus and response sets, then the results can be attributed to a process other than response selection. The other is to assume that a difference in performance with different S-R mappings, that is, an SRC effect, necessarily implies overlap between the stimulus and response sets along some perceptual or conceptual dimension. In the present article we argue that this view of response-selection processes in binary classification tasks omits a third, less obvious form of correspondence effect arising from the asymmetric nature of categorical stimulus and response codes that influences results in a wide range of research.

The Polarity Correspondence Principle

Kornblum and Lee (1995) performed an extensive evaluation of a dimensional overlap model proposed by Kornblum, Hasbroucq, and Osman (1990) using four-choice tasks. According to this model, when stimulus and response sets are perceptually or conceptually similar, a stimulus will automatically activate its associated response. Responding will be facilitated if that response is correct for the trial and slowed if it is incorrect. The model attributes the Simon effect entirely to this automatic activation and the SRC mapping effect to both automatic activation and differences in time to identify the assigned response through an intentional response-identification process. The conditions examined by Kornblum and Lee included ones in which the stimulus and response dimensions were chosen to have no perceptual or conceptual overlap and were thus predicted by the model to yield no SRC effect. These conditions involved the locations of four fingers on a hand icon mapped to four vocal letter-name responses and four letters mapped to keypresses made with the index and middle fingers of each hand. Contrary to prediction, mapping effects were obtained, with responding faster when the left-to-right order of locations was consistent with the order of the letters in the alphabet than when it was not. Kornblum and Lee attributed these SRC effects to the ordinal structure of the stimulus and response sets and added *structural similarity* to the definition of dimensional overlap. An important point is that structural similarity is much less obvious than is perceptual and conceptual similarity, as illustrated by the fact that Kornblum (1991) did not include it in his earlier definition of dimensional overlap.

Prior to Kornblum and Lee (1995), Miller (1982) and Proctor and Reeve (1985) showed structural correspondence effects in four-choice tasks with two-dimensional stimulus sets. For the stimulus set used by Proctor and Reeve—two letter identities, *O* and *Z,* of two sizes, large and small—letter identity is the salient feature. For a horizontal arrangement of four response keys on which the index and middle fingers of each hand are placed, the distinction between the left and right halves is salient. The basic finding was that RT is shorter for a left-to-right mapping of the type *o, O, Z, z,* for which the salient letter-identity feature distinguishes the two left and two right responses, than for one of the type *o, Z, O, z,* for which it does not. On the basis of these mapping effects and related benefits for precuing the two left or two right locations in spatial four-choice tasks, Proctor and Reeve proposed a salient features coding principle: The stimulus and response sets are coded with respect to their salient features, and translation of a stimulus into a response is fastest for mappings in which the salient features of the sets correspond. Evidence consistent with this principle has been obtained in a variety of four-choice tasks, including ones for which a two-dimensional set of spoken consonant–vowel stimuli mapped to four response locations was shown to yield effects similar to those of four stimulus locations mapped to the two-dimensional set of spoken consonant–vowel responses (Proctor, Dutta, Kelly, & Weeks, 1994).

A type of structural correspondence has also been shown to be a factor in binary choice tasks for which the stimuli vary along a vertical dimension and the responses along a horizontal dimension. In such tasks, RT is often shorter for the mapping of up to right and down to left than for the alternative mapping. Weeks and Proctor (1990) provided an explanation of this up–right/down–left advantage in accordance with the salient features coding principle, with the structure of the stimulus and response sets being asymmetries in the coding of the alternatives. Specifically, on the basis of results from word–picture verification tasks indicating that up and right are the salient polar referents for their respective dimensions, Weeks and Proctor hypothesized that performance is better with the up–right/down–left mapping because it maintains correspondence of the salient stimulus alternative with the salient response (and the nonsalient stimulus with the nonsalient response), whereas the other mapping does not. Substantial evidence supports the premise of Weeks and Proctor that the up–right/down–left advantage is a consequence of correspondence between asymmetric stimulus and response codes (Cho & Proctor, 2003), and it is generally accepted that such an account currently provides the only viable explanation of the advantage (e.g., Adam, Boon, Paas, & Umiltà, 1998; Lippa & Adam, 2001).

Our primary goal in this article is to provide evidence that asymmetric categorical coding of stimulus and response sets in binary choice tasks, and consequently effects due to correspondence of such codes, is relatively pervasive and extends far beyond the situation in which the up–right/down–left mapping advantage occurs. Weeks and Proctor (1990) originally used the terms "salient" and "nonsalient" to distinguish the alternative code types because their account was developed in the context of Proctor and Reeve's (1985) salient features coding principle. However, referring to one stimulus as salient and another as nonsalient may be interpreted as implying that the former is identified faster than the latter. We do not intend that implication and propose in this article that correspondence of asymmetric codes is a basic factor in binary choice tasks more generally. Consequently, we use the more neutral terminology of + *polarity* and − *polarity* and refer to the specific principle applied to binary choice tasks in general as the *polarity correspondence principle:*

> For a variety of binary classification tasks, people code the stimulus alternatives and the response alternatives as + polarity and − polarity, and response selection is faster when the polarities correspond than when they do not.

The point of this principle is that perceptual or conceptual overlap of dimensions is not necessary to produce SRC effects in binary tasks; a form of structural overlap, + and − polarity, is sufficient.

The rest of the article is organized as follows. In the first half, we develop the case for polarity coding of stimuli and responses and polarity correspondence by examining the extensive literature on word–picture and sentence–picture verification tasks involving spatial relations. This literature provides the most detailed database concerning polarity coding and was cited by Weeks and Proctor (1990) to justify their claim that the right–left and up–down dimensions are coded asymmetrically in orthogonal SRC tasks. However, a detailed examination of this literature with regard to the issue of correspondence of polarity codes has not been undertaken previously. Such an examination is necessary because descriptions of the verification literature often limit polarity coding to words and attribute its effect to the time for encoding (i.e., stimulus-identification time) and not response selection. In the first section, we proceed step by step through the database for this task and show that it (a) provides unambiguous evidence for polarity coding and (b) indicates that such coding is not restricted to linguistic stimuli but also occurs for nonlinguistic stimuli. We then provide evidence from the verification literature that polarity coding occurs for responses as well and show that an overlooked model by Seymour (1973), which emphasizes correspondence of the polarities for the stimulus and response codes, provides the most adequate account of the primary findings in the verification literature.

A criterion for establishing the validity of an explanation is that of *consilience,* a concept introduced in the 19th century by the scientific methodologist William Whewell (1840) and advocated more recently by E. O. Wilson (1998) in his bestseller *Consilience: The Unity of Knowledge.* According to Thagard (1978), "A theory is said to be consilient if it explains at least two classes of facts" (p. 79). The idea is that a theory gains in credibility to the extent that it is able to unify seemingly unrelated facts. Therefore, in the second half of the article, we demonstrate that the principle of polarity correspondence is consilient by providing evidence for such correspondence effects in three disparate categories of phenomena that have been interpreted in other manners: orthogonal SRC effects that vary as a function of response eccentricity, S-R correspondence effects for numerical judgments, and the affective implicit association effect. For each category, we show that data indicate that several findings that have been interpreted in terms of correspondence of the stimuli and responses along some perceptual or conceptual dimension can be attributed at least in part to correspondence of the polarities of the stimulus and response codes. That polarity correspondence has an effect in a range of binary classification tasks provides confirming evidence that polarity coding is a basic aspect of human information processing.

The *above*/ABOVE Advantage in Word–Picture Verification Tasks

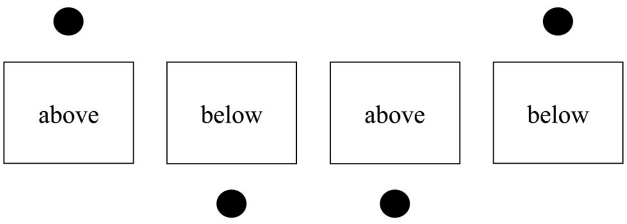
Word–picture verification tasks, and their close relatives sentence–picture verification tasks, have been used widely to examine judgments concerning spatial relations, leaving a detailed record of findings and models. In this section, we review the main findings in the spatial verification literature, developing the evidence that leads to the polarity correspondence principle. Each major point in the chain of reasoning is numbered and set off from the body of the text.

The above/ABOVE Advantage

Seymour (1969) conducted the first study that used the word–picture verification task. He displayed the word *above* or *below* inside a square that had a small, filled circle located ABOVE or BELOW it (see Figure 1). The task was to indicate whether the circle's location matched that described by the word by saying "yes" or "no." RT was 75 ms shorter to *above*/ABOVE than to *below*/BELOW, *above*/BELOW, and *below*/ABOVE pairs. Chase and Clark (1971) showed that this *above*/ABOVE advantage also occurs when yes–no responses are made with left–right key-presses. Seymour proposed that the *above*/ABOVE advantage is due to "a relatively inflexible tendency to scan shapes from the top downwards" (p. 35). However, the scanning hypothesis was rejected because Chase and Clark found similar results when the need to scan was removed by presenting the circle on only half the trials, always at the same location within a trial block.

Polarity Coding: Chase and Clark's (1971) Serial-Stage Verification Model

Chase and Clark (1971) proposed a serial-stage model to account for their and Seymour's (1969) results that distinguishes four stages: word encoding, picture encoding, comparison, and response (see Figure 2). For word encoding, Chase and Clark proposed that less time is needed to encode *above* than *below* because *below* is marked linguistically relative to *above.*[1] For picture encoding, they assumed that participants attend to the upper location and, when the circle is below the square, infer it to be in the lower position from its absence in the upper position. They based this assumption on their findings that the lower circle does not have to be physically present. Because an additional inference is required to encode the circle below square relation compared with circle above square, the duration of encoding is longer for the former picture than for the latter.



(a) *above*/ABOVE (b) *below*/BELOW (c) *above*/BELOW (d) *below*/BELOW

Figure 1. Typical stimulus configurations in word–picture verification tasks. The correct responses would be "yes" or "true" to displays a and b and "no" or "false" to displays c and d.

At the comparison stage, the word and picture encodings are compared, with the default "truth value" assumed to be true. If the encodings do not match, then an additional operation is required to change the value to false. This additional operation for false word–picture pairs at the comparison stage accounts for the fact that "true" responses are usually faster than "false" responses. The response stage "merely takes the final truth value of the Comparison stage—*true* or *false*—and converts it into a push of the correct 'true' or 'false' button" (Chase & Clark, 1971, p. 323).

Clark and Chase (1972) proposed an expanded version of this model for verification tasks in which a sentence describing a relation (e.g., star is below plus) is compared with a picture. This task differs in two critical respects from the word–picture verification task. First, the sentence and picture are typically presented on separate sides of the display, and as a consequence, only one or the other can be fixated at any one time, making order of processing a factor. Second, for sentences, which of the two objects is the referent for the other can vary from trial to trial. Thus, if the participant sees the picture first, they do not know whether to encode it as one item above the other or one item below the other (e.g., star above plus or plus below star).

Clark and Chase (1972) developed sentence-first and picture-first versions of the model. The sentence-first model attributes the RT advantage for *above* to the stage of linguistic encoding, for which the unmarked relation above can be encoded faster than the marked relation below. The assumption of less encoding time for *above* than *below* is the same as that Chase and Clark (1971) made to explain word–picture verification, but in the treatment provided by Clark and Chase (1972), this markedness relation was explicitly depicted in terms of opposite polarities for *above* and *below:*

> The antonymy of *above* and *below* is taken care of in the representations [+Verticality[+Polar]] and [+Verticality[−Polar]], respectively, in which the feature +Verticality stands for all the verticality relations that *above* and *below* have in common and ±Polar indicates the polarity of the comparison. (p. 477)

Unlike the variation of the model used for Chase and Clark's (1971) word–picture verification study, the sentence-first version postulated for the sentence–picture verification task "makes no provision for the different encoding latencies of *above* and *below* at Stage 2" (Clark & Chase, 1972, p. 478), the pictorial encoding stage. Clark and Chase (1972) based this assumption on empirical findings and the idea that the relation described in the sentence determines which relation is encoded in the figure.

The picture-first model assumes that the picture is always encoded as A above B in the picture encoding stage, which is Stage 1 for this task. The duration of Stage 2, sentence encoding, is affected by markedness in the same way as it is in the sentence-first model, with *above* encoded faster than *below.* If the relation encoded for the picture (e.g., star above plus) is not identical to that

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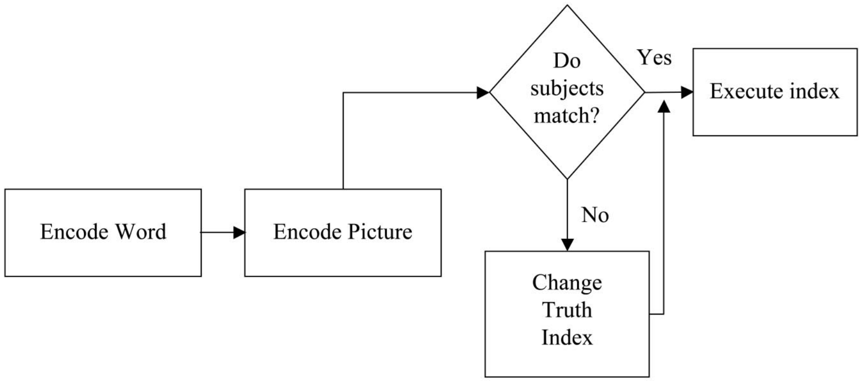
[1] A term is said to be *marked* when it does not neutralize to describe the dimension and *unmarked* when it does.



Display	Word Encoding	Picture Encoding	Comparison	Response
above/ABOVE	C above S	C above S	Match	True
below/BELOW	C below S	C below S	Match	True
above/BELOW	C above S	C below S	Mismatch	False
below/ABOVE	C below S	C above S	Mismatch	False

Figure 2. Depiction of Chase and Clark's (1971) serial-stage model of word–picture verification. Word encoding time is shorter for circle (C) above square (S) than for circle below square. The truth index is set for "true," and an extra operation is performed to change it to "false" when the word and picture relations mismatch. From "On the Process of Comparing Sentences Against Pictures," by H. H. Clark and W. G. Chase, 1972, *Cognitive Psychology, 3,* p. 480. Copyright 1972 by Academic Press. Adapted with permission.

encoded for the sentence (e.g., plus below star or star below plus), then the sentence representation is translated into a relational coding that conforms to that of the picture (in this example, *above*) before the comparison stage is completed, adding additional time.

