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When Is an Odd Number Not Odd? Influence of Task Rule on the MARC Effect for Numeric Classification

Yang Seok Cho
Korea University

Robert W. Proctor
Purdue University

When classifying numbers as odd or even with left–right keypresses, performance is better with the mapping even–right/odd–left than with the opposite mapping. This linguistic markedness association of response codes (MARC) effect has been attributed to compatibility between the linguistic markedness of stimulus and response codes. In 2 experiments participants made keypresses to the Arabic numerals or number words 3, 4, 8, and 9 using the odd–even parity rule or a multiple-of-3 rule, which yield the same keypress response for each stimulus. For both stimulus modes, the MARC effect was obtained with the odd–even rule, but tended to reverse with the multiple-of-3 rule. The reversal was complete for the right response, but task rule had little influence on the left response. The results are consistent with the view that the MARC effect and its reversal are caused by correspondence of the stimulus code designated as positive by the task rule with the positive-polarity right response code.

Keywords: polarity correspondence, MARC effect, number representation

The ability to reason numerically is important in many aspects of life. Consequently, the mental representation of numbers and how this representation affects numeric judgments are topics that have attracted considerable research interest (e.g., Gevers, Verguts, Reynvoet, Caessens, & Fias, 2006). Numerical reasoning has been examined in a variety of tasks, many of which require binary decisions, including magnitude comparisons, phoneme monitoring, and same–different judgments.

Among the tasks used most extensively are parity judgments, for which numeric stimuli are to be classified as odd or even by making a left or right keypress. Two correspondence effects between numbers and responses often occur in parity-judgment tasks. The first is the spatial–numerical association of response codes (SNARC) effect, which is that reaction time (RT) is shorter when the right response is made to large numbers and the left response to small numbers than when the relation is reversed (Dehaene, Bossini, & Giraux, 1993). The second is the linguistic markedness association of response codes (MARC) effect, which is that RT is shorter with the mapping even–right/odd–left than with the opposite mapping (Willmes & Iversen, 1995). These effects have been the focus of many recent studies because they suggest that (a) there may be a close relation between numeric and spatial representations, (b) coding of magnitude may occur automatically, and (c) asymmetric coding of categories may affect performance (e.g., Gevers et al., 2006; Nuerk, Iversen, & Willmes, 2004).

Our primary concern in the present study is the MARC effect. As implied by its name, the MARC effect has been attributed to correspondence of linguistic markedness for the parity categories of odd–even and left–right responses (Berch, Foley, Hill, & Ryan, 1999; Nuerk et al., 2004). Markedness refers to a distinction between complementary terms, where one member is "marked" relative to the other member, which is unmarked. Lyons (1977, pp. 305–311) notes that linguistic markedness has three senses, which he calls *formal*, *distributional*, and *semantic*. In formal marking, a prefix or suffix designates one word of a pair as marked relative to the other (e.g., *lioness* vs. *lion*). In distributional marking, one word of an opposing pair is more restricted in use than the other. For example, the negative member of a pair is marked relative to the positive member (e.g., *bad* vs. *good*; *low* vs. *high*). In semantic marking, the marked word is more specific than the unmarked word (e.g., *lioness* is also semantically marked relative to *lion* because *lioness* is restricted to female lions).

In the case of parity judgments, *odd* is regarded as marked relative to *even*, and *left* as marked relative to *right* (H. H. Clark & Clark, 1977; Weeks & Proctor, 1990; Zimmer, 1964), with the basis being primarily the distributional sense. Parity judgments can be considered as "divisible by 2" or "not," whereas *right* can be considered as the more salient, meaning-bearing aspect of a verbal communication or the direction in which a line originating at the left extends (consistent with reading, numerical order, etc.). Berch et al. (1999) found the MARC effect for children in Grades 6 and 8 but not Grades 2, 3, and 4; he concluded that the effect is due to "compatibility between the linguistically marked adjectives 'left' and 'odd' and the unmarked adjectives 'right' and 'even'" (p. 296). Similarly, Nuerk et al. (2004) stated, "Responses are facilitated if stimuli and response codes both have the same (congruent) linguistic markedness (even–right, odd–left) while incongruent conditions (even–left, odd–right) lead to interference" (p. 835).

Parity influences performance in another way that has also been attributed to linguistic markedness. Hines (1990, Experiment 1) had participants judge whether pairs of numbers were "same" or "different" parity. "Same" responses were 209 ms faster when both

Yang Seok Cho, Department of Psychology, Korea University, Seoul, Korea; Robert W. Proctor, Department of Psychological Sciences, Purdue University.

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Correspondence concerning this article should be addressed to Yang Seok Cho, Department of Psychology, Korea University, Anam-dong Seongbuk-Gu, Seoul, Korea 136-701. E-mail: yscho_psych@korea.ac.kr

digits were even than when both were odd. In another experiment, Hines's participants judged whether a number word was even or odd, and RT was shorter to even-number words than to odd-number words. This "odd" effect was reduced when participants judged the parity of an Arabic numeral in his Experiment 2. Hines attributed the odd effect to linguistic markedness, assuming that extra processing is required for the marked "odd" numbers.

Most models of mental number processing distinguish between Arabic number representation and verbal number representation (e.g., Lemer, Dehaene, Spelke, & Cohen, 2003). Dehaene et al. (1993) depicted four models proposed by different authors in their Figure 1, each of which distinguished the two forms of representation. Although the four models differed in the hypothesized arrangement of the subsystems, none required that an Arabic numeral representation access a verbal representation for a parity judgment to be made. Consequently, if the MARC effect is due to linguistic markedness, a reasonable implication is that the effect should be larger when the stimuli are number words than when they are Arabic numerals. Nuerk et al. (2004) noted this implication, stating, "Linguistic markedness may . . . have a greater effect for number words than Arabic numerals, because of the verbal–linguistic attribute of the concept" (p. 839). They tested this implication by having participants perform the parity-judgment task with positive numerals, negative numerals, and number words ranging from 0 to 9. An analysis of variance (ANOVA) on the mean RT data showed the MARC effect to be significant for number words (37 ms) but not for positive numerals (16 ms) or negative numerals (3 ms). Nuerk et al. interpreted the finding that only number words showed a significant MARC effect as evidence for the linguistic-markedness hypothesis. According to them, this finding indicates that "(1) the verbal notation may particularly trigger linguistic-semantic concepts such as markedness and that, vice versa (2) the MARC effect is indeed verbal–linguistic in nature" (p. 848).

