Penny Wise and Pound Foolish: The Left-Digit Effect in Price Cognition

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Through five experiments, we provide a cognitive account of when and why nine-ending prices are perceived to be smaller than a price one cent higher. First, this occurs only when the leftmost digits of the prices differ (e.g., \$2.99 vs. \$3.00). Second, the left-digit effect also depends on the numerical and psychological distances between the target price and a competing product's price. The closer the two prices being compared, the more likely is the left-digit effect. Third, the left-digit effect is not restricted to the domain of prices; it also manifests with other multidigit numbers.

Do consumers perceive a nine-ending price to be significantly lower than a price one cent higher (e.g., \$3.99 vs. \$4.00)? This question has attracted researchers' attention as early as 1932. Past research (Monroe 2003) and conventional wisdom suggest that consumers do not respond to very small price changes. Since nine endings change the price of a product by just one cent (e.g., from \$4.00 to \$3.99), several early researchers were skeptical about the effects of nine endings on magnitude perceptions (Bader and Weinland 1932; Gabor 1977; Gabor and Granger 1964; Knauth 1949). However, recent research suggests that the last digit of a price can have a significant impact on firms' revenues (Anderson and Simester 2003; Blattberg and Neslin 1990; see Monroe 2003 and Stiving and Winer 1997 for a summary of research on nine-ending prices). One commonly cited explanation for the popularity of nine-ending prices is that consumers underestimate the magnitude of such prices. Although evidence gathered from econometric analysis of UPC retail scanner data (Stiving and Winer 1997) and surveys of retailers' pricing practices (Schindler and Kirby 1997) support the underestimation hypothesis, experimental evidence has been elusive (Lambert 1975; Schindler and Kibarian 1993). More important, it is not clear why nine endings affect a price's perceived magnitude or what factors moderate the effect (Monroe 2003; Monroe and Lee 1999).

In this article, we develop a conceptual framework that draws on the analog model of numerical cognition (Adaval and Monroe 2002; Dehaene, Dupoux, and Mehler 1990; Hinrichs, Yurko, and Hu 1981; Monroe and Lee 1999) to provide a cognitive account of why and when the perceived magnitude of a nine-ending price is lower than a price one cent higher. The results of five studies provide support for this framework. We find that nine-ending prices affect magnitude perceptions only in certain specifiable situations. First, not all nine endings affect magnitude perceptions; they affect magnitude perceptions only if the leftmost digit changes. Second, we find that left-digit effects are more likely to manifest when the internal discriminability between the two numbers being compared is poor (i.e., when the activated analog magnitudes are close together). Finally, contrary to past suggestions (Gabor and Granger 1964), our results suggest that these effects may not be limited to certain types of prices or products. The effect of a left-digit change on magnitude perception seems to be a consequence of the way the human mind converts numerical symbols to analog magnitudes on the mental scale. From a theoretical perspective, our results explicate how consumers encode and compare multidigit numbers, in general, and prices, in particular. Our results also have implications for pricing practice and public policy.

CONCEPTUAL BACKGROUND

Following Monroe and Lee (1999), we use the analog model (also known as the holistic model) of numerical cognition to explain how nine-ending prices are encoded and evaluated. The analog model (Dehaene 1997; Hinrichs et

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al. 1981) suggests that, when presented with two multidigit numbers to be compared, we assess the quantitative meaning of the numbers by spontaneously mapping them onto an internal analog magnitude scale. This numerical symbol to magnitude conversion affects the precision of the numbers being encoded (Dehaene 1997). Our basic proposition is that the effect of price ending on magnitude perception occurs during this conversion from numerical symbols to mental magnitudes. Left-to-right processing of numerical symbols affects this magnitude conversion process and distorts the price magnitude toward the leftmost digit. We discuss three effects that support this proposition: the left-digit effect, the distance effect, and domain invariance.

Left-Digit Effect

The left-digit effect refers to the observation that using a nine ending versus a zero ending, for example, $2.99 versus $3.00, changes the leftmost digit (i.e., the dollar digit changes from three to two) and that it is this change in the left digit, rather than the one cent drop, that affects the magnitude perception. The analog model suggests that perceivers convert multidigit numbers into mental magnitudes.[1] We build on this model to argue that under specifiable conditions, the leftmost digit can exert a relatively greater influence than the other digits on the encoded magnitude.