The important point conveyed by Clark and Chase's (1972) verification model is

> 1. The *above*/ABOVE advantage has its basis in part in polarity coding of the words and/or picture stimuli.

Determinants of Asymmetric Coding of Picture Stimuli

The version of the verification model proposed by Chase and Clark (1971) for the word–picture verification tasks assumes that "above" is encoded faster than "below" at the word and picture encoding stages. Because "above" has a benefit over "below" at both stages, the RT disparity for *above*/ABOVE and *below*/BELOW should be larger than that for *above*/BELOW and *below*/ABOVE, as in Chase and Clark's data. Olson and Laxar (1973) similarly found *right*/RIGHT and *right*/LEFT advantages of 140 ms and 40 ms for a version of the word–picture verification task in which a circle was located to the left or right of a square containing the word *left* or *right.*

Clark and Chase (1972) tested the sentence-first model in their Experiment 1, in which participants had to encode a sentence on the left and then shift fixation to a picture on the right. Unlike the word–picture verification studies, the results showed the advantage for *above*/BELOW over *below/ABOVE* to be about equal to that for *above*/ABOVE over *below/BELOW*. This result agrees with the sentence-first model because the model attributes the advantage solely to the initial linguistic coding. For the situation in which the picture was encoded first, Clark and Chase's (Experiment 2) results were more like those for the word–picture verification tasks: The advantage for *above* was restricted primarily to the *above*/ABOVE pairs. This outcome agrees with the assumption of the picture-first version of their model that a mismatch in the spatial relation encoded for the picture (ABOVE) and that encoded for the sentence (i.e., those trials for which the sentence says *below*) requires additional time to recode the linguistic relation.

Clark and Chase (1974) suggested that the previous experiments and linguistic facts imply three ordered rules for determining whether vertically arrayed stimuli are coded as A above B or B below A:

> Rule 1: Whenever the O [observer] consciously decides to code the location of A [or B], he will code the picture as ABOVE(A, B) [or BELOW(B, A)].
>
> Rule 2: Whenever the O perceives B [or A] to be a stable, prominent point of reference, he will code the picture as ABOVE(A, B) [or BELOW(B, A)].
>
> Rule 3: Whenever neither of the above conditions holds, the O will code the picture as ABOVE(A, B). (p. 102)

They conducted three experiments to verify these rules. In the first, vertically configured pictures were presented that were symmetrical (e.g., * above *o*) or asymmetrical (e.g., * above a horizontal line). Participants were to write a description for each of the possible configurations of the symmetric and asymmetric picture sets. Consistent with Rule 2, for asymmetric pictures, the position of the star relative to the line was described most often (72% vs.

18%). In agreement with Rule 3, for symmetric pictures, 70% of the descriptions included *above* and 18% *below*. The asymmetric pictures also showed a slight bias to encode the relation as above (54% above vs. 35% below).

Clark and Chase's (1974) Experiment 2 used a picture-first sentence–picture task for which the pictures were the asymmetric star–line combinations from their Experiment 1. The results showed that 7 of 12 people were following Rule 2, coding the location of the star relative to the line, and 5 were following Rule 3, coding the location of the top object relative to the bottom object. Clark and Chase's Experiment 3 was similar, except for using the sentence-first procedure. The parameter estimates showed an additional encoding time for the word *below* relative to *above* but no extra time to transform the sentence representation to match the picture encoding. Thus, they concluded, in agreement with Rule 1, that the picture was encoded in a manner consistent with the sentence encoding, even though the picture was asymmetric.

The results of Clark and Chase's (1974) experiments thus indicate

> 2. For pictorial information, whether ABOVE will be coded as + polarity and BELOW as − polarity, or vice versa, is determined by a variety of factors including preexisting biases, stable reference points, and intentions.

The above/ABOVE Advantage Is Not Due to the Time to Encode Marked Versus Unmarked Words

The main reason Chase and Clark (1971) attributed the difference in time for *above* and *below* to linguistic markedness is that they found no *above*/ABOVE advantage when up and down arrows, which are nonlinguistic stimuli, signaled above or below. However, Just and Carpenter (1975) proposed instead that the arrow displays used by Chase and Clark allowed participants to respond directly on the basis of perceptual properties. They said,

> For example, the decision rule could have been 'Respond *true* if the arrowhead is close to the dot [circle]; otherwise respond *false*'. Subjects may not have compared the 'meaning' of the arrow to the representation of the location of the dot. Rather they might have responded on the basis of global perceptual features. (pp. 428–429)

Just and Carpenter (1975, Experiment 1) tested this proposal with arrows that were three carets, all pointing up or down. The carets were displayed in a left column, and a vowel and a consonant, one above the other, were shown in a right column. A "yes" or "no" response button was to be pressed, depending on whether the arrows designated the location of the vowel. With this arrangement, responses could not be based on global perceptual features. In contrast to the results of Chase and Clark's (1971) Experiment 2, Just and Carpenter found an *above*/ABOVE advantage of 76 ms (and 0.4% in percentage of error), leading them to conclude, "the current result suggests that the advantage of upwardness does not lie in the encoding of words *per se*" (p. 430).

Just and Carpenter's (1975) Experiment 2 evaluated the possibility that the *above*/ABOVE advantage might still reside in the stage of encoding the word or symbol. Verification judgments were made about the position of one letter relative to another in a square array of four consonants. On each trial, participants first heard a sentence that described one letter as above or below another, left or right of another, or diagonal to another. For example, the sentence might be "X is above Y." When the participant had comprehended the sentence, he or she pushed a button. The array was presented 500-ms later, and the participant responded "true" or "false" by pressing one of two buttons. Both an *above*/ABOVE advantage (78 ms and 2.1%) and a *right*/RIGHT advantage (118 ms and 2.6%) were obtained. Because sentence encoding was completed prior to presentation of the array, these effects cannot be attributed to sentence encoding time. In addition, because the sentence was attended to first, the applicable verification model is the sentence-first version, according to which there should be no difference in picture encoding time for the two relations.

In Just and Carpenter's (1975) Experiment 3, the letter array was held constant, allowing it to be memorized, and RT was measured from the onset of a visual sentence. "True" RT showed an 825-ms *above*/ABOVE advantage and a 743-ms *left*/LEFT advantage, whereas "false" RT showed advantages of 437 and 494 ms for *below*/ABOVE over *above*/BELOW and *right*/LEFT over *left*/RIGHT, respectively. But because RT was over 3.5 s and was quite variable and the *right*/RIGHT advantage found in Experiment 2 reversed to a *left*/LEFT advantage, the authors concluded that the results differed from those of Experiment 2. They attributed this difference to removal of picture encoding: "The absence of a reliable advantage suggests that perhaps the effect is due primarily to picture encoding, the stage that was eliminated with the present procedure" (p. 435).

The following tentative conclusion can be drawn from the results of the three experiments:

> 3. The *above*/ABOVE advantage is obtained with upward and downward pointing arrows, as well as with the words *above* and *below,* and is not due to the duration of the stage of encoding the relation signaled by the word or arrow.

Picture Encoding Account

Just and Carpenter (1975) suggested as an alternative that the *above*/ABOVE advantage is due entirely to picture encoding: "The proposal that we advance attributes the advantage of *above* and *right* to the picture-encoding stage" (p. 437). According to their account,

> In a situation where a sentence precedes a picture, the preposition of the sentence determines the nature of the encoding of the picture. The words *above* and *right* engender a more natural, canonical and therefore faster encoding. *Below* and *left* cause the picture to be encoded in a way that is not canonical and consumes more time. (1975, pp. 437–438)

More generally, Just and Carpenter proposed that, rather than linguistic marking affecting the time to encode the sentence or word, "the marking effect occurs whenever a linguistically marked description determines the encoding of information from a second source, like a picture" (p. 438).

The main evidence on which Just and Carpenter (1975) based their conclusion was that (a) their Experiment 2 "showed the usual marking effect, although sentence encoding time was not included in the response latency" (p. 438) and (b) in their Experiment 3, in which the picture was encoded in advance, "the marking effect was abolished for *right–left,* and made unreliable for *above–below*" (p. 438). However, those experiments do not provide strong evidence that picture encoding is the source of the *above*/ABOVE advantage because the four-element displays likely required scanning, and this advantage was evident in Experiment 3 as well as Experiment 2. Moreover, as we show in the next major subsection, results of other experiments indicate that picture encoding time is not the primary determinant of the *above*/ABOVE advantage.

Summary

Chase and Clark (1971; Clark & Chase, 1972) provided the most detailed model of the word– and sentence–picture verification tasks. They developed three versions, one for word–picture verification tasks in which the picture is asymmetric and two for sentence–picture verification tasks in which the sentence or picture is viewed first. In all versions, *above* is encoded faster than *below* at the word–sentence encoding stage. The models differ in whether participants are biased to attend to the top of the picture, encode the picture in a manner consistent with the sentence, or encode the picture with the ABOVE relation and transform a mismatching sentence to the same relation at the comparison stage. The differences in picture processing for the various models seem reasonable when the symmetric or asymmetric nature of the pictures and the viewing order (sentence or picture first) are considered. Just and Carpenter's (1975) account differs from Chase and Clark's in attributing the *above*/ABOVE advantage solely to picture encoding time, even when the picture is encoded after the word, sentence, or arrow.

The research conducted by Chase and Clark (1971; Clark & Chase, 1972, 1974) and Just and Carpenter (1975) focused on whether the *above*/ABOVE advantage is due to differences in time for word–sentence encoding or picture encoding. The only exception is the picture-first version of Clark and Chase's (1972) model, for which the encoding of the initial picture could also add time to the comparison stage when it mismatched the relation described by the sentence. Otherwise, the conclusions from the two research groups are in close agreement, as captured by the closing statements in a review chapter coauthored by Clark, Carpenter, and Just (1973):

> In all, it is apparent from the available evidence that there is a very abstract, but well-organized relation between language and perception: both linguistic and perceptual coding must rely on the common notions of polarity, reference point, underlying dimension, and conditions of application. (p. 378)

Thus, regardless of whether one is dealing with verbal descriptions or spatially arranged pictures,

> 4. The two alternatives along the underlying dimension differ in polarity, with the polarity determined by the reference point for the dimension.

Research conducted since 1975 using the sentence–picture verification task to examine spatial judgments has not contradicted the view that such judgments are typically based on asymmetrically coded abstract representations, although other processes contribute when the complexity of the displays is increased (Logan, 1994; Underwood, Jebbett, & Roberts, 2004).[2]

Correspondence of Polar Stimulus and Classification Codes

Because the studies described in the prior section used similar response sets, it is not surprising that the accounts focused on time to encode stimuli. However, several results imply that stimulus encoding duration is not the main source of the effects. Consequently, Seymour (1973) developed a model that attributes the *above*/ABOVE advantage to response selection. The main idea of his model is that correspondence of the polarity codes for the stimulus features with those for the "yes" (+ polarity) and "no" (– polarity) responses is the major cause of the effects.

Evidence Implying a Comparison, or Response-Selection, Locus

In Clark and Chase's (1972) Experiment 4, the word *above* or *below* was presented to the left of a picture of a star and plus sign, and a left or right keypress was made. Participants performed a verification task in which "true"–"false" responses were made based on whether the word described the location of the star relative to the plus and performed a "forced-choice" identification task in which "star"–"plus" responses were made based on whether the word described the location of the star or the plus sign. The *above*/ABOVE advantage was found for the verification task but not the forced-choice task. If the advantage were due to stimulus encoding, it should have been evident in both tasks. That the advantage is dependent on the required judgment suggests that its locus is in the comparison stage in which the encoded information is classified into responses.

Chase and Clark (1972) described a study by Young and Chase (1971) that also implies a comparison locus for the *above*/ABOVE advantage. Participants were told to convert negative relations (e.g., "isn't above") to positive (e.g., "below") by changing the preposition before making a comparison to the picture. RT was longer when the relation was negative and had to be converted to positive than when it was positive initially, and the *above*/ABOVE advantage reversed to an *isn't below*/ABOVE advantage. Chase and Clark noted, "It was not that the printed word *above* is easier to read and discover than *below,* but rather that the encoded word *above* takes less time in the process than *below*" (p. 213). Because these results provide evidence that the duration of word encoding is not the distinguishing factor for *above* and *below* and there is no

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[2] When participants can view the sentence for as long as they want prior to initiating the picture display, they can adopt a strategy of creating a coordinate spatial representation (visual image) of the relation described in the sentence that does not yield an *above*/ABOVE advantage (MacLeod, Hunt, & Mathews, 1978; Mathews, Hunt, & MacLeod, 1980; Reichle, Carpenter, & Just, 2000). Because time and effort are required to generate the mental image, less than 25% of participants adopt the imagery strategy when not instructed explicitly to do so (MacLeod et al., 1978). It is unlikely that the imagery strategy is used in most versions of the verification task, for which unlimited viewing time for the sentence is not allowed. Thus, the conclusion reached by Clark et al. (1973), that polar codes underlie most spatial verification judgments, remains valid today.

reason to think that the conversion on negative trials would be more difficult for one relation than the other, they imply that the effect of polarity from the final encoded representation is on the duration of the subsequent process by which a response is selected.

Seymour (1973) used the display of a filled circle above or below a box containing the word *above* or *below* but told participants to say "no" to matches and "yes" to mismatches. With this reverse mapping, *below*/BELOW was 11 ms faster than *above*/ABOVE, compared with the 68-ms *above*/ABOVE advantage found by Seymour (1969) with a normal mapping. Seymour (1971) showed similar results for the words *large* (unmarked) and *small* (marked) presented below large and small squares: *large*/LARGE showed an 82-ms benefit over *small*/SMALL when matching pairs were assigned to "yes," but this benefit was eliminated when they were assigned to "no." Seymour's results are counter to Chase and Clark's (1971) model because it attributes the RT differences to encoding times that should be unaffected by the S-R mapping.

In summary, the experiments described in this section imply the following:

> 5. The locus of the *above*/ABOVE advantage is in the duration of the comparison stage of processing and not the duration of the encoding stage.