However, the MARC effect is not restricted to number words. Some evidence in Nuerk et al.'s (2004) study suggested that the 16-ms effect for positive numerals was not just due to chance. They performed a multidimensional scaling analysis that showed the MARC effect for positive numerals to be significant, although it was not in the ANOVA. Also, Reynvoet and Brysbaert (1999) found a significant MARC effect of 20 ms in an experiment in which participants made left–right keypresses to the parity of numerals ranging from 7 to 12. It is not even clear that Arabic numerals regularly produce smaller effects than number words. For example, Hines (1990) found the largest difference between even and odd in a same–different parity judgment task for which the stimuli were pairs of digits.

The account advanced for the MARC effect—shorter RT for the mapping that maintains correspondence of the markedness attributes than for the one that does not—is a variant of a polarity correspondence explanation that has been applied to several other phenomena obtained in binary-decision tasks (Proctor & Cho, 2006). H. H. Clark and Chase (1972) were the first to note that the unmarked member of a dimension could be represented as + polarity and the marked member as – polarity. Seymour (1974) extended the polarity concept to responses, providing a model that accounted for many findings from word–picture verification tasks (in which participants must respond "yes" or "no" to indicate whether a word matches a spatial relation depicted in a picture) through correspondence of the stimulus- and response-code polarities. In previous research, we (Proctor & Cho, 2006) emphasized that asymmetric coding is also a property of categorical spatial codes (e.g., Kosslyn, Thompson, Gitelman, & Alpert, 1998) and not restricted to linguistic codes, and proposed polarity correspondence as a general principle operating in many two-choice reaction tasks: "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" (Proctor & Cho, 2006, p. 418). Thus, in this view, although linguistic markedness is one form of polarity coding, polarity coding is a property of categorical codes in general, both verbal and nonverbal.

Among the phenomena that can be attributed to polarity correspondence, the evidence is strongest for the up–right/down–left mapping advantage (Cho & Proctor, 2003; Weeks & Proctor, 1990): When "left" and "right" responses are made to *up* and *down* (or *above* and *below*) stimuli, RT is shorter for the mapping of *up* to right and *down* to left than for the opposite mapping. Because evidence indicates that *up* or *above* is the "unmarked" or + polarity category for the vertical dimension (e.g., H. H. Clark & Chase, 1972), Weeks and Proctor (1990) proposed that the advantage for the up–right/down–left mapping is due to its maintaining correspondence of the + polarity stimulus (*up*) with the + polarity response (right) and the – polarity stimulus (*down*) with the – polarity response (left). They showed that this orthogonal stimulus–response compatibility effect generalizes across different stimulus modes (physical locations and arrows; also location words *above* and *below*, Proctor, Wang, & Vu, 2002) and response modes (bimanual keypresses; unimanual movements of a finger to a left or right key; vocal "left"–"right" responses). Because the up–right/down–left advantage was evident with stimulus–response modes that are unlikely to involve verbal coding (e.g., *up–down* stimulus locations mapped to left–right keypresses), as well as with ones that are (e.g., *up–down* stimulus locations mapped to "left"–"right" vocal responses), Weeks and Proctor concluded that polarity coding and correspondence in orthogonal stimulus–response compatibility tasks is not restricted to linguistic codes.

In a commentary on Weeks and Proctor's (1990) study, Umiltà (1991) noted that the up–right/down–left advantage tended to be larger for their conditions with vocal responses than for those with manual responses. Consequently, he hypothesized that polarity correspondence is solely a property of linguistic codes—or, in other words, of linguistic markedness. Adam, Boon, Paas, and Umiltà (1998) elaborated this argument further, proposing that the up–right/down–left advantage is obtained only under conditions that promote a verbal-coding strategy (e.g., participant-paced trials vs. computer-paced trials). However, subsequent experiments have provided strong evidence that the coding asymmetry underlying the up–right/down–left mapping advantage is not restricted to linguistic codes (Cho & Proctor, 2001, 2003; Proctor & Cho, 2001; Proctor et al., 2002): The up–right/down–left mapping advantage is not reliably larger for vocal than keypress responses, for location–word stimuli presented at a centered location than for stimuli presented in up and down locations, or for participant-paced trials.

Rothermund and Wentura (2004), Kinoshita and Peek-O'Leary (2005), and Proctor and Cho (2006) have advocated a polarity correspondence account for the implicit association test used widely in social psychology (Blaison, Chassard, Kop, & Gana, 2006). For the implicit association test, compatibility effects are obtained as a function of which of two target-word categories (e.g., flower or insect) is paired with pleasant words and which with unpleasant words in the mapping to left–right keypress responses. According to the polarity correspondence account, *pleasant* is the + polarity category for the *pleasant–unpleasant* pair, and performance is best when the member of the pair of target categories that is also of + polarity is paired with *pleasant* and the – polarity member with *unpleasant*. Rothermund and Wentura (2004) and Kinoshita and Peek-O'Leary (2005) have also referred to the + polarity category as "figure" relative to which the – polarity category is "ground."

The MARC effect is another phenomenon that we (Proctor & Cho, 2006) have argued is due to correspondence of asymmetrically coded features. The major difference between the linguistic markedness hypothesis for the MARC effect and the polarity correspondence account is that the former treats the representation of parity as a fixed property of linguistic codes and the latter treats it as a variable property of binary codes in general that is a function of a variety of factors including familiarity and task requirements. Whereas linguistic markedness implies that coding of odd as marked and even as unmarked is solely a consequence of activation of their linguistic codes, the polarity correspondence view implies that this coding is a consequence of the parity task rule defining even as the unmarked category. According to the linguistic markedness account, the MARC effect should not depend on the task rule but should depend on the stimuli being coded linguistically. In contrast, according to the polarity correspondence account, the MARC effect should depend on the task rule but not on whether the stimuli are coded linguistically.