For example, consider a consumer who is comparing the prices of two pens: a target pen, priced at $3.00, and another pen, priced at $4.00. Although our interest is in the magnitude perception of the target price, the comparison process plays an important role. When presented with these prices, this consumer automatically encodes them into mental magnitudes on an internal analog scale. The $3.00 price is likely to be mapped onto the lower end of this scale while $4.00 will be mapped onto the relatively higher end of the scale. How would the encoding process differ if the target pen, instead of being priced at $3.00, were priced at $2.99? As stated earlier, multidigit numbers are encoded holistically as one analog representation (Dehaene 1997; Hinrichs et al. 1981; Monroe and Lee 1999). Even though we read three separate digits in $2.99, these digits would be represented as one analog quantity on the internal scale. However, because of left-to-right processing, the encoded magnitude of $2.99 could, at least in some situations, be significantly lower than that of $3.00. Note that this difference in magnitude is because the target price dollar digit changes from $3 to $2 and not because of the one cent price difference. We do not predict a discernible change in magnitude perception if the target price changes from $3.60 to $3.59 because in this case the leftmost digit remains the same.

One possible explanation for this left-digit effect is that encoding the magnitude of a multidigit number begins even before we finish reading all the digits. Dehaene (1997) postulated that the process of numerical symbol to magnitude conversion occurs very rapidly and beyond consciousness. Since we read numbers from left to right, while evaluating "2.99," the magnitude encoding process starts as soon as our eyes encounter the digit "2." Consequently, the encoded magnitude of $2.99 gets anchored on the leftmost digit (i.e., $2) and becomes significantly lower than the encoded magnitude of $3.00. It may be argued that the leftmost digit exerts a primacy effect on magnitude encoding of multidigit numbers. Thus:

H1: Nine-ending prices will be perceived to be smaller than a price one cent higher if the leftmost digit changes to a lower level (e.g., $3.00 to $2.99) but not if the leftmost digit remains unchanged (e.g., $3.60 to $3.59).

Distance Effect

The left-digit effect does not always manifest. Perceivers tend to anchor magnitudes of multidigit numbers on the left digit only when the internal discriminability between the two numbers being compared is poor. Price evaluation usually involves comparing two numerical stimuli, a target price and a comparison standard (Adaval and Monroe 2002; Janiszewski and Lichtenstein 1999; Niedrich, Sharma, and Wedell 2001). Before two numbers can be compared, the numerical symbols must be mapped onto the internal analog scale. The closer the perceived distance between the two analog magnitudes, the greater the difficulty in discriminating them on this scale. Consequently, the time required for comparing them is greater. This phenomenon has been labeled the "distance effect" (Moyer and Landauer 1967). Hinrichs et al. (1981) showed that, when asked to judge whether a given two digit number is higher or lower than 55, participants took significantly more time to judge numbers in the 40–70 range than in the 10–40 or 70–100 ranges. Thus, the distance between 55 and the target number moderated the cognitive difficulty in judging the magnitudes of numbers being compared. The distance effect is a very robust phenomenon and has stood up very well to systematic replication (Shepard and Podgorny 1978).

We draw on this research to propose that the perceived distance between the two prices being compared will moderate the left-digit effect. Our brain is more likely to use a heuristic involving anchoring the magnitude on the leftmost digit when the comparison process makes the magnitude encoding task relatively difficult. When the magnitude encoding is relatively easy, then the left-digit effect should diminish. So, the farther (closer) the two prices being compared, the greater the ease (difficulty) in encoding the magnitude of the nine-ending price. Consequently, the farther (closer) the two prices, the less (greater) the distorting influence of the leftmost digit. Stated simply, $4 versus $5 is not quite the same as $3.99 versus $5, but $4 versus $10 may not be perceptibly different from $3.99 versus $10. Formally:

[1]The digital model (Poltrock and Schwartz 1984; Stiving and Winer 1997) suggests that multidigit numbers are compared digit by digit rather than holistically. See Hinrichs et al. (1981) for a more detailed discussion of analog versus digital models of multidigit numerical comparison.

H2: A left-digit change caused by a nine-ending price is less (more) likely to affect the price's magnitude perception when the comparison standard is perceived to be far away (close).

It needs to be underscored that our focus is on perceived or psychological distance. The distance as perceived on the internal analog scale, rather than the nominal distance, moderates the left-digit effect. Sometimes, nominal distance may not reflect the psychological distance. The experiments presented in this article examine the effect of nominal as well as psychological distance. Further, in order to gain insight into the underlying process, we also examine how distance affects response latencies for numerical judgments.