Schaeffer and Wallace's (1970) Comparison Model for Same–Different Judgments

Schaeffer and Wallace (1970) developed a model to explain "same"–"different" judgments about the meanings of words from two superordinate categories composed from two subordinate categories (for example, living things [mammals and flowers] and nonliving things [metals and fabrics]). Although this model does not deal with coding alternatives as + or − polarity, Seymour (1974a) relied on it for development of his model because the model illustrates how stimulus codes can affect performance through their impact on comparison processes. It has the following properties:

> (a) When word meanings are compared, the concepts underlying the words are compared in their entirety; (b) concepts are composed of elements; (c) the connection between the elements of the concept which represent the task decision criterion forms the decision unit for the comparison; and (d) the amount of information that must be sampled from a decision unit, its threshold, is a function of the overlap between the concepts: the greater the overlap, the smaller the amount of information required for a "same" judgment, and the greater the amount of information for a "different" judgment. (Schaeffer & Wallace, 1970, p. 145)

In other words, according to the model, similarity primes the "same" response and dissimilarity the "different" response. Thus, responses should be faster to stimuli that are more similar than to ones that are less similar when they are to be classified as "same" but slower when they are to be classified as "different." Such findings provided the main evidence for Schaeffer and Wallace's model: Belonging to the same subordinate category facilitated "same" responses for words classified as "same" if they were from the same superordinate category, whereas belonging to the same superordinate category slowed "different" responses when words were classified as same only if they were from the same subordinate category (Schaeffer & Wallace, 1969, 1970).

The primary point of Schaeffer and Wallace's (1970) model is

> 6. Stimuli are coded in terms of multiple features, and the effect of any given feature on performance depends on the response category to which it is assigned.

Seymour's Polarity Coding Account

Seymour (1973) based his verification model on the idea that "variation in reaction time is . . . an index of the ease or difficulty of translating from a particular display to a particular response" (p. 198). In his model, above and below are coded as + and − on the dimension of verticality, and large and small as + and − on the dimension of size. Also, same and different are coded as + and − on the dimension of sameness, and "yes" and "no" responses as + and − on the dimension of affirmation. The model assumes "that effects of the *above–below* or *large–small* type reflect facilitation in selection of a 'Yes' response to stimuli having predominantly positive semantic representations" (Seymour, 1973, p. 198). Selection of a "yes" response is faster when the word–picture pair is *above*/ABOVE than when it is *below*/BELOW because the "above" relations are the same polarity (+) as the "yes" response, but the "below" relations are not.

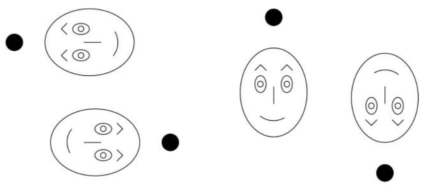
Seymour (1973) outlined the model more specifically as follows:

> Essentially, the outcome of the encoding stages for the sentence and the picture will be a representation of values on a verticality dimension and of a value on a sameness dimension. This composite representation of verticality features and congruence features will include both positive and negative components, with the predominance of positive features being greatest in the case of a *same* unmarked term and picture, for example, *above*/ABOVE or *large*/LARGE. If the "Yes" response is selected by sampling semantic features until a threshold is exceeded, this will occur sooner for *above*/ABOVE than for *below*/BELOW, on account of the predominance of positive components in the *above*/ABOVE representation. (p. 196)

Seymour (1973) interpreted his findings that the *above*/ABOVE and *large*/LARGE advantages are eliminated when the S-R mapping is reversed to one of saying "no" to matching pairs and "yes" to mismatching pairs as evidence in favor of his model, which attributes the polarity effects to response selection, over that of Chase and Clark's (1971), which attributes the effects to stimulus encoding.

Frames of Reference

Seymour (1974a) modified his 1973 account slightly in attributing the polarity effects to adjustments of the "yes" and "no" response criteria, rather than to the rate at which the evidence accumulates in the response mechanism, and called it the "response availability" model. Two experiments contrasted implications of this response availability model against the perceptual scanning and linguistic encoding time accounts described earlier. The experiments used a schematic face as a reference frame relative to which a dot was to be judged as above or below. In Experiment 1, the face was positioned horizontally, with the top of the head to the left or right (randomly intermixed) and a dot located at the top of the head (above) or the chin (below; see Figure 3a); the word *above* or *below* was displayed above the face.



(a) Horizontal (b) Vertical

Figure 3. Displays from Seymour's (1974a) study in which the location of a filled circle was judged relative to a face context. The face could be oriented along the horizontal dimension (a) or the vertical dimension (b). For the four examples shown, the correct response would be "yes" when presented with word *above* and "no" when presented with the word *below*. From "Asymmetries in Judgments of Verticality," by P. H. K. Seymour, 1974, *Journal of Experimental Psychology, 102,* p. 448. Copyright 1974 by the American Psychological Association.

In Experiment 2, the face was in an upright or inverted position (see Figure 3b). To explain the experimental results with the response availability model, Seymour (1974a) analyzed the various location features for each task into positive, negative, or neutral and provided summed positivity and negativity values for each stimulus condition. To determine the relative RT for "true" pairs, he counted the number of + features, and to determine the relative RT for "false" pairs, he counted the number of − features.

Table 1 contains Seymour's (1974a) assumptions regarding the polarity values for his Experiment 2, in which the face context was upright or inverted. Consistent with the markedness distinction, words were coded with *above* as + and *below* as –. The upright face was coded as + and the inverted face as –, because upright is the canonical orientation. The dot was coded as + when located above the figure and − when located below it. Seymour assumed that each of these stimuli received a + code for all conditions because they involved the vertical as opposed to horizontal axis. He also assumed that dot location was coded relative to face top, being + when the dot was at the top (above the face) and − when it was at the bottom (below the face). A match of the word with the relation between the dot and face was assigned a +, and a mismatch a –; this is the outcome with which the response must agree if it is to be correct. The decision itself was given + if it was "yes" and − if it was "no." The idea seems to be that a determination is first made of whether the word matches the relation, and then a "true"–"false" decision is made.

With the normal face the summed positivity is larger for *above*/ABOVE (9) than *below*/BELOW (6), thus predicting an *above*/ABOVE advantage, as obtained (75 ms). With the inverted face the difference is less (7 for *above*/ABOVE; 6 for *below*/BELOW), and this advantage should be reduced: In fact, there was a tendency toward a *below*/BELOW advantage of about 25 ms. For "no" responses, the model predicts that *above*/BELOW will be faster than *below*/ABOVE with the normal face orientation but slower with the inverted orientation, as was found (normal face = 125 ms *above*/BELOW advantage; inverted face = 125 ms *below*/ABOVE advantage).

For Experiment 1, Seymour (1974a) assumed that the horizontal dimension was − vertical (see Table 2). Thus, dot and face location each received a − value for all conditions because their

Table 1
Possible Semantic Representation of Normal and Inverted Face above–below *Displays (Seymour, 1974a)*

	Normal				Inverted			
Item	*above*/ABOVE	*below*/BELOW	*above*/BELOW	*below*/ABOVE	*above*/ABOVE	*below*/BELOW	*above*/BELOW	*below*/ABOVE
Word	+ vert/+ polar	+ vert/− polar	+ vert/+ polar	+ vert/− polar	+ vert/+ polar	+ vert/− polar	+ vert/+ polar	+ vert/− polar
Dot	+ vert/+ polar	+ vert/− polar	+ vert/− polar	+ vert/+ polar	+ vert/− polar	+ vert/+ polar	+ vert/+ polar	+ vert/− polar
Face	+ vert/+ polar	+ vert/+ polar	+ vert/+ polar	+ vert/+ polar	+ vert/− polar	+ vert/− polar	+ vert/− polar	+ vert/− polar
Dot, face top	+ match	− match	− match	+ match	+ match	− match	− match	+ match
Word, dot, face top	+ match	+ match	− match	− match	+ match	+ match	− match	− match
Decision	+ true	+ true	− true	− true	+ true	+ true	− true	− true
Summed positivity	9	6	5	6	7	6	5	4
Summed negativity	0	3	4	3	2	3	4	5

Note. vert = verticality; polar = polarity. Adapted from "Asymmetries in Judgments of Verticality," by P. H. K. Seymour, 1974, *Journal of Experimental Psychology, 102,* p. 451. Copyright 1974 by the American Psychological Association.

Table 2
Possible Semantic Representation of above–below *Displays When the Reference Face Was Horizontally Oriented (Seymour, 1974a)*

Item	*above*/ABOVE	*below*/BELOW	*above*/BELOW	*below*/ABOVE
Word	+ vert/+ polar	+ vert/− polar	+ vert/+ polar	+ vert/− polar
Dot	− vert/→ right	− vert/← left	− vert/← left	− vert/→ right
Face	− vert/→ right	− vert/→ right	− vert/→ right	− vert/→ right
Dot, face top	+ match	− match	− match	+ match
Word, dot, face top	+ match	+ match	− match	− match
Decision	+ true	+ true	− true	− true
Summed positivity	5	3	2	2
Summed negativity	2	4	5	5
Neutral components	2	3	2	2

Note. vert = verticality; polar = polarity. Adapted from "Asymmetries in Judgments of Verticality," by P. H. K. Seymour, 1974, *Journal of Experimental Psychology, 102,* p. 450. Copyright 1974 by the American Psychological Association.

positions differed along the horizontal axis. However, the left and right positions were treated as neutral because Seymour assumed that "the horizontal dimension probably is not bipolar" (p. 451). The summed positivity was 5 for *above*/ABOVE and 3 for *below*/BELOW, predicting an *above*/ABOVE advantage: A 66-ms *above*/ABOVE advantage was in fact obtained that did not differ between the left and right face orientations. The summed negativity values were 5 for *above*/BELOW and *below*/ABOVE, predicting no difference, which again was consistent with the results. This experiment shows that the *above*/ABOVE advantage can occur relative to a reference object even when that object is oriented along the horizontal dimension.

Seymour (1974a) concluded that the response availability model predicted not only the patterns of results obtained for the "yes" responses but also those for the "no" responses:

> The summed negativity scores correctly predict (a) the absence of a difference between *above*–below and *below*–above displays when the face is horizontal, (b) similar RTs for *above*–below for normal and inverted face displays, (c) faster times for *below*–above when the face is inverted than when it is normally oriented, and (d) a reversal in the direction of the difference between *above*–below and *below*–above for normal vs. inverted face displays. (Seymour, 1974a, p. 455)

Seymour's (1974a) study provides strong evidence for the following:

> 7. Stimuli are coded as + or − polarity on multiple dimensions, and the aggregate correspondences of these stimulus polarity codes with response polarity codes is the critical factor producing the *above*/ABOVE advantage and related effects.

Effects of Irrelevant Stimulus Dimensions

Seymour (1974b) reported three experiments that used versions of the word–picture verification task in which participants judged the location of an irrelevant word relative to a square, making the spoken response "yes" or "no." He called the resulting correspondence effects Stroop-type effects, but they can also be regarded as Simon-type effects, at least in Experiments 1 and 2, because they involve correspondence of the irrelevant stimulus dimension with the response. For the critical irrelevant-word conditions, instead of a neutral stimulus above or below the square that contained the word *above* or *below,* a congruent or incongruent word occurred.

In Experiments 1 and 2, the irrelevant word was *yes* or *no,* a distinction that has conceptual overlap with the "yes"–"no" and right–wrong responses used in Experiments 1 and 2, respectively. In Experiment 1, the neutral stimuli showed a 113-ms advantage for *above*/ABOVE over *below*/BELOW and no interaction of condition (control, corresponding, noncorresponding) with display (*above*/ABOVE, *above*/BELOW, *below*/ABOVE, *below*/BELOW). However, the *above*/ABOVE advantage increased to 128 ms when the irrelevant word was *yes* and decreased to 50 ms when it was *no.* For Experiment 2, the results showed a similar, weaker interaction, with the *above*/ABOVE advantage being 75 ms for neutral stimuli, 69 ms for *right,* and 44 ms for *wrong.* The smaller effect size is expected because the words *right* and *wrong* have less overlap with the "yes"–"no" responses than do the words *yes* and *no*. In both experiments, the irrelevant word facilitated responding for *above*/ABOVE displays relative to *below*/BELOW displays if it was + polarity and interfered if it was – polarity.

In Experiment 3, the irrelevant word was *up* or *down.* The matching pairs showed the same pattern of results as in Experiments 1 and 2. The *above*/ABOVE advantage was 110 ms for the control, 80 ms for a match, and 30 ms for a mismatch. The larger *above*/ABOVE advantage when the irrelevant word matched the relevant relations (the word *up* paired with *above*/ABOVE, and the word *down* paired with *below*/BELOW) than when it did not (*above*/ABOVE paired with the irrelevant word *down,* and *below*/BELOW paired with the irrelevant word *up*) indicates a correspondence effect based on overlap of the irrelevant word and the relevant stimulus properties.

An interesting aspect of Seymour's (1974b) results is that the effect of polarity of the irrelevant word was strong enough to override the benefit due to correspondence of the content of the word with that of the response. This is evident in the trials from his Experiment 1 in which the relevant word and spatial relation were both below (i.e., the *below*/BELOW trials) and the correct response was "yes." "Yes" RT on these trials was 20 ms shorter when the word was *no* than when it was *yes,* even though *yes* corresponds with the correct "yes" response and *no* does not. Thus, the polarity correspondence of the irrelevant word with *below*/BELOW was more important than the meaning correspondence of the irrelevant word with the response.

The main point from Seymour's (1973, 1974a, 1974b) studies is

> 8. A model that assumes that stimulus dimensions and responses are coded as + or − polarity and that the aggregate correspondence of the polarities for the stimulus and response codes determines the speed and accuracy of selection of the response category provides a viable account of word–picture verification performance.

Summary

The *above*/ABOVE advantage is due to coding the above–below alternatives as + or − polarity. However, – polarity relations do not take longer to encode than + polarity relations for either words or pictures. Rather, the mapping of the polarity of stimulus features into responses is crucial. Response selection benefits from correspondence of + polarity stimulus features with + polarity responses and − polarity stimulus features with − polarity responses.

Seymour (1973, 1974a, 1974b) developed a model that captures many of the result patterns for word–picture verification tasks on the basis of the idea that relevant and irrelevant stimulus features are coded as + or − polarity. Separate accumulators collect evidence for "yes" (+) and "no" (–) responses, with each + polarity feature decreasing the threshold for a "yes" response and each − polarity feature decreasing the threshold for a "no" response. Seymour's model provides an account for the polarity coding effects in the word–picture verification task that not only is more consistent with the data than are the accounts that attribute the effects to stimulus encoding time but also is in closer agreement with contemporary sequential sampling models of comparison and choice in binary tasks (e.g., Van Zandt, Colonius, & Proctor, 2000).