We tested these implications of the linguistic markedness and polarity correspondence accounts in two experiments. In Experiment 1 participants made left–right keypresses to the digits *3*, *4*, *8*, and *9*, using the odd–even parity rule or a rule in which one response was to be made if the digit was a multiple of 3 and the other if it was not. With this stimulus set, the keypress responses to the individual stimuli are identical for the two task rules. The only difference is whether the instructions specify odd–even parity decisions or multiple-of-3 decisions. If the MARC effect is a consequence of coding linguistic markedness for odd–even parity that occurs automatically as part of the verbal number representation, the effect should also be evident (though possibly to a lesser extent) with the multiple-of-3 rule, much as location correspondence effects are when stimulus location is irrelevant to the task (Lu & Proctor, 1995). This result is expected because the relation between parity and the left–right responses is not altered by the change in task rules. However, if the MARC effect is due to the parity rule defining "even" as the + polarity member (or figure) of the odd–even pair, then the effect should reverse with the multiple-of-3 rule because it defines "odd" as the + polarity category.

The basis for the predicted reversal is as follows. One view of parity judgments is that they are performed by attempting to mentally divide the number by 2, and then responding "even" if it is divisible by 2 and "odd" if it is not (e.g., J. M. Clark & Campbell, 1991). With the multiple-of-3 rule, the task would be performed by mentally dividing each number by 3, responding "multiple of 3" if this resulted in a whole number and "not multiple of 3" if it did not. Thus, the pair of numerals *3* and *9* that is the "not divisible by 2" set for the parity judgments switches to be the "divisible by 3" set for the multiple-of-3 judgments, and vice versa for the pair of numerals *4* and *8*. An alternative view is that parity judgments are made by retrieving whether a number is classified as odd or even (Dehaene et al., 1993); multiple-of-3 judgments could likewise be made by retrieving whether the number is classified as a multiple of 3 or not. Note that, with either view, "even" is defined as figure (+ polarity) for the parity rule and "multiple of 3" as figure for the multiple-of-3 rule. Thus, the + polarity right response should be selected relatively faster when even is mapped to it in the parity task and multiple-of-3 is mapped to it in the multiple-of-3 task, regardless of whether participants are calculating or retrieving the classification.

In Experiment 2, the stimuli were the same digits or their corresponding number words. In advocating the linguistic markedness account, Nuerk et al. (2004) stated, "If this linguistic markedness account is valid, markedness-related parity effects should therefore *always* be stronger for number words than for Arabic numbers" (p. 860, emphasis ours). Thus, according to Nuerk et al., if the MARC effect is due to linguistic markedness, the effect should be larger when the stimulus is a number word than when it is a numeral. Also, because the relation between the unmarked even numbers and marked odd numbers is the same for the parity and multiple-of-3 tasks, the MARC effect should be evident for both task rules with both stimulus modes. In contrast, because the polarity correspondence account attributes + polarity to coding induced by the task rule and not to a property of linguistic codes, it does not predict any difference in size of the MARC effect with the parity rule (or the reversed effect with the multiple-of-3 rule) for Arabic numerals and number words.

Both experiments also allowed examination of the SNARC effect. This effect is typically attributed to numbers being coded with respect to their positions on a mental number line for which magnitude increases from left to right. According to the mental number-line account, responding is faster when the position on the line corresponds with that of the correct response than when it does not (e.g., Dehaene et al., 1993; Gevers et al., 2006). That is, it is a variant of the Simon effect, for which RT is shorter when stimulus location corresponds with response location than when it does not, when stimulus location is irrelevant to the task (see Lu & Proctor, 1995, for a review). Because magnitude is irrelevant for both the parity judgment rule and the multiple-of-3 rule, the SNARC effect should not be affected by task rule. Moreover, because coding with respect to the mental number line is presumed to occur for both numerals and number words, the SNARC effect should be of similar magnitude for the two stimulus types (e.g., Nuerk et al., 2004).

Experiment 1

Participants classified the Arabic numerals *3, 4, 8*, and *9* with left–right keypresses using the parity rule or multiple-of-3 rule. Of most concern was whether the MARC effect obtained with the parity rule would be reversed with the multiple-of-3 rule, as predicted by the hypothesis that whereas the even numbers are the + polarity category for parity judgments, the odd numbers (divisible by 3) are the + polarity category for multiple-of-3 judgments.

Method

Participants. Forty-eight undergraduates enrolled in Introductory Psychology at Purdue University participated for research credits. All were right-handed and reported normal or corrected-to-normal visual acuity. Participants were randomly assigned to a parity-judgment group or a multiple-of-3 judgment group.

Stimuli and apparatus. Micro Experimental Laboratory (MEL, 2.01; Schneider, 1995) software was used to program the experiment. Stimuli were the digits *3, 4, 6, 7, 8*, and *9* in the practice session and *3, 4, 8*, and *9* (1.2 × 0.9 cm; 1.15 × 0.86 cm) in the test sessions. They were presented in MEL's System48 font in the center of the display screen of a personal computer at a viewing distance of approximately 60 cm. Responses were made by pressing the leftmost or rightmost of five keys on a MEL 2.0 response box with the left and right index fingers. The distance between the two response keys was 6.7 cm, and the keys were unlabeled.

Procedure. Participants in the parity group were instructed to press one key if the number was odd and the other if it was even: "When the number is odd, press the RIGHT key; otherwise press the LEFT key," or "When the number is odd, press the LEFT key; otherwise press the RIGHT key." The instructions explicitly mentioned odd, and not even, so that the same number set would be referred to as in the instructions for the multiple-of-3 group. Participants in this latter group were instructed to press one key if the number was a multiple of 3 and the other if it was not: "When the number is a multiple of 3, press the RIGHT key; otherwise press the LEFT key," or "When the number is a multiple of 3, press the LEFT key; otherwise press the RIGHT key." Each participant was tested in two 3-session blocks, including a practice session of 18 trials and two test sessions of 64 trials each, with 30-s rest periods between each session and a 1-min rest period between blocks. The even–right/odd–left mapping (or nonmultiple of 3–right/multiple of 3–left mapping) was used for one block, and the even–left/odd–right mapping (or multiple of 3–right/nonmultiple of 3–left mapping) for the other, with order counterbalanced across participants.

Each trial began with a fixation cross (0.7 × 0.7 cm; 0.67 × 0.67 cm) presented at the center of the screen for 500 ms. After offset of the cross, a blank display was presented for 500 ms, followed by an Arabic numeral at the center of the screen, which remained in view until a response was made. An incorrect response was followed by a 500-ms feedback tone. The fixation cross for the next trial appeared 1,500 ms after a correct response and 1,000 ms after the feedback tone when the response was incorrect.