Domain Invariance

Domain invariance refers to the property that the left-digit and distance effects are not restricted to the domain of prices; they also manifest with other multidigit numbers. Past research has often attributed the popularity of nine-ending prices to perpetuated retailing practices (Gabor 1977; Gabor and Granger 1964; Schindler 1991). Based on a survey of published material and informal conversations with consumers and retailers, Schindler (1991) proposed a list of fourteen meanings that price endings are likely to communicate to consumers (e.g., price-related meanings, such as "low price," "discount price," or meanings concerning nonprice attributes of the product or retailer, such as "low quality").

If consumers' favorable responses to nine-ending prices are based solely on such images, then these effects should be confined to the domain of prices. However, if these effects are, at least partly, due to left-to-right processing, then these effects should be invariant to domain. (Note, we are not ruling out image effects; rather, we suggest that nine-ending numbers can be perceived to be smaller than a number one unit high even when image effects are absent.) Drawing on the premise that the left-digit effect is a characteristic of the multidigit encoding process, we predict that this effect and its interaction with the distance effect will manifest for most types of nine-ending numbers. Thus:

H3: Decreasing the distance between the numbers being compared will increase the left-digit effect not only in the domain of prices but also in other types of nine-ending numbers.

STUDY 1A: LEFT-DIGIT EFFECT

If the effect of nine endings on magnitude perceptions is a consequence of the primacy of the leftmost digit, then it should manifest only when the left digit changes. We test this (hypothesis 1) using a between-subjects experimental design in which we manipulated two orthogonal factors: whether a target product's price ending was nine or zero and whether its dollar digit remained the same or was changed by the price-ending manipulation. Participants were also introduced to a comparison standard, the price of a comparable product, that remained unchanged across conditions. Using a comparison standard was expected to initiate the number comparison process and thus facilitate the conversion of these numerical symbols into magnitudes on an internal analog scale. Further, it also ensured that participants always evaluated the magnitude of the target price with respect to a common reference point.

Method

Participants. Fifty-two undergraduate students from a large northeastern university participated in the experiment in return for partial course credit.

Design. This study employed a 2 × 2 mixed factorial design; the effect of the nine ending (nine vs. zero) was examined between subjects while the effect of the left digit of the target price (same vs. different) was examined within subjects. The stimuli for this study were pens, and each participant saw prices for four pens: first two ballpoint pens and then two fountain pens (see table 1). In each category, one brand was the target and other the comparison standard pen. Price endings for the target pens were manipulated to either have a zero or a nine ending. Half the participants saw target prices that ended in the digit nine ($2.99 and $3.59) and half in the digit zero ($3.00 and $3.60). The price of the target ballpoint pen was chosen such that the price ending manipulation resulted in a nine-ending price with a lower dollar-digit ($3.00 vs. $2.99), while that of the target fountain pen was chosen such that the nine-ending manipulation did not affect the dollar-digit ($3.60 vs. $3.59). The comparison standards were always held constant at $4.00. The dependent variable was the magnitude perception of the target price. Since the comparison standard was held constant across conditions, the target price manipulations were not expected to have any effect on the magnitude perceptions of the comparison standard.

Procedure. Participants were told that Aprilla and Avalon are two brands of pens being sold online and that they should compare these brands within each product category. Participants were given a booklet with advertisements for all four pens (first for the two brands of ballpoint pens and then for the two brands of fountain pens). The pictures of

TABLE 1

STIMULI USED IN STUDY 1A

	Nine-ending condition ($)	Zero-ending condition ($)
Pair 1 (nine-ending target has lower left digit):		
Ballpoint (target)	2.99	3.00
Ballpoint (standard)	4.00	4.00
Pair 2 (nine-ending target has same left digit):		
Fountain (target)	3.59	3.60
Fountain (standard)	4.00	4.00

the pens were similar and the pen descriptions were short and nondiagnostic (e.g., "Avalon ballpoint pen, black-laser engraved, solid brass cap and barrel, state-of-the-art laser-engraved logo, twist action mechanism, ink color: black"). Details concerning the size and imprint area were also provided. Below each pen's description was its price, including delivery charges. The target pen prices were the only elements manipulated between conditions; all other information remained the same.