Polarity Correspondence in Other Binary Choice Reaction Tasks

We have shown that correspondence of the polarities of stimulus and response codes is a significant factor in the performance of word–picture and sentence–picture verification tasks. If it is a fundamental aspect of human information processing, as we argue, effects due to polarity correspondence should be evident in other research using binary classification tasks. In the present section, we examine three different types of binary choice reaction tasks from disparate research areas. In each case, we provide evidence that polarity correspondence plays a significant role in the observed effects. By showing that polarity correspondence is a factor in seemingly unrelated tasks, we seek to establish the consilience of the polarity correspondence principle.

Orthogonal SRC Effects

As indicated in the introduction, SRC effects occur when the dimensions along which stimuli and responses vary are orthogonal (e.g., up–down stimuli mapped to left–right responses). Bauer and Miller (1982) provided the first demonstration of orthogonal SRC effects, concluding that the left and right hands showed different mapping preferences when the responses were unimanual (e.g., left or right movements from a home key to one of two target keys in response to a stimulus in an upper or lower position). Because there was no spatial correspondence between the stimulus and response dimensions, as for the typical SRC and Simon effects that Wallace (1971) and others attributed to spatial coding, Bauer and Miller concluded "this finding limits the generality of Wallace's [1971] argument that compatibility effects arise in the process of matching internal spatial codes for stimulus and response" (p. 378). Instead, they attributed the orthogonal SRC effect to the structure of the motor system. This argument assumes that for correspondence of spatial codes to be a factor, the stimuli and responses must be coded along the same spatial dimension, or in other words, the dimensions must be perceptually or conceptually similar. However, the evidence we provided for the polarity correspondence principle in word–picture verification tasks indicates that correspondence of the polarities of the categorical spatial codes is sufficient for SRC effects to occur in response selection.

Lippa and Adam (2001) distinguished two aspects of the results for orthogonal SRC: an overall up–right/down–left mapping advantage and effects that vary as a function of response eccentricity and responding hand. As noted in the introduction, there is little disagreement that the up–right/down–left advantage is due to polarity correspondence. Consequently, we provide only a brief discussion of this advantage and then focus on recent evidence that the second category of orthogonal SRC effects can be attributed to polarity correspondence as well. More detailed coverage of both categories of orthogonal SRC effects can be found in Cho and Proctor (2003).

The Up–Right/Down–Left Mapping Advantage

The up–right/down–left mapping advantage is found not only when the stimuli are physical up–down locations and the responses left–right keypresses but also when the stimuli are the words *up* and *down* and the responses are left–right unimanual movements (of a switch or joystick, or from a home key to a target) or spoken words "left" and "right" (e.g., Cho & Proctor, 2002; Proctor, Wang, & Vu, 2002; Weeks & Proctor, 1990).[3] A similar preference for mapping right to up and left to down is also obtained, in some cases, when the stimuli refer to horizontal locations and the responses to vertical locations (Cho & Proctor, 2004a; Weeks & Proctor, 1990).

Weeks and Proctor's (1990) account of the up–right/down–left advantage, described in the introduction, is similar to Seymour's (1973, 1974a) explanation of the *above*/ABOVE advantage in word–picture verification tasks. Their account attributes the benefit for the up–right/down–left mapping to its maintaining correspondence of the salient stimulus code (+ polarity) with the salient response code (+ polarity) and the nonsalient stimulus code (– polarity) with the nonsalient response code (– polarity). The primary issue concerning this account of the up–right/down–left

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[3] Proctor and Cho (2001) reported an exception when a 450-ms response deadline was imposed for a task in which left–right keypresses were made to up–down stimuli. They suggested that participants rely primarily on coordinate spatial representations rather than on categorical spatial codes when responses must be made very rapidly.

advantage is whether the polarity difference is restricted to verbal codes (Adam et al., 1998; Umiltà, 1991) or is a more general property of spatial codes (Weeks & Proctor, 1990). The evidence concerning orthogonal SRC effects, in agreement with that from the word–picture verification literature and many other findings, now indicates that polarity is a property of categorical spatial codes in general (Cho & Proctor, 2001, 2003; Proctor & Cho, 2001).

The literature on the up–right/down–left advantage, therefore, implies the following:

> 9. A model that assumes that stimuli and responses are coded as + and − polarity and that polarity correspondence of these stimulus and response codes determines the speed and accuracy of response selection provides the best explanation of the up–right/down–left advantage for orthogonal SRC tasks.

Response Eccentricity and Hand Effects

As noted, the response eccentricity effect refers to the fact that the orthogonal SRC effect varies with location of the response set along the horizontal dimension: With unimanual left–right movement responses, the up–right/down–left advantage increases in size when the responses are made in the right hemispace and tends to reverse to an up–left/down–right advantage when the responses are made in the left hemispace (Cho & Proctor, 2004b; Michaels, 1989; Weeks, Proctor, & Beyak, 1995). The overall up–right/down–left advantage is usually present as well, implying that the response eccentricity effect is superimposed on the advantage.

Because the response eccentricity effect indicates that orthogonal SRC varies as a function of the placement of the responding limb, some researchers have attributed the effect to properties of the motor system (e.g., Michaels, 1989). Lippa and Adam (2001) proposed an end-state comfort hypothesis to explain the response eccentricity effect that attributes it to an implicit rotation of the response set, made at the beginning of the experiment, that aligns the axis of the response set with that of the stimulus set. The rotation is in the direction that would produce the most comfortable end state if the limb were actually rotated; thus, end-state comfort allows prediction of which response will correspond with which stimulus location after the rotation of the response set has been made. Note that although the end-state comfort hypothesis relies on a property of the motor system to derive its predictions, it attributes the response eccentricity effect to the mental representations of the stimulus and response sets varying along the same dimension, even though physically they do not. Lippa and Adam considered this aspect of the end-state comfort hypothesis to be one of its major contributions to the understanding of SRC effects, stating

> It conforms with the assumptions postulated by current theories of S-R compatibility. Most of these theories state that for SRC effects to occur, overlap between the S-R dimensions is required (see, e.g., Hommel & Prinz, 1997). By assuming that physically orthogonal stimuli and responses are cognitively represented on a common spatial dimension, the present orthogonal SRC effects meet this criterion and are thus open to a conventional explanation. (p. 172)

Of course, the major point of the polarity correspondence principle is that there is no need to assume that stimuli and responses must be represented on a common spatial dimension for SRC effects to occur. Nothing more than correspondence of the polarities of the stimulus and response codes is necessary to produce SRC effects.

The problem facing a polarity correspondence account of the response eccentricity effect is that to explain the interaction of mapping preference with eccentricity, the polarities of the stimuli or responses must be hypothesized to change as a function of response eccentricity. Given that response eccentricity is a manipulation of placement of the response apparatus and the effectors, any influence on polarity coding would likely involve the response set. Weeks et al. (1995) proposed that responding in the left or right hemispace increases the salience of the response associated with that hemispace. For example, when responding in the left hemispace, the salience of the left response increases, and consequently, the up–right/down–left advantage tends to reverse to one for the up–left/down–right mapping. The main evidence provided by Weeks et al. to support this proposal is that the response eccentricity effect shows a similar pattern regardless of whether the right or left hand is used for responding at all positions (Experiment 1). Moreover, a similar result pattern is obtained when the unimanual left–right responses are made at body midline but an inactive switch is placed to the left or right, thus allowing the relative position of the active switch to be coded as right or left (Experiment 2; see also Proctor & Cho, 2003).

Although the response eccentricity effect does not depend on which hand is used for responding, the size of the up–right/down–left advantage does vary independently as a function of hand and hand posture (Cho & Proctor, 2002; Michaels & Schilder, 1991). When the responding hand is in a normal, prone posture, the advantage for the up–right/down–left mapping is larger for the left hand than for the right hand. However, when the responding hand is in a supine posture, the advantage is larger for the right hand than for the left hand. All these effects, including that of response eccentricity, can be explained by assuming that the response-set location is represented relative to available reference frames. We have developed this account in a series of recent articles (Cho & Proctor, 2002, 2004a, 2004b, 2005; Proctor & Cho, 2003). The idea is that for any representation in which the response-set location is "right," the right response is coded as + polarity and the left response as − polarity; for any representation in which the response-set location is "left," the right response is coded as − polarity and the left response as + polarity. When one response is coded as + polarity relative to all reference frames and the other response as − polarity, a large SRC effect will be obtained for which response selection is fastest for the mapping in which the polarities of the stimulus codes correspond to those of the codes for their assigned responses. When each response is coded as + polarity relative to one or more reference frames and − polarity relative to one or more other reference frames, the SRC effect will be smaller, with the combined effects of the compatibility relations for the respective response codes determining the magnitude and direction of the SRC effect. In other words, the element polarities for each reference frame combine to produce the overall polarities of the response alternatives, analogous to the way that the charge of an atom is determined by the sum of the element polarities of its protons (+) and electrons (–). Note that this view of response coding is similar to Seymour's (1973) view of stimulus coding in that each response is represented by multiple features of + and −

polarity, with the summed effects of polarity correspondence being critical.

Numerous findings converge to support this polarity correspondence account of the response eccentricity and hand effects on orthogonal SRC. First, both the response eccentricity effect and the effect of response position relative to an inactive response device also occur for keypress responses made with the left and right index fingers (Proctor & Cho, 2003), a finding that is inconsistent with the view that the response eccentricity effect obtained with unimanual movement responses is due to properties of the motor system. Second, when the horizontal relation between the location of the stimulus display and the response-set location is varied separately from the location of the response set relative to body midline, the response eccentricity effect is determined primarily by coding of the response-set location relative to the display and not by its position relative to midline (Cho & Proctor, 2004a, 2004b, 2005). Third, for unimanual switch-movement responses, the pattern of results obtained when hand posture (prone or supine) is varied conforms to what would be expected on the basis of the location of the response switch being represented as left or right relative to the main part of the hand (Cho & Proctor, 2002, 2005). For example, with the right hand, for which the switch is to the left of the main part of the hand when in a prone posture and to the right when in a supine posture, the up–right/down–left advantage is smaller for the prone posture than for the supine posture. Moreover, this effect of hand posture does not interact with the effect of response eccentricity on orthogonal SRC.

There are two central messages of our work on the response eccentricity effect and related phenomena. First, there is no need to invoke characteristics of the motor system or mechanisms that bring stimulus and response dimensions into alignment. The direction and magnitude of the orthogonal SRC effect as a function of a variety of factors can be explained by polarity correspondence. Second, responses are composed from features in much the same way that stimuli are. More specifically,

> 10. In two-choice tasks with orthogonal stimulus and response sets, the responses are coded relative to multiple frames of reference, and within each reference frame, the response that is consistent with the relative location of the response set is coded as + polarity and the other response as − polarity. The sum of the elemental polarities determines the overall polarity of each response alternative.

A Simon-Type Effect for Orthogonal SRC

Cho and Proctor (2005) conducted an experiment in which the stimulus locations were up and down and the stimulus set could occur above fixation in the upper half of the display screen or below fixation in the lower half (see Figure 4). The responses were left–right unimanual toggle-switch movements made at body midline or in the left or right hemispace in different trial blocks. The typical effect of response-set location was obtained (an up–right/down–left advantage at midline that increased in the right hemispace and tended to reverse in the left hemispace), but stimulus-set location had no influence on these S-R mapping effects. However, stimulus-set location itself produced a Simon-type effect, showing an effect similar to, but smaller than, that shown by stimulus location within the set. This outcome is consistent with Seymour's (1974a) results for the word–picture verification task in suggesting that an irrelevant stimulus dimension (in this case, stimulus-set location) is coded asymmetrically under some circumstances and that correspondence of the irrelevant asymmetric codes with the response codes can yield a Simon-type effect. This outcome implies that a stimulus code tends to automatically activate the response code of the same polarity, much as occurs when an irrelevant stimulus dimension overlaps perceptually or conceptually with the response set (e.g., Kornblum et al., 1990). This study illustrates that

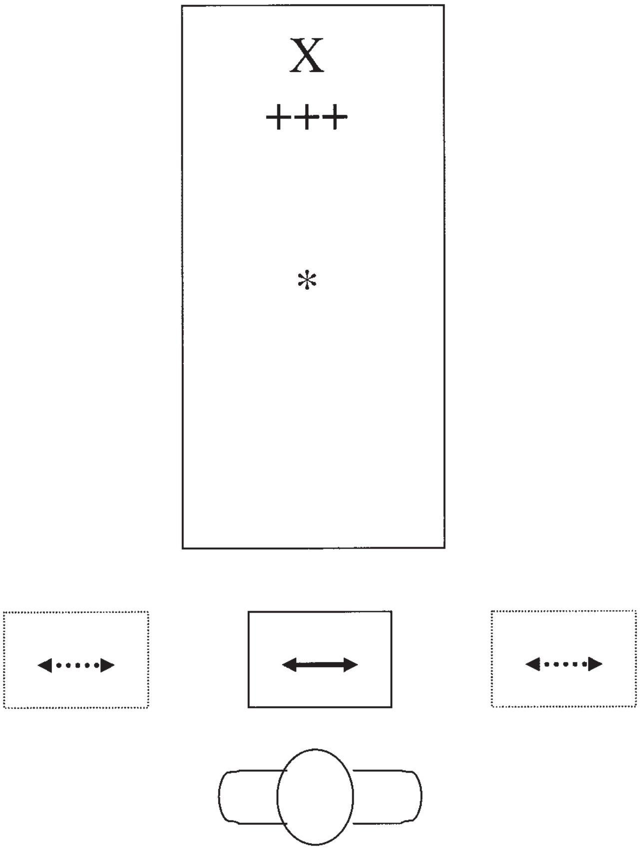

Figure 4. Example display from Cho and Proctor's (2004a) experiment in which the stimulus set could occur in the upper or lower half of the display screen and the stimulus was up or down within the set. Different placements of the response switch are also indicated.

> 11. The alternatives on an irrelevant stimulus dimension may be coded as + or − polarity and show Simon-type correspondence effects with the polarity of the response dimension.

Summary

Because of the lack of obvious basis for correspondence of stimulus and response codes in response selection when stimulus and response sets are orthogonal, several authors have assumed that the resulting SRC effects must have their basis in the structure of the motor system (Bauer & Miller, 1982; Lippa & Adam, 2001; Michaels, 1989). Moreover, Lippa and Adam's (2001) account explicitly proposed that the effects are really spatial correspondence effects, with the motor system determining the direction in which the representation of the response set is rotated to mentally align it with the orientation of the stimulus set. The polarity correspondence principle indicates that none of these machinations is necessary. There is a basis for correspondence effects when stimulus and response dimensions are orthogonal, and that basis is the correspondence among the polarity relations of the stimulus codes and those of the response codes. We reiterate that, at present, no viable alternative to polarity correspondence exists as an explanation of the overall up–right advantage. In addition, the evidence now strongly indicates that polarity correspondence is also the major determinant of the response eccentricity effect, enabling a coherent account of almost all of the major findings involving orthogonal SRC.