Results

RTs less than 125 ms or greater than 1,250 ms (0.39%) were removed from analysis. Mean RT and percentage of error (PE) were calculated for each participant as a function of mapping (even–right/odd–left or even–left/odd–right), response (left or right), and magnitude (small or large number). ANOVAs were conducted on mean RT and PE data (see Table 1), with task rule (parity or multiple-of-3) as a between-subject factor (see Table 2). An alpha level of .05 was used to determine significance.

RT. RT was nonsignificantly shorter with the multiple-of-3 rule (M = 439 ms) than with the parity rule (M = 457 ms), and significantly shorter for the right response (M = 442 ms) than the left response (M = 454 ms). The main effect of mapping was not significant, but the interaction of mapping and response was: The left response showed a 12-ms even–right/odd–left advantage, but the right response did not.

Most important are the terms involving both mapping and task rule. The two-way interaction of these variables was significant (see Table 2). The parity rule showed a 17-ms even–right/odd–left advantage (MARC effect), $F(1, 46) = 9.23$, $p = .0039$, but this reversed to a nonsignificant 6-ms even–left/odd–right advantage with the multiple-of-3 rule, $F(1, 46) = 1.26$, $p = .267$. The three-way interaction of these variables with response was even more strongly significant (see Figure 1): For the right response, the even–right/odd–left advantage was large (26 ms) with the parity rule and reversed to an equally large even–left/odd–right advantage (29 ms) with the multiple-of-3 rule. In contrast, for the left response, the even–right/odd–left advantage (9 ms) was small with

Table 1
Mean Reaction Time (in Milliseconds) and Percentage of Error in Experiment 1 as a Function of Task Rule, Mapping, Magnitude, and Response Hand

	Left				Right			
	Even–left/odd–right		Even–right/odd–left		Even–left/odd–right		Even–right/odd–left	
Magnitude	RT	PE	RT	PE	RT	PE	RT	PE
Parity rule								
Small (3, 4)	460	3.48	448	4.16	471	8.79	437	4.71
Large (8, 9)	478	6.57	473	6.54	454	5.12	437	4.48
M	469	5.02	460	5.35	464	7.32	437	4.73
Multiple-of-3 rule								
Small (3, 4)	442	1.71	431	4.30	430	6.25	444	2.61
Large (8, 9)	461	3.79	441	5.47	410	1.82	452	1.56
M	451	2.75	436	4.88	420	4.04	448	2.09

Note. Because the data are tabled by small and large subsets, reaction time (RT) and percentage of error (PE) to a specific digit can be determined by locating the column for the assigned response under the appropriate mapping.

Table 2
ANOVAs for Reaction Time and Percentage of Error From Experiment 1

Source	*df*	RT *F*	RT *p*	RT η^2	PE *F*	PE *p*	PE η^2
Between-subject variables							
Rule	1	1.57	.2164	.03	4.08	.0491	.08
Subject (rule)	46	(21,175)			(98.10)		
Within-subject variables							
Mapping	1	1.83	.1824	.04	1.45	.2343	.03
Mapping × Rule	1	8.67	.0051	.16	2.10	.1538	.04
Mapping × Subject (rule)	46	(1,570)			(13.99)		
Response	1	29.57	<.0001	.39	0.05	.8222	.00
Response × Rule	1	1.14	.2918	.02	3.38	.0725	.07
Response × Subject (rule)	46	(499)			(12.77)		
Magnitude	1	3.63	.0631	.07	0.03	.8602	.00
Magnitude × Rule	1	0.15	.7029	.00	1.02	.3179	.02
Magnitude × Subject (rule)	46	(709)			(21.03)		
Mapping × Response	1	6.10	.0173	.12	24.4	<.0001	.35
Mapping × Response × Rule	1	32.81	<.0001	.42	1.04	.3131	.02
Mapping × Response × Subject (rule)	46	(660)			(11.25)		
Mapping × Magnitude	1	3.85	.0560	.08	1.70	.1985	.04
Mapping × Magnitude × Rule	1	0.06	.8066	.00	0.00	.9486	.00
Mapping × Magnitude × Subject (rule)	46	(702)			(23.73)		
Response × Magnitude	1	24.98	<.0001	.35	21.80	<.0001	.32
Response × Magnitude × Rule	1	0.90	.3473	.02	0.03	.8713	.00
Response × Magnitude × Subject (rule)	46	(623)			(22.53)		
Mapping × Response × Magnitude	1	3.38	.0726	.07	3.45	.0695	.07
Mapping × Response × Magnitude × Rule	1	1.36	.2502	.03	0.00	.9748	.00
Error	46	(971)			(30.89)		

Note. Values in parentheses are mean square errors. Sometimes markedness association of response codes effect data are analyzed with parity as a factor instead of mapping, in which case the Mapping × Response interaction becomes the parity factor and the Mapping main effect becomes the Parity × Response interaction. ANOVAs = analyses of variance; RT = reaction time; PE = percentage of error.

the parity rule and increased numerically (to 15 ms) with the multiple-of-3 rule.

The interaction of magnitude and response was significant: Right responses were faster to the two large numbers (*8* and *9*, *M* = 438 ms) than to the two small numbers (*3* and *4*, *M* = 446 ms), whereas left responses were faster to the small numbers (*M* = 445 ms) than to the large numbers (*M* = 463 ms). This SNARC effect was unaffected by task rule.

PE. PE was higher with the parity rule (5.48%) than with the multiple-of-3 rule (3.44%). The two-way interaction of mapping and response was significant: Right responses showed a 2.16% even–right/odd–left advantage, whereas left responses showed a 1.24% even–left/odd–right advantage.

A 1.02% even–right/odd–left advantage was obtained with the parity rule, whereas a 0.10% even–left/odd–right advantage was obtained with the multiple-of-3 rule, but this interaction was not significant. The interaction of magnitude and response was significant, indicating a SNARC effect: For right responses, PE was lower to large numbers (*M* = 3.25%) than to small numbers (*M* = 5.59%), whereas for the left response, it was lower to small numbers (*M* = 3.41%) than to large numbers (*M* = 5.59%).

Discussion

The MARC effect was obtained for the parity judgment task: A 17-ms even–right/odd–left advantage was evident for RT, and a 1.02% even–right/odd–left advantage tendency was shown for PE. However, for the multiple-of-3 rule, a nonsignificant reversed MARC effect was obtained: A 6-ms even–left/odd–right advantage occurred in the RT data, and a 0.10% advantage occurred in PE data.