It is important to note the striking similarity between the types of results obtained in orthogonal SRC tasks and those obtained in word–picture and sentence–picture verification tasks, despite the fact that there are many differences between the two types of tasks: presentation of a single, very simple stimulus versus a more complex stimulus involving verbal and pictorial aspects, response determination being based on stimulus identity versus verification of a verbally described relation, and assignment to spatially identified responses as opposed to "yes"–"no" decisions. Yet, the results from both task types indicate that (a) both verbal and nonverbal spatial relations are coded as + and − polarity, (b) this is true not only for stimuli but also for responses, (c) multiple codes are formed for various features and relative to various referents, and (d) the pattern of RT is determined primarily by the combined contributions of the element polarities.

Numerical Judgment Effects

A large literature exists on the representation and processing of numerical information. One task used to study the nature of the representations and processes is that of parity judgments. The task requires that a displayed number be classified as odd or even, typically with a left or right keypress. Two effects involving asymmetries between numbers and responses have been found, the linguistic markedness association of response codes (MARC) and spatial–numerical association of response codes (SNARC) effects. The MARC effect is that performance is better when even is mapped to right and odd to left than when the mapping is opposite. The SNARC effect is that performance is better when the response to a large number is right than when it is left and the response to a small number is left than when it is right. The MARC effect involves the mapping of the relevant stimulus information (parity) to responses, whereas the SNARC effect involves the relation between an irrelevant stimulus dimension (magnitude) and the responses.

The MARC Effect

Shepard, Kilpatric, and Cunningham (1975) showed that when participants judged the similarity of single digits as abstract concepts, odd versus even was a major dimension on which their judgments were based. Moreover, Hines (1990) demonstrated that the odd–even distinction affects performance in choice reaction tasks. In his Experiment 1, pairs of digits were presented on each trial, and a left key was pressed to indicate "same" if the digits were both odd or both even, and a right key to indicate "different" if one digit was odd and the other even. "Same" RT was 209 ms faster when both digits were even than when both were odd. This difference was reduced to 114 ms in Hines's Experiment 3 in which the left key was pressed if both digits were odd, the right key if both were even, and no response was to be made if they were different. In his Experiment 2, when a single digit was to be classified as odd or even, the difference in performance was very small, being a nonsignificant 5 ms in the RT data and a significant 1.1% in the error data. Hines concluded that the difference in RT for odd and even pairs across his tasks reflected linguistic markedness, as described earlier. He attributed the poorer performance with odd than with even to extra processing required for odd numbers, because odd is the marked member of the category and even the unmarked member.

Hines's (1990) results strongly imply that the phenomenon of faster responses for even judgments than for odd judgments is task specific. Specifically, responses to odd numbers were unambiguously slower than those to even judgments only in the tasks that required an explicit or implicit "same"–"different" judgment. Because even is + polarity and odd is − polarity, even matches the + polarity of the same response and odd does not. Thus, Hines's results are consistent with the view that markedness, or polarity, of the stimuli does not exert its effect primarily on stimulus identification but on response selection.

In subsequent studies examining the odd–even distinction, participants have performed parity judgment tasks of the type described above, which yield the MARC effect, first noted by Willmes and Iversen (1995). For example, Reynvoet and Brysbaert (1999, Experiment 2) had participants perform parity judgments for the numbers 7–12. Their participants performed that task twice, once with the even response assigned to the right hand and the odd response to the left hand and once with the opposite mapping. They obtained the basic MARC effect: faster responding to even numbers with the right hand and odd numbers with the left hand than with the opposite mapping. Berch, Foley, Hill, and Ryan (1999) found that the MARC effect was absent for children in Grades 2, 3, and 4 but present for those in Grades 6 and 8. Berch et al. concluded that the MARC effect is "a linguistic effect based on associations between the unmarked adjectives 'even' and 'right' and between the marked adjectives 'odd' and 'left' " (p. 287).

Nuerk, Iversen, and Willmes (2004) reached a similar conclusion from examining the MARC effect for different number notations. The effect was larger for number words (37 ms) than for positive Arabic numbers (16 ms), and negative Arabic numbers showed no MARC effect. Because the MARC effect was larger for number words than numerals, Nuerk et al. concluded that the effect is a consequence of linguistic markedness. Similar to Berch et al. (1999), their account is that correspondence of the unmarked (even) and marked (odd) verbal codes with the unmarked (right) and marked (left) response codes leads to better performance. The point is that this account conforms to the polarity correspondence principle. The MARC effect thus demonstrates

> 12. The nonspatial dimension of digit parity is coded with even as + polarity and odd as − polarity, producing mapping effects with left and right keypresses similar to those obtained with orthogonal stimulus and response spatial dimensions.

The SNARC Effect

The SNARC effect, first demonstrated by Dehaene, Bossini, and Giraux (1993), has been attributed to numbers being encoded in the form of a spatial image for which small numbers are to the left side and large numbers to the right side. As we show in this section, however, an account in terms of polarity correspondence for categorical spatial codes provides an alternative to image-based accounts in terms of coordinate spatial codes.

In Dehaene et al.'s (1993) Experiment 1, a digit from the set 0–9 was displayed in the center of a screen, and the participant was to make an odd–even parity judgment by pressing a left or right key. RT was approximately 30 ms shorter for large digits and longer for small digits when the correct response was "right" than when it was "left." Dehaene et al.'s Experiment 3 showed that the SNARC effect is not due to incidental properties of the digits that are correlated with magnitude (see also Fias, Brysbaert, Geypens, & d'Ydewalle, 1996). In that experiment, participants performed parity judgments with two separate sets of digits, 0–5 and 4–9. The digits 4 and 5 were included in both sets, being the largest two numbers in the former set and the smallest two in the latter set. These digits were responded to faster with the right response than the left response when they were "large" and faster with the left response than the right response when they were "small." The other point illustrated by these experiments is that the categorization of a number as large or small is relative to the specific stimulus set.

Among other findings, Dehaene et al. (1993) showed that the SNARC effect was as large for left-handed as for right-handed individuals. Also, when the hands were crossed such that the left key was pressed by the right hand and the right key by the left hand, the SNARC effect was still determined by the locations of the response keys. This outcome is in agreement with the finding that the direction and magnitude of SRC proper and Simon effects are not affected significantly by crossing the hands (Roswarski & Proctor, 2000; Wallace, 1971).

From their results concerning the SNARC effect for Arabic numerals, Dehaene et al. (1993) concluded

> A representation of number magnitude is automatically accessed during parity judgments of Arabic digits. This representation may be likened to a mental number line (Restle, 1970), because it bears a natural and seemingly irrepressible correspondence with the left–right coordinates of external space. (p. 394)

Note that this explanation assumes that the SNARC effect is a Simon-type spatial correspondence effect for which responding is faster when the irrelevant left or right location of the number on the number line corresponds with the location of the left or right response than when it does not.

The SNARC effect has been shown to generalize across response and stimulus modes. Fischer (2003) obtained the SNARC effect for digits when the responses were aimed movements of a hand from a start position to a left or right target position on a touch screen. Dehaene et al. (1993, Experiment 8), Fias (2001), and Nuerk et al. (2004) obtained the SNARC effect when the stimuli were number words instead of digits. The effect has also been shown to generalize to tasks that do not involve parity judgments. Fias, Lauwereyns, and Lammertyn (2001) and Lammertyn, Fias, and Lauwereyns (2002) obtained a SNARC effect when orientation (upright or tilted) of the digit or the direction in which a superimposed triangle pointed (up or down) was the relevant dimension, as did Fias et al. (1996, Experiment 2) when participants performed a phoneme monitoring task that required indicating whether the phoneme /e/ was contained in the name of the number that was presented. Fias (2001) did not obtain a SNARC effect for the phoneme-monitoring task when the stimuli were number words, which he interpreted as suggesting that numeric magnitude may not be activated as automatically for the words as for the numerals.

As in Dehaene et al.'s (1993) original explanation, accounts of the SNARC effect have typically interpreted it as a spatial correspondence effect similar to the Simon effect. Because the numbers are presumed to be represented along an analog dimension that goes from low at the left to high at the right, large numbers would be "right" and small numbers "left," and they would correspond with their respective responses. Mapelli, Rusconi, and Umiltà (2003) considered this possibility by presenting the digits for the parity judgments in a left or right location, instead of at the center of the screen. They obtained a 12-ms SNARC effect and 10-ms Simon effect, but these two effects did not interact. Consequently, Mapelli et al. concluded that their results showed that "the SNARC effect does not simply constitute a variant of the Simon effect" (p. B1). Also, the SNARC effect does not occur when the task is to make one response if the digit is one color and another response if it is a different color (Fias et al., 2001; Lammertyn et al., 2002), which is a standard condition in which the Simon effect occurs.

If the SNARC effect is due to numbers being coded along a left-to-right spatial dimension, thus producing a correspondence effect for the irrelevant left–right dimension with the horizontal dimension along which the responses differ, then no SNARC effect should be obtained when the responses are up–down locations instead of left–right ones. In contrast, if the SNARC effect is due to correspondence of the magnitude polarity (large number +; small number –) with that of the response (right +; left –), then a SNARC effect should be obtained with up–down responses because up is + polarity and down is − polarity. Ito and Hatta (2004) had Japanese participants perform the standard parity judgment task with left and right keypresses to Arabic numerals in their Experiment 1; in their Experiment 2, the response keys were aligned vertically on the tabletop, and participants pressed the upper key with one index finger and the lower key with the other index finger. Both experiments yielded SNARC effects, with the magnitude being at least as large for the up–down responses as for the right–left responses, providing evidence that the SNARC effect is not due to representing the number dimension as left to right but due to coding large numbers as + polarity and small numbers as − polarity. In summary,

> 13. The SNARC effect has been attributed to representing the numbers along a horizontal line, but evidence suggests that it may be a consequence of coding large as + polarity and small as − polarity.

Magnitude Judgments

In parity judgment tasks, the magnitude dimension that yields the SNARC effect is irrelevant, but the odd–even feature that yields the MARC effect is relevant. An interesting question is whether these effects are observed if the relevance of the dimensions is switched. Bächtold, Baumüller, and Brugger (1998) conducted two experiments in which participants made magnitude judgments under conditions in which they were given explicit instructions to create a mental image along which the numbers were placed. In both experiments, participants classified digits from the set 1–11, excluding 6, as less than or greater than 6. In Experiment 1, 20 practice trials were conducted for which the digit appeared slightly above and at the center of a horizontal marked ruler. Participants were told to conceive of the numbers as indicators of distances in centimeters and instructed to make one response if the number was longer than 6 cm and the other response if it was shorter. For the test trials, the ruler was removed and the participant was to mentally align an image of the ruler in its place. Each participant performed one block of trials for which they responded left to the smaller numbers and right to the larger numbers and another block with the reversed mapping. The results showed a large SNARC effect of greater than 150 ms, with the effect being equally evident for all numbers within each subset.

For Bächtold et al.'s (1998) Experiment 2, the ruler was replaced with the outline of a clock face within which the digit was centered. Participants were told to conceive of the numbers as representing the time of day and to make one response if the time was earlier than 6 o'clock and the other if it was later than 6 o'clock. As in Experiment 1, after the first 20 practice trials the clock face was removed and participants were to continue imaging it in its absence. For this situation, in which the large numbers are on the left side of the image and the small numbers on the right side, a reverse SNARC effect (small numbers faster with the right response and large numbers faster with the left response) of greater than 150 ms was obtained.

Because the SNARC effect reversed in their Experiment 2, Bächtold et al. (1998) concluded that coding of magnitude along the horizontal dimension is not restricted to a left-to-right order but may also have the larger numbers to the left and the smaller ones to the right. On the basis of the assumption that their results were due to the left–right position in the image, Bächtold et al. interpreted them as a left–right spatial Simon-type effect, with RT shorter when the numbers to the right side of the image are mapped to the right response and the numbers to the left side to the left response than when the mapping is opposite. Although it is likely that Bächtold et al.'s results are due to correspondence of the mental image with the responses, explicit images probably are not responsible for the typical SNARC effect obtained in tasks for which no mention of an image is made and no exposure to an image is provided. Results suggestive of a difference in basis for the effects are that the SNARC effect is typically 20–30 ms, not 150 ms, and is usually accompanied by a MARC effect, which was not apparent in Bächtold et al.'s experiments.

If the typical SNARC effect were due to representing the number dimension as left to right, as in the ruler condition of Bächtold et al.'s (1998) study, then a SNARC effect should also occur when greater than or less than judgments are made in the absence of an imaged referent. Ito and Hatta (2004) had participants perform a magnitude judgment task in their Experiment 3, pressing one key if the number was greater than 5 and another key if the number was less than 5. For one block of trials, the mapping was small to left and large to right, whereas for another block it was large to left and small to right. Unlike Bächtold et al., Ito and Hatta found no SNARC effect for this task in which magnitude was the relevant dimension but no explicit imagery instructions were given. On the basis of this finding and additional analyses, Ito and Hatta concluded that the semantic representation of a number does not itself have a prototypical spatial structure and that the SNARC effect is due to some other factor.

Summary

The MARC effect has been attributed to linguistic markedness, as indicated by its name. In agreement with the polarity correspondence principle, responses are faster when even, which is + polarity, is mapped to the right response, which is also + polarity, and odd, which is − polarity, is mapped to the left response, which is also − polarity. Although evidence suggests that the MARC effect may be larger for digit words than for Arabic numerals, it is present for both types of stimuli, suggesting that it is not restricted to verbal codes.

In contrast, the SNARC effect has typically been interpreted as a spatial correspondence effect in which number stimuli are represented along a horizontal dimension that, for English-speaking participants, is ordered from smallest values at the left to largest values at the right. However, several findings question this account. One such finding is that the SNARC effect is found for number words, as well as for digits. This finding can be accommodated if it is assumed that verbal numbers are translated into an image, but the effect magnitudes for number words are much smaller than those obtained when participants are specifically instructed to use images. More seriously, a SNARC effect of equal magnitude is obtained when the responses are up and down, which is orthogonal to the hypothesized dimension for the horizontal number line. Also, no SNARC effect is evident when large–small magnitude judgments are required (except when instructions stress explicit imagery), which should yield a larger spatial correspondence effect than when magnitude is irrelevant, because position on the number line is relevant for the magnitude task.

Although polarity correspondence has not been considered as a possible basis for the SNARC effect, such an account fares at least as well as the horizontal number-line account. The polarity correspondence account views the SNARC effect as being more similar to the orthogonal SRC effects than to spatial correspondence SRC effects: Large is coded as + polarity and small as − polarity, and the relation with asymmetrically coded response alternatives that maintains polarity correspondence produces faster responses than does the relation that does not. This account can explain why the SNARC effect is evident with up–down keypresses and with verbal number stimuli. The likely reason why the SNARC effect was absent when large–small magnitude judgments were made is that participants relied on coordinate spatial codes (Kosslyn, 1994), which do not have polar attributes, rather than on the categorical spatial codes that do.

An implication of our analysis is that the finding of a SNARC effect in itself does not necessarily indicate that numbers are coded along a spatial dimension. For example, Caessens, Hommel, Reynvoet, and van der Goten (2004) recently reported experiments in which they demonstrated "backward compatibility" effects in dual tasks of the response for the second task (vocal response "1" or "2" to red or blue color) on RT for the first task (left or right keypress to left or right pointing arrow in Experiment 1 and the letter *H* or

S in Experiment 3): RT was 12 ms shorter for the response pairings of left and "1" and right and "2" than for the other two response pairings. Caessens et al. interpreted these results as showing that "magnitude representations are associated with spatial codes" (p. 418). However, this conclusion does not necessarily follow from their results, because the backward compatibility effects could be due solely to correspondence of code polarities (– polarities for left and 1, + polarities for right and 2).

Implicit Association Test

Greenwald, McGhee, and Schwartz (1998) introduced a binary classification task called the Implicit Association Test (IAT). In the IAT, left and right keypresses are made to stimuli from two target categories (e.g., flower and insect names) and two attribute categories (e.g., pleasant and unpleasant words). The typical sequence for the IAT is as follows. First, one target category (e.g., flowers) is assigned to the left response and the other (e.g., insects) to the right response, and a block of trials is performed using only stimuli from the target categories. Second, one attribute category (e.g., unpleasant) is assigned to the left response and the other (e.g., pleasant) to the right response, and a block of trials is performed using only stimuli from the attribute categories. In the crucial third block of trials, the target and attribute stimuli are intermixed so that some stimuli are from the target set and others from the attribute set. The fourth trial block is similar to the first in that only the target categories are used but with the opposite mapping of categories to keypresses. In the fifth, and also crucial, block of trials, the target and attribute stimuli are again intermixed but with the new mapping of the target categories to responses.

The IAT effect refers to the finding that in the third and fifth trial blocks, performance is better for one mapping of target and attribute categories to responses than for the other. For the attribute of affective valence, which is used in many studies, RT is shorter when the more positive target category is assigned to the same response as the pleasant attribute category than when it is not. For example, Greenwald et al. (1998) tested participants with the IAT for the flower–insect distinction and musical instrument names versus weapon names. Across these two distinctions, RT was 176 ms shorter when flowers or musical instruments were paired with pleasant words (and insects or weapons with unpleasant words) than when the pairings of target and attribute categories were reversed. Greenwald et al. interpreted these effects as "indicating more positive attitudes toward flowers than insects or toward musical instruments than weapons" (p. 1468).

Both the flower–insect and instrument–weapon distinctions connote positive and negative values on the dimension of affect. However, Greenwald et al. (1998) argued that the IAT is useful more generally "for measuring evaluative associations that underlie implicit attitudes" (p. 1464), including ones for which there is not an unambiguous connotation of affect. In support of this argument, they presented evidence that they interpreted as showing that the IAT reveals implicit ethnic and racial attitudes that are disavowed in conscious judgments. In their Experiment 3, White American college students performed the IAT with target categories of common first names for Black Americans and for White Americans. An IAT effect was obtained, with RT shorter when White names were paired with pleasant words and Black names with unpleasant words than with the opposite pairings. Because explicit measures showed that most participants did not state a negative attitude toward Black individuals, Greenwald et al. concluded "the data indicated an implicit attitudinal preference for White over Black" (p. 1474). In their Experiment 2, Greenwald et al. conducted the IAT with Korean Americans and Japanese Americans using a target distinction between Korean and Japanese surnames. An IAT effect was also obtained in this case, with RT being about 100 ms shorter when the participant's own ethnicity was paired with pleasant words and the other ethnicity with unpleasant words than when the pairing was the opposite.

Since Greenwald et al.'s (1998) study, the IAT has become the most widely used method for measuring implicit attitudes (De Houwer, 2003). Greenwald et al. and most other researchers (e.g., De Houwer, 2001) have attributed IAT effects in general to "differential association of the 2 concepts with the attribute" (p. 1464), with Greenwald and Farnham (2000) stating "the IAT (Greenwald et al., 1998) is a general purpose procedure for measuring strengths of automatic associations between concepts" (p. 1022). The main idea behind differential association accounts is that when the target and attribute categories overlap on a conceptual (or perceptual) dimension, the pairing of target and attribute categories that are most strongly associated yields the shortest RT. Though this logic for interpreting the IAT can be applied to any attribute category for which there is perceptual or conceptual overlap with the target concepts, the original study by Greenwald et al. and many subsequent ones have used the attribute category of affective valence. Consequently, we focus our discussion on the issue of whether results obtained with the affective valence version of the IAT necessarily require an explanation in terms of evaluative associations.

A Salience Asymmetry Account

Note that associative accounts of the IAT effect are based on the assumption that it is a consequence of conceptual or perceptual overlap between the target and attribute categories, which in the case of the evaluative IAT effect is the affective valence dimension. As we have emphasized throughout this article, though, compatibility effects can arise from structural overlap of + and − polarity codes without any conceptual or perceptual overlap. In other words, associations between the content of dimensions are not necessary to obtain compatibility effects such as the IAT. Rothermund and Wentura (2001, 2004) have recognized this point with regard to the evaluative IAT effect and proposed a salience asymmetry model that attributes IAT effects to asymmetries in salience of the alternatives instead of to affective valence.

According to the salience asymmetry account, in the pleasant–unpleasant attribute task often used for the IAT, unpleasant words are "figure" relative to the "ground" of pleasant words and thus are more salient. For any pair of target categories, then, if the more salient category is mapped to the same response as unpleasant words and the less salient category to the same response as pleasant words, the mapping of salience (or the figure–ground distinction) is consistent. In contrast, when the relation between target and attribute categories is reversed, each response has one category mapped to it that is salient and one that is not. The salience asymmetry account attributes the IAT effect to whether the relative salience for the target and attribute categories is compatible in the mapping to responses. That is, when salience compatibility is maintained, the task is simplified to one of making one response if the stimulus on a trial is salient and the other response if it is not. This strategy cannot be used when the figure–ground mappings for the target and attribute categories are incompatible, leading to slower responses.

An important aspect of Rothermund and Wentura's (2001, 2004) account of the evaluative IAT effect is as follows. When the attribute categories are pleasant and unpleasant, salience asymmetry in coding can occur for target categories that differ on dimensions other than affective valence, such as familiarity and linguistic markedness, and these category distinctions should also yield "evaluative" IAT effects. In other words, the IAT effect does not necessarily imply that there is conceptual overlap between the target and attribute categories. Note that Rothermund and Wentura's (2004) explanation for the IAT effect is a close relative of Weeks and Proctor's (1990) salient features account for the orthogonal SRC effect.[4] Both accounts assume that the alternatives along a dimension are coded asymmetrically, with one salient and the other not, and that RT is shorter when the salient members for each dimension and the nonsalient members are mapped consistently. This is equivalent to saying that the alternatives are coded as + and − polarity on the respective dimensions, with performance best when the polarities of the dimensions correspond than when they do not. Consequently, Rothermund and Wentura's account implies

> 14. An account of the IAT effect in terms of polarity correspondence provides a viable alternative to accounts that emphasize conceptual overlap of the target category distinction with the dimension of the attribute category distinction.

Evidence That IAT Effects Can Be Obtained on the Basis of Code Polarity

The crucial difference between affective valence explanations of the evaluative IAT effect and the salience asymmetry explanation is whether overlap on the conceptual dimension of affect or on the structural dimension of code polarity for the target and attribute categories is the main determinant of the IAT effect. Whereas Greenwald et al.'s (1998) associative account and other affective valence explanations predict that the evaluative IAT effect should be absent when only either the target or attribute category distinction involves affective valence, Rothermund and Wentura's (2004) salience asymmetry account predicts that an IAT effect should be obtained as long as the alternatives on both dimensions differ in salience or polarity. There are now several demonstrations of IAT effects that cannot be attributed to overlap of affective valence in particular or conceptual meaning in general.

IAT effects for target categories of similar or reverse affective valence. Karpinski and Hilton (2001, Experiment 2) used stimulus sets from target categories that were "likely to be positively valenced for most participants" (p. 780): words associated with the category of apple and words associated with the category of candy bar. Karpinski and Hilton noted that when words from the apple and candy target categories were mixed with the attribute categories of pleasant and unpleasant words, "there is no obvious consistent or inconsistent pairing" (p. 780). Yet, they obtained an IAT effect of 138 ms for which the pairings of apple with pleasant and candy bar with unpleasant were more compatible than the opposite pairings. When participants were given the opportunity to choose a Snickers candy bar or an apple to eat, the IAT did not predict the choice behavior, although explicit measures of attitudes toward candy bars and apples did.

Mitchell (2004) conducted two experiments in which he varied which of two target categories conformed to an instructed rule. In Experiment 1, one target category was animals or objects that possess teeth (and do not fly), and the other was animals or objects that fly (and do not possess teeth). These categories were assigned to left and right keypresses along with words from pleasant and unpleasant attribute categories. Half the participants were told to categorize the targets as teeth or no teeth stimuli and half as flight or no flight stimuli. The category that is positive with one of these instructions is negative with the other, and vice versa. The results showed IAT effects of about 125 ms for both instruction conditions, with the mapping of the positive category with pleasant and the negative category with unpleasant yielding the shortest RTs for each effect. Similarly, in Mitchell's Experiment 2, stimuli consisted of two columns of three numbers that were the same along rows or along columns. Participants instructed to judge whether the target stimuli had matching rows showed an IAT effect of approximately 150 ms favoring the matching row stimuli paired with the pleasant attribute stimuli, whereas those instructed to judge whether the target stimuli had matching columns showed an IAT of similar magnitude but favoring the matching column stimuli paired with the pleasant attribute stimuli.

Brendl, Markman, and Messner (2001, Experiment 2) demonstrated an IAT effect for a situation in which the "positive" target category was affectively negative. Their study examined a situation in which one target category was insects and the other was nonwords. RTs to the target categories were 122 ms shorter when insects were paired with pleasant and nonwords with unpleasant than with the opposite pairings, even though insects were judged to be more negatively valenced. In Brendl et al.'s Experiment 3, a cover story was used to get participants to code the nonwords as positive (i.e., they were told that they would tend to automatically think positive thoughts when hearing words of a language with which they were unfamiliar). Despite these instructions, a negative IAT effect of 107 ms was again obtained. Both of Brendl et al.'s experiments thus showed large IAT effects favoring insects as more compatible than nonwords with "pleasant" than "unpleas-

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[4] Rothermund and Wentura (2001, 2004) used a reverse classification of relative salience for the alternatives along a dimension because they based their analysis on visual search tasks, in which negative or unfamiliar stimuli tend to "pop out" (e.g., Wolfe, 2001), whereas Weeks and Proctor (1990) based their classification on verification tasks, in which verification time is longer for the marked alternative than for the unmarked. Kinoshita and Peek-O'Leary (2005) noted the discrepancy of Rothermund and Wentura's (2001, 2004) designation of positive and negative with that from verification tasks, in which positive is typically considered to be figure, and concluded that the visual search data could be interpreted in a similar manner. The fact that opposing classifications of salience can be used to make similar predictions emphasizes the point that correspondence of the code polarities is more important than which pole is designated as positive and which as negative.

ant," even though the affective valence for insects is more negative than that of nonwords.

IAT effects for attribute categories of similar affective valence. IAT effects have also been found when the attribute categories are of similar valence. Rothermund and Wentura (2004) used a version of the IAT in which the target categories were "old" names that are not currently popular (e.g., Gerda and Heinz) and "young" names that are (e.g., Julia and Patrick). Nosek, Banaji, and Greenwald (2002) previously showed that the old–young name distinction yields an IAT effect when mixed with unpleasant–pleasant words. Rothermund and Wentura replicated this result in their Experiment 1A: RT was 153 ms shorter when old and unpleasant were assigned to one response and young and pleasant to the other than for the opposite target and attribute mapping.

Rothermund and Wentura (2004) replaced the pleasantness task with a lexical decision task (word–nonword, with the words being affectively neutral) in their Experiment 1B. Although there was no association between the word–nonword attribute categories and the old–young target distinction, an IAT effect of 91 ms was obtained for which the mapping of young names with word and old names with nonword was more compatible than the opposite mapping (see also Rothermund & Wentura, 2001, Experiment 1). In their Experiments 2A and 2B, Rothermund and Wentura (2004) showed that IAT effects can be obtained for other target categories when the attribute categories are replaced with the word–nonword task.

Rothermund and Wentura (2004) also demonstrated that the IAT effect could be obtained when the categories for the attribute task involve a nonverbal distinction that does not differ in affective valence. In their Experiment 1E, the old–young target categories were paired with a task in which the stimuli were multicolored or single-colored character strings. RT was 37 ms shorter when old and multicolored were assigned to one response and young and single-colored to the other than when this relation was reversed. The authors attributed the smaller size of the IAT effect in this case to the fact that the dissimilarity of the stimuli for the two tasks allowed them to be performed together easily and thus allowed less room for benefit from the compatible relation.

An important aspect of Rothermund and Wentura's (2004) study is that they provided independent evidence of the salience asymmetries implied by the IAT effects in their Experiments 1A, 1B, and 1E using visual search tasks in their Experiment 1D. For each search task, four stimuli were presented on each trial, with all four being words from the same category (e.g., old names) or only three being from that category and one from the alternative category (e.g., young names). A "same" response was to be made if all stimuli were from the same category and a "different" response if they were not. In different tasks, asymmetries were obtained such that RT was longer when most or all of the stimuli on a trial were old names as opposed to young names, nonwords as opposed to words, unpleasant words as opposed to pleasant words, and multicolored strings as opposed to single-colored strings. Thus, all of the stimulus sets used for the target and attribute categories in Rothermund and Wentura's Experiments 1A, 1B, and 1E showed an asymmetry in coding consistent with that predicted by their salience asymmetry account of the observed IAT effects. That polarity coding generalizes across a variety of binary decision tasks, allowing prediction of results based on polarity correspondence, is the central point of this article.