The incomplete reversal of the MARC effect with the multiple-of-3 rule could be taken as indicating that linguistic parity continued to exert an effect that countered the effect of multiple-of-3 being + polarity. However, the three-way interaction with response indicates instead that the incomplete reversal was a consequence of the rule manipulation affecting RT only for the right response. That response showed a complete reversal of the preferred mapping as a function of task rule, whereas the left response showed none. Because right is the + polarity response, this finding indicates that performance benefits when the + polarity member of the stimulus category matches the + polarity response but not when the – polarity stimulus category matches the – polarity response. This unanticipated outcome suggests that the identified stimulus category is being matched to the right response in response selection, with left being treated more as a default response that is executed if the right response is not chosen. Though this outcome is not predicted by the polarity correspondence account, it is generally consistent with the hypothesis that the task rule determines whether multiple-of-2 or multiple-of-3 is foregrounded.

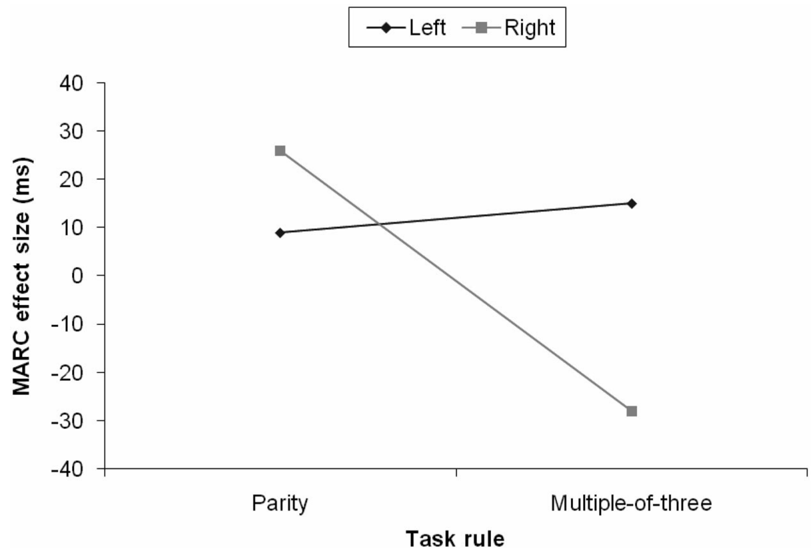

Figure 1. The markedness association of response codes (MARC) effect as a function of task rule and response in Experiment 1.

It should be emphasized, again, that with both rules participants responded to *3* and *9* by pressing one key and *4* and *8* by pressing the other. Yet, the two task rules produced different result patterns. This outcome indicates that the MARC effect for parity judgments is due primarily to "even" (i.e., divisible by 2) being defined as figure (+ polarity) by the parity rule. If the MARC effect had been due to a fixed property of linguistic markedness, the effect should not have reversed when the task rule was switched to multiple-of-3.

The SNARC effect was evident regardless of task rule in both RT and PE. Large–right/small–left advantages of 15 ms and 2.34% were obtained when responses were based on number parity and of 10 ms and 2.19% when responses were based on multiple-of-3. This outcome indicates that the number magnitude was activated automatically, influencing response-selection processes even though it was irrelevant.

Experiment 2

Experiment 2 tested whether the task rule also influences the MARC effect when the stimuli are number words and whether the MARC effect and its reversal are more evident for number words than for Arabic numerals. Another purpose was to replicate the finding of Experiment 1 that correspondence with the positive polarity right response is more important than correspondence with the negative polarity left response.

As in Experiment 1, participants made responses with one of two task rules, parity or multiple-of-3. However, the stimuli were number words or Arabic numerals. If the MARC effect is due to the linguistic markedness of parity, the effect would likely be larger for number words than numerals (Nuerk et al., 2004). Also, the influence of task rule on the MARC effect should be less evident for number words than numerals because number words should activate the linguistic parity codes for odd and even more strongly than numerals do under both rules. However, if the mapping effects are determined primarily by the polarity defined by the task rule, then task rule should influence performance similarly for both stimulus modes. As in Experiment 1, the MARC effect favoring the mapping of *4* and *8* to the positive right response should reverse with the multiple-of-3 rule to favor the mapping of *3* and *9* to that response.

Method

Forty-eight undergraduate student participants who had not participated in the previous study were drawn from the same subject pool used in Experiment 1. Participants were randomly assigned to parity and multiple-of-3 groups.

The apparatus, stimuli, and procedure were identical to those used in Experiment 1, with the following exceptions. Stimuli were the numerals *3, 4, 8*, and *9* and the number words *THREE, FOUR, EIGHT*, and *NINE* (2.4–2.9 cm × 0.6 cm; 2.3–2.8 × 0.57 cm), in uppercase letters. On a given trial, one of the numerals or number words was randomly presented as the imperative stimulus. Each participant performed 16 practice trials when the new mapping was introduced, and each of the two test sessions consisted of 96 trials.

Results

Using the same criteria as Experiment 1, we removed 1.39% of trials from analysis. ANOVAs were conducted on the RT and PE data (see Table 3), as in Experiment 1, with task rule (parity or multiple-of-3) as a between-subject factor and stimulus mode (numeral or number word), mapping (even–right/odd–left or even–left/odd–right), response (left or right), and magnitude (small or large number) as within-subject factors (see Table 4).

RT. As in Experiment 1, RT was shorter for the multiple-of-3 group (M = 480 ms) than the parity group (M = 546 ms), and in this case the difference was significant. The pattern of slightly shorter RT for the right response (M = 511 ms) than for the left response (M = 516 ms) was again obtained, but in this case it did

Table 3
Mean Reaction Time (in Milliseconds) and Percentage of Error in Experiment 2 as a Function of Task Rule, Mapping, Magnitude, Mode, and Response Hand