Along what category dimensions does polarity coding occur? The studies cited in the preceding subsections provide strong evidence that IAT effects can be obtained when there is no association between target and attribute categories (i.e., no conceptual or perceptual overlap) but the respective categories can both be coded as + or − polarity along unrelated dimensions. Polarity coding was evident for old–young, nonword–word, and multicolored–single-colored, as well as unpleasant–pleasant. This leads to the question of what the underlying dimensions are along which the category alternatives can be coded as + or − polarity and thus produce IAT effects. Dimensions in addition to affect that have been suggested include familiarity and markedness.

Greenwald et al. (1998) interpreted their previously mentioned finding that the IAT effect for Korean surnames and Japanese surnames is in opposite directions for Korean American and Japanese American participants as indicating positive affective valence for own ethnicity and negative affective valence for other ethnicity. However, this difference could be due to familiarity, because Korean names would be more familiar to Korean Americans and Japanese names to Japanese Americans. Familiarity could also explain why White Americans showed an IAT effect for which the mapping of White names and positive attributes to one response and Black names and negative attributes to the other response produced shorter RT than did the opposite mapping.

Dasgupta, McGhee, Greenwald, and Banaji (2000) considered whether familiarity could account for the White–Black IAT effect and concluded that it could not. The target categories in their experiment were Black and White, with the stimuli being surnames in one case, as in Greenwald et al.'s (1998) previous study, and facial photographs chosen to be unfamiliar to all participants in the other case. An IAT effect was obtained for both the names (140 ms) and photographs (81 ms). Dasgupta et al. assumed that because all of the faces were unfamiliar, the latter effect could not be due to a familiarity difference. However, because people are likely exposed more to faces from their own race or ethnic group than from others, differences in familiarity of facial features across the categories still could be the cause of the IAT effect. Dasgupta et al. provided evidence that at least part of the IAT effect for Black and White names could not be attributed to familiarity of the individual names. They had participants classify words as names or pseudonames and found that they could do so faster for White names than for Black names, indicating a difference in familiarity. However, a regression analysis showed that even when this difference was accounted for, there was still an IAT effect.

Although Dasgupta et al.'s (2000) regression analysis suggests that a factor other than familiarity of the individual names contributes to the race IAT effect, Kinoshita and Peek-O'Leary (2005) pointed out that this factor could be differences in familiarity of the categories White and Black names. Kinoshita and Peek-O'Leary also critically examined other experimental studies of the race IAT that matched familiarity of exemplars in the different categories (see Dasgupta, Greenwald, & Banaji, 2003, for a summary), brain imaging and neuropsychological evidence, and correlational evidence of the race IAT with overt interactions of participants with White and Black experimenters (e.g., Richeson & Shelton, 2003). They concluded that (a) the experimental results do not show that familiarity with the alternative categories is unimportant, (b) the physiological evidence shows dissociations of affect with the IAT, and (c) the behavioral correlations could be due to differences in familiarity. After evaluating all of the evidence that has been presented against a familiarity interpretation of the race IAT effect, Kinoshita and Peek-O'Leary said, in summary, "In contradiction to the claim that familiarity has been ruled out, our analysis of the studies using the race IAT suggested that these studies in fact did not provide evidence against familiarity" (p. 451). Instead, they argued, "We suggest instead that the race IAT effect is better interpreted in terms of the salience asymmetry account proposed by Rothermund and Wentura (2004), whereby greater familiarity with the white category makes it more salient" (p. 442).

Other evidence suggests that familiarity may also be crucial in other versions of the IAT. Brendl et al.'s (2001) aforementioned finding of better performance when insect and pleasant were mapped to one response and nonword and unpleasant to the other response than with the opposite pairings may be due to words being more familiar than nonwords. Kinoshita and Peek-O'Leary (2003) obtained an IAT effect of 159 ms for the target categories of even and odd numbers paired with the attribute categories of pleasant and unpleasant words, with RT being shorter with the pairing of odd with unpleasant and even with pleasant. Because there is little difference in affective valence between the odd and even number categories, this IAT effect is unlikely to be due to associations along that dimension. Kinoshita and Peek-O'Leary suggested that this parity IAT is due to familiarity: Because even digits tend to be more prevalent than odd digits, they are coded as + polarity for even and − polarity for odd along the dimension of familiarity.

One aspect of Kinoshita and Peek-O'Leary's (2003) results suggests that markedness, rather than familiarity, may be the critical dimension for the odd–even categories in the parity IAT effect. For the trial blocks in which the odd–even parity judgments were performed alone, Kinoshita and Peek-O'Leary reported a MARC effect (46-ms shorter RT for the mapping of even–right/odd–left than for the opposite mapping). Because unpleasant was always assigned to the left response and pleasant to the right response in the mixed trial blocks of their study, Kinoshita and Peek-O'Leary's parity judgment results can be characterized as showing that the MARC effect was larger when the parity judgments were interspersed with the pleasant–unpleasant judgments. The importance of this point is that, as described in the last section, the MARC effect is thought to be due to markedness. Thus, the parity IAT effect could be due to this factor. Markedness may also be the dimension along which word (unmarked) and nonword (marked) categories differ that allows an IAT effect to occur when the attribute judgments are lexical decisions.

Rothermund and Wentura's (2004) finding that an IAT effect can be obtained when the attribute task is multicolored versus single-colored character strings indicates that perceptual asymmetries for the attribute category can provide a basis for the IAT effect when the target category distinction does not overlap with it perceptually or conceptually. Although the attribute distinction in that experiment was not linguistic, the resulting IAT effect could still be a markedness-type phenomenon, consistent with the evidence presented earlier that asymmetric coding is not restricted to linguistic codes.

Summary. For tasks that yield an evaluative IAT effect, IAT effects can still be obtained when either the target concepts or pleasant–unpleasant attribute categories are replaced with ones that do not differ in affective valence. Thus, evaluative associations between the target concepts and the affective categories are not necessary to produce an IAT effect. Evidence suggests that familiarity and markedness are among the target concept features that contribute to the evaluative IAT effect.

Although conceptual or perceptual overlap of target and attribute categories is not necessary to obtain an IAT effect, this is not to say that such overlap does not contribute at all. Our basic point regarding structural overlap in terms of polarity correspondence is that it is an often overlooked contributor to SRC effects in general, not that conceptual and perceptual overlap play no role. With regard to the IAT effect, then, it is reasonable to expect that conceptual and perceptual overlap contribute as well. Both Rothermund and Wentura (2004) and Kinoshita and Peek-O'Leary (2005), though advocating a coding asymmetry account of certain IAT effects, allow that others may be due in whole or part to associations between target and attribute categories on affect or some other conceptual dimension. Indeed, in a recent commentary by Greenwald, Nosek, Banaji, and Klauer (2005) on Rothermund and Wentura's article and reply by Rothermund, Wentura, and De Houwer (2005), the two groups of researchers agree that both polarity correspondence and conceptual correspondence contribute to the IAT, with the extent to which each contributes to specific IAT effects being an empirical issue that needs to be resolved.

For our purpose, the major point is that the evidence indicates

> 15. IAT effects can occur on the basis of correspondence of polarity codes, and conceptual or perceptual overlap is not necessary to obtain an IAT effect.

Summary

Beginning with Greenwald et al. (1998), there have been many studies of the evaluative IAT effect. The modal interpretation has been that it is a correspondence effect between the target categories and the attribute categories on the dimension of affective valence: Performance is better when the positive target category is assigned to the same response as the positive attribute category. This interpretation is much like a spatial correspondence effect when stimuli and responses vary along the same dimension. However, as the research reviewed throughout this article indicates, it is not necessary for the categories to be coded along the same dimension for correspondence effects to occur. Several of the results obtained for the IAT indicate that this is the case for it as well. IAT effects were evident when the target categories did not differ in affective valence, although the attribute categories did, and when the attribute categories did not vary in affective valence but were paired with target categories that typically yield an evaluative IAT effect. The results indicate that correspondence of the category polarities along several dimensions, of which affective valence may be one for certain stimulus sets, is a significant contributor to IAT effects. Rothermund and Wentura (2001) described the implication of this fact succinctly: "Interpreting compatibility effects in the IAT as evidence for cognitive associations requires that these associations are not only sufficient but also *necessary* determinants of these effects" (p. 96). Because cognitive associations are not necessary determinants, attributing any specific IAT effect to such associations should be done only with caution.

General Discussion

Overview of Major Points

Evidence that binary stimuli are coded as + or − polarity was obtained initially using word–picture and sentence–picture verification tasks. The polarity differences were originally attributed to linguistic markedness, with the idea being that encoding takes longer for the marked member of a word pair than for the unmarked member. Experiments showed, however, that polarity coding is not limited to words but also occurs for nonverbal stimuli such as up–down pointing arrows and spatial relations depicted in pictures. These findings match the general asymmetric property of categorical spatial codes (e.g., Kosslyn et al., 1998; Logan, 1994) described in the introduction. Although the most well-known models, those of Chase and Clark (1972), attribute the markedness effects mainly to time to encode the stimuli, several findings indicate that the effect of polarity is chiefly on the comparison process involved in response selection. The main evidence for this point is that effects of stimulus polarity depend on how the stimuli are mapped to responses.

Seymour (1973, 1974a, 1974b) developed a model of word–picture verification in which not only the stimuli but also the responses are coded as + or − polarity. In this model, the impact of stimulus polarity on performance occurs through its relation to response polarity: Translation of a stimulus coded as + polarity into a response is faster when the response is also + polarity than when it is − polarity, and vice versa for a stimulus coded as − polarity. The model assumes that stimuli are coded along multiple dimensions, whereas the response alternatives are coded only along a single dimension (e.g., "yes" as + polarity and "no" as − polarity). In Seymour's model, differences in verification time are attributed to the combined contributions of the correspondences of the polar stimulus codes for each stimulus dimension with the polar response codes. Although this model has had relatively little impact, the evidence from word–picture and sentence–picture verification tasks leads inescapably to the conclusion that stimulus polarity exerts its effect primarily through correspondence relations with response polarity, as Seymour proposed.

The second half of this article was devoted to establishing the consilience of polarity correspondence, that is, that it is a general principle of compatibility in binary choice tasks. We examined effects from three disparate literatures—orthogonal SRC effects from the SRC literature, MARC and SNARC effects from the numerical representation literature, and the IAT effect from the social cognition literature. In each case, polarity correspondence is implicated as a significant contributor to the obtained effects and as providing an adequate account of much of the existing data. The main point of our analyses of these effects is that it is unnecessary to assume that dimensions have perceptual or conceptual similarity to account for effects of these types. Rather, structural similarity in the form of polarity correspondence is sufficient to produce them.

Orthogonal SRC effects have been a puzzle to researchers because there is no dimension along which the stimuli and responses overlap. Consequently, explanations have tended to focus on properties of the motor system that provide the conceptual similarity deemed necessary to produce the SRC effects. However, polarity correspondence provides an elegant solution to the puzzle: RT is shorter when the mapping is such that the + or − polarity codes for the stimuli correspond with + or − polarity codes for the responses. Research on orthogonal SRC effects has provided strong support for an account in terms of polarity correspondence: Polarity correspondence currently offers the only viable explanation of the overall up–right/down–left mapping advantage. Moreover, converging evidence now indicates that polarity correspondence provides the best account of the influence of response eccentricity and other response-related variables on orthogonal SRC (e.g., Cho & Proctor, 2003, 2004a, 2004b). The key to accounting for these response eccentricity and related effects is the realization that the response alternatives, as well as the stimuli, are coded as + or − polarity with respect to multiple reference frames or features. The direction and magnitude of the orthogonal SRC effect is a function of the combined contributions of correspondence–noncorrespondence of the codes on the multiple dimensions.

The MARC and SNARC effects for numeric judgments have been widely studied. As with the up–right/down–left advantage, there has been little disagreement that the MARC effect is due to polarity correspondence (see, e.g., Nuerk et al., 2004): The mapping of even–right/odd–left yields shorter RT than does the opposite mapping because the unmarked (+ polarity) codes are paired, as are the marked (– polarity) codes. In contrast, most accounts of the SNARC effect attribute it to magnitude being represented as increasing from left to right along a horizontally oriented number line. This left–right representation presumably allows for correspondence of small numbers with a left keypress and large numbers with a right keypress, thus yielding a Simon-type correspondence effect based on the spatial relations. However, evidence concerning the SNARC effect is also at least as much in general agreement with a polarity correspondence account, with large digits being coded as + polarity and small digits as − polarity, as with a spatial correspondence account.

In the case of the IAT effect, the correspondence proposed in most accounts is between the target and attribute categories along some conceptual dimension, presumably affective valence when the attribute categories are pleasant–unpleasant words. Though associations on the affect dimension seem to contribute to at least some versions of this evaluative IAT effect, there is evidence that they are not the only, and possibly not even the main, source of the effect: The IAT effect has been obtained for many stimulus sets for which the target and attribute categories have no overlap on the affect dimension or any other dimension. Polarity correspondence is implicated as a significant source of the correspondence between categories that produces the IAT effect.

The evidence for polarity correspondence across these diverse domains indicates that it is a fundamental principle of response selection that plays a major role in performance of binary choice tasks in general. Because binary decisions are used to investigate a wide range of issues in both basic and applied psychological research, researchers need to develop greater awareness of, and appreciation for, the ways in which polarity coding and correspondence can come into play in such tasks. Failure to appreciate the impact of polarity correspondence on performance may lead researchers to assume that certain correspondence phenomena necessarily imply physical or conceptual similarity when an account in terms of polarity correspondence is sufficient.

Updating and Elaborating Seymour's (1973, 1974a, 1974b) Model

The most complete description of Seymour's response availability model is in his 1974a article. As described earlier, in that article he reported results of two experiments in which participants judged the position of a dot relative to its location above or below a schematic face. In one experiment, the face was oriented horizontally, with the top to the left or right, and the dot occurred physically to the left or right of the face; in the other, the face was oriented vertically, in an upright or inverted position, and the dot was located above or below the face. Seymour classified the various location features for each task as positive or negative and provided summed positivity and negativity values for each stimulus condition (see Tables 1 and 2), from which he derived predictions about the qualitative patterns of results, which were generally confirmed.

Although Seymour's (1974a) study did not include a word–picture verification condition without the face context, the representation for it can be derived from his tables. For the basic task, the word *above* is coded as + polarity and the word *below* as − polarity, and the location of the circle with respect to the referent object (the square containing the word in the basic task) is coded as + for above and − for below. Both the word and the dot also receive a + code for varying along the relevant vertical dimension. Finally, a match of the word and dot location codes yields a + polarity code, and a mismatch a − polarity code; a true decision receives a + code, and a false decision a − code. The summed positivity is 6 for *above*/ABOVE and 4 for *below*/BELOW, which predicts an *above*/ABOVE advantage because the correct "yes" response is also coded as +. The summed positivity for *above*/BELOW is 3, as is that for *below*/ABOVE, which leads to a prediction of no difference for the two mismatching pairs, a result that is often obtained.

For the vertically oriented face context in Seymour's (1974a) Experiment 2, the words *above* and *below* are coded as + and − polarity as in the basic task. In addition, the upright face is coded as + polarity, and the inverted face as − polarity, with the absolute location of the dot coded as + polarity when it is physically above the referent face and − polarity when it is physically below the face; both of these features also receive a + polarity code for varying along the vertical axis (see Table 1). Moreover, dot location is coded relative to the top of the face, being + when at the top and − when at the bottom, and a comparison of this representation to the word yields a + code for a match and a − code for a mismatch. Finally, the "true"–"false" decision based on the match or mismatch also produces a + code for "true" and a − code for "false." As illustrated by the summed positivities and negativities in Table 1, the *above*/ABOVE advantage is predicted for the normal face orientation and should be attenuated for the inverted orientation. Seymour's (1974a) data actually showed a 30-ms tendency toward a *below*/BELOW advantage for the inverted face orientation, which is not predicted. The model also seems to predict no difference between *above*/BELOW for the normal and inverted faces, but RT tends to be faster with the normal face, and it does predict a large difference for *below*/ABOVE, which is obtained.

For the task in which the face was rotated 90°, with the top to the right or left, Seymour (1974a) assumed that the horizontal dimension was coded as − vertical (see Table 2). Thus, dot and face location received a − value for all conditions because their positions varied along the horizontal axis. He also assumed that the left and right positions are neutral features. The summed positive values of 5 for *above*/ABOVE and 3 for *below*/BELOW predict an *above*/ABOVE advantage, as was found, and the summed negativity values of 5 for both *above*/BELOW and *below*/ABOVE predict no significant difference, which again is consistent with the results.

Seymour's (1974a) assumptions regarding coding of the location information for the word, dot, and face orientation all seem reasonable because they are based on above or top being coded as + polarity and below or bottom as − polarity, for which we have shown there is considerable evidence. The assumption that each of these stimulus features also receives a + code when the alternatives vary along the vertical dimension and a − code when they vary along the horizontal dimension is more questionable. Within each experiment, the dimension along which each of these features varied was held constant and, therefore, likely was not coded by participants. In addition, Seymour's (1974a) assumption that left and right positions are coded neutrally is counter to many findings reviewed in this article that indicate right is typically coded as + polarity and left as − polarity. Also, Seymour (1974a) did not justify why the "true"–"false" decision is coded separately from the outcome of the word, dot, and face top match, although the decision code is redundant with the match or mismatch code. Though not mentioned by Seymour (1974a), one purpose this serves is to give the relevant comparison greater weighting in the choice than the irrelevant features. Finally, Seymour's (1974a) emphasis on the summed positivity or negativity in deriving his predictions is probably an oversimplification. He was aware of this fact, stating, "a very gross prediction of RTs within each response category can be made by taking a simple count of positive and negative values for each display" (Seymour, 1975, pp. 276–277). It seems likely that the polarity codes for different features are not all weighted equally and that the relative amount of positivity to negativity is more important than the sum of the values.

The other areas of research we reviewed with respect to polarity coding extend the model developed by Seymour (1973, 1974a, 1974b). Perhaps the most important extension is that responses, as well as stimuli, are coded with respect to multiple features and reference frames. This point is illustrated in the research on the effects of response and display positions on orthogonal SRC (e.g., Cho & Proctor, 2003). An implication of the multiple coding of responses is that when keypresses are used to indicate "yes" or "no," or some other distinction, the coding of the right response as + and the left response as − likely contributes to performance and should be counterbalanced if not of direct interest. The second extension is that polarity coding is not restricted to spatial features. Polarity coding can occur for virtually any dimension along which stimuli and responses may vary. The evidence we presented, for example, indicates that choices among numeric stimuli are affected by polarity coding of odd versus even and large versus small. Within studies examining the IAT, affective dimensions and many others are coded as + or − polarity.

Relation of Polarity Correspondence to Other Types of Correspondence

The view that emerges is that stimuli are coded as + and − polarity on several dimensions. As Seymour (1974a) argued, the multiple stimulus codes are compared with representations of the responses (also composed of multiple codes), with the time required for the activation to reach a response threshold being an increasing function of the degree to which the stimulus representation matches the response representation. Irrelevant dimensions are weighted less heavily than relevant dimensions, a view generally accepted in the SRC literature (e.g., Hommel & Prinz, 1997), but the activation they produce will in many cases be of sufficient magnitude to affect performance. Correspondence of code polarities for irrelevant stimulus dimensions with responses can produce Simon-type effects similar to those produced by conceptual or perceptual correspondence; that is, a stimulus can produce "automatic" activation of the response of corresponding code polarity.

Seymour's (1973, 1974a, 1974b) model was restricted to correspondence of the polar stimulus codes with the polar response codes, but the concept of multiple correspondences determining performance applies more generally. Schaeffer and Wallace's (1969, 1970) model, on which Seymour's was based, was developed to explain effects of category similarity on comparisons of word meanings. More recently, Eviatar, Zaidel, and Wickens (1994) proposed a similar model, called the confluence model, to explain performance with nominal and physical decision criteria in letter-matching tasks. With a nominal criterion, uppercase and lowercase letters of the same identity (e.g., *Aa*) are to be classified as "same," whereas with a physical criterion, they are to be classified as "different." To explain the major findings obtained for tasks using both criteria, Eviatar et al. proposed their confluence model "in which the physical and nominal dimensions of the stimuli are processed automatically and in parallel, irrespectively of the task [that is, the mapping to "same" or "different"] . . . , and in which identity and nonidentity on all of the dimensions affect responses" (p. 71).

Evidence for automatic and parallel processing of stimulus dimensions irrespective of the task mapping of that information to responses has been obtained for a variety of other dimensions, including comparisons between letters in different positions of multiletter strings (e.g., Proctor & Healy, 1985), comparisons of five-dot patterns to inferred equivalence sets (i.e., patterns that are rotated and reflected versions of each other; Lachmann & van Leeuwen, 2005), and comparisons of positive or negative affect (e.g., Klauer & Stern, 1992). Klauer and Stern (1992) developed an affective-matching model to explain why, in tasks for which word pairs are to be classified as "same"–"different" (or "true"–"false") on a dimension such as lexicality, "same" (or "true") responses are faster when the words are affectively consistent (e.g., both pleasant) than when they are inconsistent. Although Klauer and Musch (2002) suggested that affective processing exerts its effects through different mechanisms than does cognitive processing, the fact that similar effects are obtained for a variety of other dimensions suggests that this is not the case.

An implication of the multiple comparisons view is that both polarity correspondence and other forms of correspondence can contribute to performance in the same task. This is illustrated in experiments that used a face, tilted left or right, to provide a context with respect to which stimuli in up–down locations (corresponding to the eye positions) could be coded as left or right (Hommel & Lippa, 1995; Proctor & Pick, 1999). When left–right keypresses were made to the stimulus locations, RT was shorter for the mapping of the "left" stimulus (relative to the face) to the "left" response and the "right" stimulus to "right" response than for the opposite mapping. A separate up–right/down–left mapping advantage, indicative of polarity correspondence, was also evident in the performance data. This finding illustrates that polarity correspondence is a close relative to perceptual and conceptual correspondence that contributes to performance in a similar manner.

Relation to Quantitative Models of Binary Classification

Although Seymour (1973) did not put his model into a quantitative form, he described the process as one of sampling features until a threshold is exceeded. Thus, the basic idea of polarity correspondence is well suited to sequential sampling models of binary decisions that distinguish accumulation of information from response thresholds or criteria (e.g., Van Zandt et al., 2000). The connection with sequential sampling models is apparent in Ratcliff, Gomez, and McKoon's (2004) application of Ratcliff's (1978) diffusion model to lexical decision tasks. In this model, noisy information from a stimulus accumulates toward one of two decision criteria, with the rate of accumulation called the drift rate. When a criterion is reached, the response associated with it is executed. Ratcliff et al. fit the diffusion model to data from experiments using lexical decision tasks in which word frequency, type of nonwords (pseudowords and random letter strings), and repetition varied. These variables all had reliable large effects on the drift rate. Ratcliff et al. noted,

> From the diffusion model point of view, the effects of these variables are simply to alter the amount and kind of information contributing to the degree of wordness that drives the decision process and nothing more. The lexical system that feeds information to the decision process may have many facets, but once information is output from the system, it can be considered unidimensional. (p. 176)

Note that the drift rates are not determined by properties of the stimuli alone but by their relation to the attributes on which the decision is to be based, which in the case of Ratcliff et al.'s (2004) study was wordness versus nonwordness. Moreover, in the model, multiple sources of information combine in their effects on the drift rate, which is in agreement with the view advocated throughout this article. Within the diffusion model, polarity correspondence can be conceived of as one of the sources of information that affects the drift rate. When response alternatives differ in code polarity, stimulus codes of + polarity will increase the drift rate toward the criterion of the + polarity response and those of − polarity will increase the drift rate toward the criterion of the − response. There should be little difficulty in extending sequential sampling models such as the diffusion model to account for polarity correspondence effects.

Issues in Developing and Evaluating Code Polarity Accounts

The evidence that polarity correspondence yields effects in binary choice tasks similar to those produced by perceptual and conceptual correspondence is compelling. However, when trying to develop a particular explanation of a specific phenomenon in terms of polarity correspondence and to determine whether polarity correspondence provides the best explanation of the phenomenon, an issue of circularity arises. That is, an ad hoc code-polarity interpretation can be proposed to explain any pattern of relative compatibility in particular binary choice tasks by assuming that the mapping that yields the best performance is the one for which code polarities match. There is no single way to resolve this issue, but there are various ways to address it and minimize the problem. The best solution, when possible, is to derive specific predictions about which mappings will yield the best performance from an independent measure of polarity. This was the approach taken by Weeks and Proctor (1990) in basing their predictions for orthogonal SRC effects on the marked versus unmarked distinction for spatial terms and evidence from the word–picture verification literature that this distinction affects performance systematically. Rothermund and Wentura (2004) also took this approach, using asymmetries in performance of visual search tasks as independent confirmation of the coding asymmetries implied in their IAT tasks.

Another approach is to form specific hypotheses about polarity coding and the factors that influence it and to test predictions derived from these hypotheses. These predictions can be contrasted with those of alternative accounts to evaluate whether polarity correspondence provides the best explanation. This was the approach taken by Weeks et al. (1995) and Cho and Proctor (2003) to develop a polarity coding account of the orthogonal SRC effects that vary as a function of hand placement and related factors. The approach was necessary because the measures of polarity from which Weeks and Proctor (1990) predicted the up–right/down–left advantage did not allow prediction of changes in magnitude and reversals of the advantage as a function of physical response factors. Through conducting several tests of hypotheses concerning coding with respect to multiple frames of reference, converging evidence has been obtained that implicates the polarity correspondence account over alternative accounts (e.g., Cho & Proctor, 2004a, 2004b, 2005).

The polarity correspondence principle implies that the specific contents of the stimuli and responses, and the modes by which these contents are conveyed, is not important as long as the same polarity distinctions are maintained. Consequently, effects of polarity correspondence can be dissociated from effects due to other factors, such as perceptual or conceptual correspondence and the nature of the motor system, by varying the specific stimulus or response sets. Three examples of this line of reasoning are as follows. Weeks and Proctor (1990) provided evidence that the up–right/down–left mapping advantage generalized across physical location and arrow-direction stimuli as well as unimanual movement, bimanual keypress, and vocal responses. Proctor and Cho (2003) demonstrated that the effects of relative position of the response apparatus generalized from unimanual joystick and switch movements to keypresses made with the left and right index fingers. Rothermund and Wentura (2004) showed that similar IAT effects are obtained when the attribute categories are word–nonword as well as when they are pleasant–unpleasant. Moreover, they were quite specific in recommending this procedure to dissociate the effects of coding asymmetry from those due to associations of concepts on conceptually overlapping dimensions:

> Standard IATs should be accompanied by a corresponding word–nonword version of the task (or by any other technical version of the task that makes use of an asymmetrical attribute dichotomy, e.g., clearly not associated with the target categories). Finding comparable results in the two IATs would indicate a strong contribution of salience asymmetries. (p. 159)

The unstated alternative finding is that dissimilar results for the two IATs would provide evidence against an account in terms of salience or polarity correspondence.

Another issue for interpreting specific results is that performance can be based on coordinate spatial representations as well as on categorical codes. For any situation in which coordinate spatial representations are used, no polarity correspondence effect should occur. The conditions under which judgments are based on coordinate representations rather than categorical codes are not well understood. We noted in the introduction that coordinate representations often seem to be used in tasks that require absolute judgments of quantities. Some evidence suggests that coordinate representations may also provide the basis for binary decisions made under speed stress (Proctor & Cho, 2001) or using explicit visual images (Bächtold et al., 1998). It is also an open issue as to whether the polarities of categorical codes affect performance in tasks with more than two choices, for which other structural features of the S-R sets become more prominent, and more generally whether decisions other than binary ones rely on categorical rather than coordinate codes. Resolution of these issues is a difficult, though necessary, step toward increasing our understanding of the factors that influence rapid decisions in a variety of task contexts.

Conclusion

We have presented evidence that code polarities are a fundamental aspect of stimulus and response representations in binary classification tasks. Correspondence and noncorrespondence of stimuli and responses with respect to these polarities produce activation that is combined into the decision process along with that produced by correspondence and noncorrespondence on physical and conceptual dimensions. Polarity correspondence is an essential aspect of compatibility between stimuli and responses that needs to be incorporated into models of stimulus–response and stimulus–stimulus correspondence in binary decisions to provide a more complete picture of the comparison processes involved in categorization and response selection.

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