Stimulus mode and magnitude	Left				Right			
	Even–left/odd–right		Even–right/odd–left		Even–left/odd–right		Even–right/odd–left	
	RT	PE	RT	PE	RT	PE	RT	PE
Parity rule								
Numeral								
Small (3, 4)	530	3.36	502	2.82	545	5.56	527	5.07
Large (8, 9)	550	5.58	543	4.66	539	3.98	509	2.74
M	540	4.47	523	3.74	542	4.77	518	3.90
Number word								
Small (3, 4)	552	3.82	544	2.83	584	7.57	532	2.85
Large (8, 9)	584	4.75	574	5.30	576	2.87	553	2.46
M	568	4.28	559	4.07	580	5.22	543	2.65
Multiple-of-3 rule								
Numeral								
Small (3, 4)	469	2.35	445	1.91	446	3.85	479	2.08
Large (8, 9)	463	3.50	480	4.38	445	3.15	470	2.44
M	466	2.93	463	3.14	445	3.50	474	2.26
Number word								
Small (3, 4)	497	3.32	486	1.92	477	4.17	498	3.72
Large (8, 9)	512	4.88	520	7.29	484	4.04	510	2.78
M	505	4.10	503	4.60	481	4.10	504	3.25

Note. Because the data are tabled by small and large subsets, reaction time (RT) and percentage of error (PE) to a specific number can be determined by locating the column for the assigned response under the appropriate mapping.

not quite attain statistical significance. Responses were faster to numerals ($M = 496$ ms) than to number words ($M = 530$ ms). The main effect of magnitude was also significant, with RT being shorter to small numbers ($M = 507$ ms) than to large numbers ($M = 519$ ms). This small-number advantage was more evident for number words (18 ms) than numerals (7 ms), as indicated by significant interaction of magnitude and stimulus mode.

Of most concern was the effect of mapping. The main effect of mapping was not significant, but the interaction of mapping and task rule was: A 21-ms even–right/odd–left advantage was obtained with the parity rule, $F(1, 46) = 7.17$, $p = .0102$, whereas a nonsignificant 12-ms even–left/odd–right advantage was obtained with the multiple-of-3 rule, $F(1, 46) = 2.09$, $p = .155$. As in Experiment 1, the three-way interaction of mapping, task rule, and response was significant and did not interact with stimulus mode (see Figure 2). Right responses showed a 31-ms even–right/odd–left advantage with the parity rule that reversed to a 26-ms even–left/odd–right advantage with the multiple-of-3 rule. In contrast, left responses showed a 13-ms even–right/odd–left advantage with the parity rule that decreased to 2 ms with the multiple-of-3 rule.

The SNARC effect was also evident: For large numbers, right responses ($M = 511$ ms) were faster than left responses ($M = 528$ ms). However, for small numbers, left responses ($M = 503$ ms) were faster than right responses ($M = 511$ ms). This SNARC effect was not affected significantly by task rule or stimulus mode.

Remaining significant effects were as follows. Mapping interacted with magnitude: Responses to small numbers showed a 10-ms even–right/odd–left advantage, but responses to large numbers showed a 1-ms even–left/odd–right advantage. In addition, the three-way interaction of mapping, response, and stimulus mode was significant. For numerals, right responses showed a 2-ms even–left/odd–right advantage, but left responses showed a 10-ms even–right/odd–left advantage. However, for number words, the right and left responses showed a similar magnitude of even–right/odd–left advantage (7 ms and 5 ms, respectively). The four-way interaction of mapping, response, magnitude, and stimulus mode was significant. For small numbers, right responses showed an even–right/odd–left advantage to the number words (16 ms) but not to the numerals (−8 ms), whereas the left responses showed a smaller even–right/odd–left advantage to number words (9 ms) than to the numerals (25 ms). However, for large numbers, no tendency was evident (−1, 3, 1, and −5 ms, respectively).

PE. A 0.72% even–right/odd–left advantage was obtained, but this advantage was not significant. Although a 1.10% even–right/odd–left advantage obtained with the parity rule decreased to a 0.35% even–right/odd–left advantage, the interaction of mapping and task rule also was not significant. The interaction of mapping and magnitude was significant: As in the RT data, the even–right/odd–left advantage was more evident for small numbers (1.35%) than large numbers (0.08%). Mapping also interacted with response: Right responses showed a 1.38% even–right/odd–left advantage, whereas left responses showed only a 0.06% advantage.

The SNARC effect was apparent in the PE data. The interaction of response and magnitude was significant. For large numbers, PE was lower with right responses (3.06%) than with left responses (5.04%), whereas for small numbers, it was higher with right responses (4.36%) then with left responses (2.79%). This SNARC effect was not affected significantly by task rule or stimulus mode.

Table 4
ANOVAs for Reaction Time (RT) and Percentage of Error (PE) From Experiment 2

		RT			PE		
Source	*df*	*F*	*p*	η^2	*F*	*p*	η^2
Between-subject variables							
Rule	1	11.04	.0018	.19	0.47	.4982	.01
Subject (rule)	46	(76.726)			(175.79)		
Within-subject variables							
Mapping	1	0.76	.3879	.02	3.11	.0844	.06
Mapping × Rule	1	8.50	.0055	.16	0.85	.3606	.02
Mapping × Subject (rule)	46	(6,378)			(31.86)		
Response	1	3.01	.0893	.06	0.60	.4429	.01
Response × Rule	1	1.40	.2428	.03	0.57	.4529	.01
Response × Subject (rule)	46	(1,490)			(14.10)		
Magnitude	1	25.33	<.0001	.36	1.99	.1650	.04
Magnitude × Rule	1	0.29	.5920	.01	3.94	.0532	.08
Magnitude × Subject (rule)	46	(1,175)			(21.72)		
Mode	1	145.34	<.0001	.76	1.60	.2119	.03
Mode × Rule	1	0.56	.4582	.01	3.01	.0895	.06
Mode × Subject (rule)	46	(1,506)			(23.78)		
Mapping × Response	1	0.76	.3894	.02	6.44	.0146	.12
Mapping × Response × Rule	1	14.30	.0004	.24	0.03	.8737	.00
Mapping × Response × Subject (rule)	46	(1,821)			(13.09)		
Mapping × Magnitude	1	10.72	.0020	.19	5.69	.0212	.11
Mapping × Magnitude × Rule	1	0.57	.4558	.01	0.03	.8742	.00
Mapping × Magnitude × Subject (rule)	46	(584)			(13.36)		
Mapping × Mode	1	0.42	.5186	.01	0.04	.8492	.00
Mapping × Mode × Rule	1	0.01	.9182	.00	0.47	.4977	.01
Mapping × Mode × Subject (rule)	46	(599)			(22.16)		
Response × Magnitude	1	14.98	.0003	.25	11.53	.0014	.20
Response × Magnitude × Rule	1	1.38	.2457	.03	0.28	.5965	.01
Response × Magnitude × Subject (rule)	46	(2,104)			(52.49)		
Response × Mode	1	1.09	.3016	.02	0.63	.4329	.01
Response × Mode × Rule	1	0.68	.4146	.01	0.00	.9682	.00
Response × Mode × Subject (rule)	46	(684)			(18.79)		
Magnitude × Mode	1	9.36	.0037	.17	0.03	.8625	.00
Magnitude × Mode × Rule	1	0.17	.6796	.00	1.06	.3081	.02
Magnitude × Mode × Subject (rule)	46	(581)			(13.76)		
Mapping × Response × Magnitude	1	1.06	.3090	.02	0.12	.7259	.00
Mapping × Response × Magnitude × Rule	1	0.99	.3241	.02	1.06	.3091	.02
Mapping × Response × Magnitude × Subject (rule)	46	(2,936)			(37.55)		
Mapping × Response × Mode	1	4.06	.0498	.08	0.95	.3347	.02
Mapping × Response × Mode × Rule	1	0.95	.3356	.02	1.14	.2915	.02
Mapping × Response × Mode × Subject (rule)	46	(640)			(14.16)		
Mapping × Magnitude × Mode	1	0.07	.7996	.00	3.67	.0618	.07
Mapping × Magnitude × Mode × Rule	1	0.58	.4496	.01	2.56	.1168	.05
Mapping × Magnitude × Mode × Subject (rule)	46	(787)			(11.87)		
Response × Magnitude × Mode	1	3.28	.0765	.07	0.97	.3306	.02
Response × Magnitude × Mode × Rule	1	1.22	.2746	.03	0.58	.4520	.01
Response × Magnitude × Mode × Subject (rule)	46	(446)			(15.98)		
Mapping × Response × Magnitude × Mode	1	8.90	.0046	.16	0.11	.7402	.00
Mapping × Response × Magnitude × Mode × Rule	1	0.67	.4160	.01	4.07	.0496	.08
Error	46	(849)			(10.41)		

Note. Values in parentheses are mean square errors. When the data are analyzed with parity as a factor instead of mapping, the Mapping × Response interaction becomes the parity factor and the mapping main effect becomes the Parity × Response interaction. ANOVAs = analyses of variance.

Finally, the five-way interaction of all variables just attained the .05 significance level. Although the pattern underlying this interaction is difficult to summarize, the major contributor to the interaction appears to be a larger MARC effect for the right response with number words of small magnitude for the parity-judgment task than for the multiple-of-3 judgment task. There is no obvious interpretation of this result, and one should be sought only if the result turns out to be replicable.

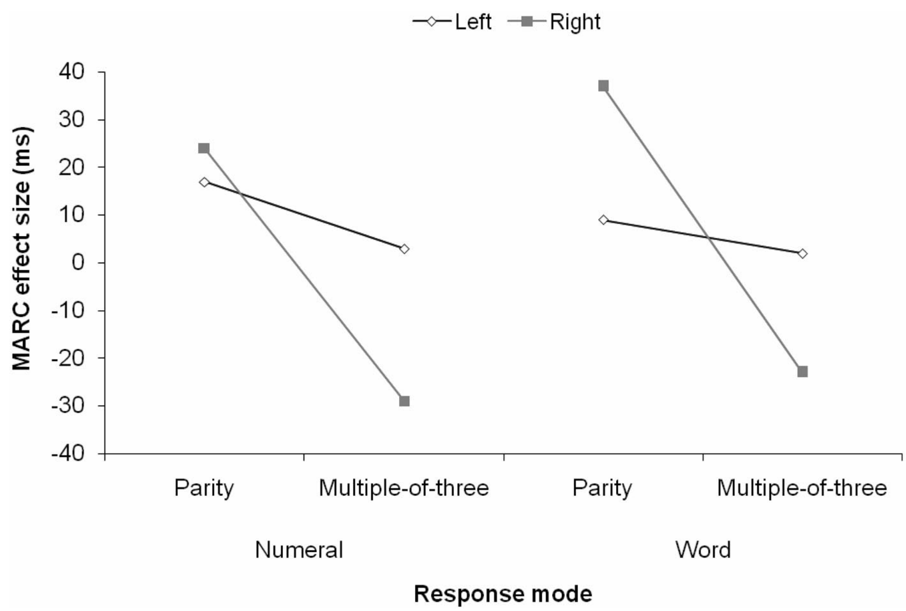

Figure 2. The markedness association of response codes (MARC) effect as a function of task rule, stimulus mode, and response in Experiment 2.

Discussion

As in Experiment 1, the MARC effect was dependent on task rule. With the parity rule, a 21-ms even–right/odd–left advantage was obtained. However, this MARC effect reversed to a nonsignificant 12-ms even–left/odd–right advantage with the multiple-of-3 rule. Again, the influence of task rule was evident mainly for the + polarity right response, for which the MARC effect of 31 ms with the parity rule reversed to a negative MARC effect of 26 ms with the multiple-of-3 rule.

Importantly, the MARC effect with the parity rule and the influence of task rule on the MARC effect did not vary as a function of stimulus mode. Regardless of mode, performance was better for even numbers than odd numbers with the parity rule, whereas it was better for odd numbers than even numbers with the multiple-of-3 rule. This implies that the MARC effect is due primarily to asymmetries in code polarity brought about by the task rule rather than to a fixed property of linguistic markedness. The number words were intermixed with the numerals in trial blocks for this experiment, which may account for our finding no difference in MARC and reverse MARC effects for the two modes, counter to Nuerk et al. (2004; their method also differed in several other ways from that of the present experiment). However, even if intermixing the stimulus modes is a critical factor, the lack of influence on the MARC effect is in contradiction to the implication of the linguistic markedness account that the effect "should . . . always be stronger for number words than for Arabic numbers" (Nuerk et al., 2004, p. 860).

The SNARC effect was again obtained. Right responses were faster to the large numbers than the small numbers, whereas left responses were faster to the small numbers than the large numbers. This SNARC effect was not influenced by the task rule or stimulus mode, consistent with the view that its basis is distinct from that of the MARC effect and is not a function of linguistic codes (e.g., Nuerk, Wood, & Willmes, 2005).

General Discussion

Two experiments investigated whether the MARC effect is due to correspondence between (a) the linguistically unmarked categories even and right and the marked categories odd and left or (b) the digit subset defined as figure (+ polarity) for the task and the positive polarity response "right." Experiments 1 and 2 both showed the MARC effect when participants performed the odd–even classification task, in agreement with previous studies. The MARC effect was as large for numerals as for number words in Experiment 2, which suggests that linguistic marking is not the source of the effect.

More important, in both experiments the MARC effect reversed to an advantage for the odd numbers mapped to the right response and the even numbers to the left response when the task rule was defined as making one response if the number was a multiple of 3 (the odd numbers *3* and *9*) and the other response if it was not (the even numbers *4* and *8*). Although the overall advantage for the even–left/odd–right mapping with the multiple-of-3 task was not as large as the MARC effect with the parity task, this was because the reversal resided almost entirely in the + polarity right response. For that response, the reversal was complete, with the MARC effect for parity judgments averaging 28.5 ms across experiments and the reverse MARC effect for multiple-of-3 judgments averaging 27.5 ms. This reversal illustrates the importance of the task rule: Although the even numbers were coded as + polarity for the parity judgments, the odd numbers were coded as + polarity for the multiple-of-3 judgments because they were the multiples of 3. As noted, in Experiment 2, the reversal of the MARC effect with the multiple-of-3 rule was equally strong for the Arabic numerals and the number words, providing further evidence that linguistic markedness is most likely not the critical factor.

Our conclusion that the MARC effect is not a fixed property of linguistic markedness but of flexible, task-defined coding is in agreement with an aside made by Nuerk et al. (2005) in a recent article on the SNARC effect for numerals, number words, auditory number words, and dice patterns. In that aside, Nuerk et al. noted that the MARC effect for words occurred only when the first trial block in the experiment used numerals. Consequently, they speculated, "Thus, it would seem that the coupling between the markedness of stimulus attribute (odd/even) and response (left hand/right hand) operates in a flexible and task-dependent way" (p. 191). The results of our study provide strong confirmation of Nuerk et al.'s (2005) speculation.

The unexpected finding that the MARC effect and its reversal were most strongly evident for the right response implies that explicit response selection was done primarily with respect to the right response. For the parity judgment task, participants evidently tended to determine whether the displayed number was assigned to the right response and to make the left response if the answer was not affirmative. Such a strategy is generally consistent with the idea that right is figure (+ polarity) for the responses and divisible by 2 or divisible by 3 is figure (+ polarity) for the parity and multiple-of-3 tasks, respectively.

Both experiments also showed a significant SNARC effect, and it was not modulated by task rule. This outcome is not surprising because number magnitude was an irrelevant stimulus dimension unrelated to the instructions for both tasks. Thus, though irrelevant, number magnitude produced a consistent correspondence effect. The accepted explanation of the SNARC effect is that it reflects correspondence of the left–right location of the number on a mental number line with the left or right keypress (e.g., Hubbard, Piazza, Pinel, & Dehaene, 2005). However, we (Proctor & Cho, 2006) previously cited evidence suggesting that the SNARC effect may also be due at least in part to polarity correspondence rather than spatial correspondence on a mental number line. In this case, the idea is that low value is negative polarity and high value is positive polarity, with each number from low to high being progressively more positive. The present experiment does not provide a test of these alternatives because both accounts predicted that the SNARC effect would be uninfluenced by the task rule.

As noted in the introduction, there are two possible processes that people can use to classify a number based on its parity. According to J. M. Clark and Campbell (1991), parity information is extracted from a number by using a mental calculation strategy. That is, each number is classified as odd or even by mentally dividing it by 2. By analogy, if participants were asked to classify a number as a multiple of 3 or not, they would be expected to divide the number by 3. Explicit division clearly alters the task from one in which the digits *4* and *8* are in the "divisible by" set and the digits *3* and *9* in the "not" set to one in which this relation is reversed.

Another possible process for classifying a number as odd or even is retrieval of the parity information from semantic memory (Dehaene et al., 1993). Dehaene et al. (1993) suggested that if the parity information is computed by use of a mental calculation strategy, RT for the parity classification task should increase with the size of the operands. However, in experiments showing the MARC effect or parity effect, this problem-size effect was not obtained (Berch et al., 1999; Dehaene et al., 1993; Nuerk et al., 2004). Consequently, Dehaene et al. concluded that the parity information is directly retrieved from semantic memory. In that case, the shift in processing caused by the task instructions may be one from retrieval of parity for parity judgments to retrieval of multiple-of-3, or possibly computation, for the multiple-of-3 task.

It is unclear whether judgments in the present experiments were based on calculation or retrieval. If calculation were used, division by 3 would seemingly be more difficult than division by 2. Yet, the multiple-of-3 task was easier than the parity judgment task, as indicated by shorter RT and lower PE, suggesting that calculation was not the primary basis for the responses. Unlike prior studies, the operand-size effect (longer RT for the larger numbers than for the smaller ones) was evident for both the parity judgments and the multiple-of-3 judgments in Experiments 1 and 2, though the effect did not quite attain the .05 level in Experiment 1, which is consistent with a mental calculation account. However, because operand size is negatively correlated with the frequency with which the numbers occur in the English language (Dehaene & Mehler, 1992; the numbers three, four, eight and nine have frequencies of 610, 359, 104 and 81 per million in the Kuĉera & Francis, 1967, count), these data cannot be taken as strong evidence for the calculation view. It is even possible, given the small stimulus set used in the study, that participants were retrieving the category from previous episodes on at least some trials.

Regardless of the way in which the decisions were reached, whether the odd numbers were treated as marked, or – polarity, and the even numbers as unmarked, or + polarity, depended on the task representation conveyed by the task rule. Thus, the polarities of the stimulus sets are flexible and task-dependent rather than a fixed linguistic property. Nuerk et al. (2005) recently noted, "Future research needs to specify under which conditions . . . the markedness association between stimulus and response operates in its task-specific . . . way" (p. 191). Our study illustrates that one such condition is which stimulus set is designated as figure, or + polarity, for the task: With the same stimulus numbers assigned to the same keypress responses, the way that the stimulus categories are defined for the task determines whether performance is better with a mapping of the even numbers or the odd numbers to the right response. As we previously argued (Proctor & Cho, 2006), the MARC effect is one of several phenomena that reflect a basic principle that binary alternatives are coded asymmetrically, one as polar referent and the other relative to the polar referent, with performance benefiting when the stimulus–response mapping maintains correspondence of the polarities of the stimulus and response alternatives.

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