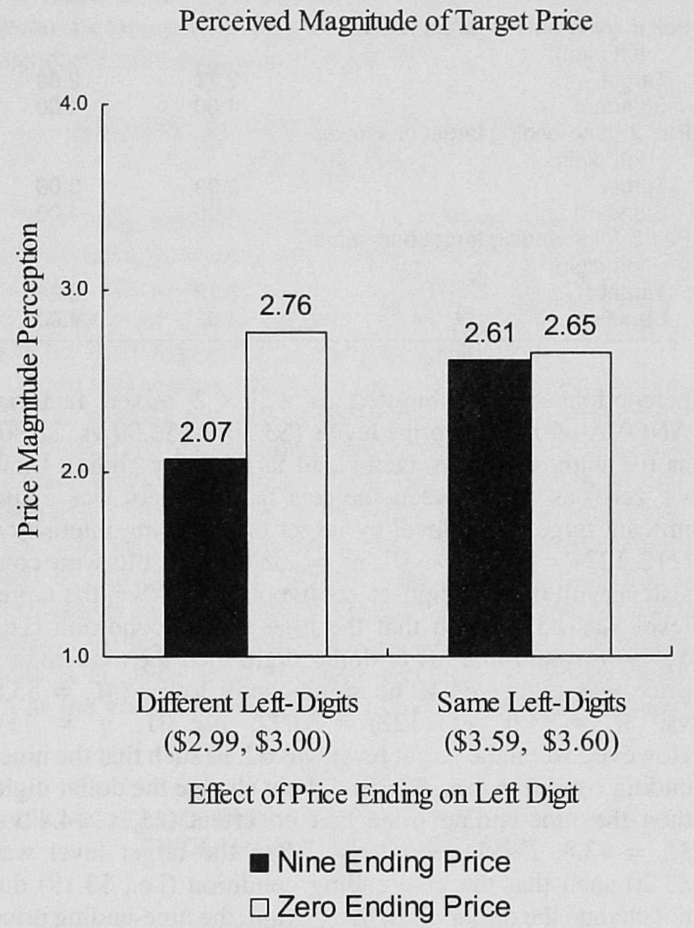
Dependent Variable. Participants reported their price magnitude perceptions for each brand on five-point Likert scales with responses, 1 = "Strongly disagree" and 5 = "Strongly agree." Specifically, participants indicated the degree to which they agreed or disagreed with the statement "___ pen's price is high" for each brand and type of pen they reviewed.

Results

Target pen perceived price magnitude was submitted to a 2 × 2 mixed factorial ANOVA. Nine endings increased the difference in perceived price magnitude between the zero and the nine-ending prices only when the dollar digit changed, supporting hypothesis 1 (see fig. 1). The dollar digit by price ending interaction was significant ($F(1,50) = 4.27$, $p < .05$, $\eta^2 = .08$). When the left digits differed (i.e., \$3.00 vs. \$2.99 for ballpoint pens), then the mean magnitude perception was lower when the price had a nine versus a zero ending ($M_0 = 2.76$ vs. $M_9 = 2.07$; $F(1,50) = 9.57$, $p < .01$, $\eta^2 = .16$). However, when the leftmost digits were the same (i.e., \$3.59 vs. \$3.60 for fountain pens), then the effect of price ending on price magnitude was not significant ($M_0 = 2.65$ vs. $M_9 = 2.61$, $F < 1$). No other effect reached significance. As expected, magnitude perceptions of the comparison standards, which remained constant at \$4.00 across conditions, were not affected by the target price ending manipulation ($F < 1$).

FIGURE 1

LOWERING THE PRICE BY ONE CENT TO A NINE-ENDING PRICE AFFECTS MAGNITUDE PERCEPTION ONLY WHEN THE LEFT DIGIT CHANGES



STUDY 1B

Method

Study 1B was similar to the previous study except for the following. First, the numerical stimuli in the same-left-digit conditions were changed, since in study 1a, the distance between the target and the comparison was confounded with whether the left digits differed. Second, we use a different scale to measure perceived magnitude. Participants indicated their magnitude perceptions for each brand by placing an "X" on an uncalibrated 110 mm horizontal line anchored at "low" and "high." Responses were recorded by measuring the distance from the left end of the line to the "X" using a standard ruler calibrated in millimeters, and thus ranged from zero to 110. Third, the same- and lower-left-digit prices were counterbalanced across product types, and the order of price presentation was also manipulated between subjects.

The study employed a 2 × 2 × 2 × 3 mixed factorial design. Sixty-three undergraduate students from a large northeastern university were randomly assigned to one of the between-subjects conditions: target price ending (nine vs. zero), product counterbalancing, and order of price exposure. Participants were told that they have to compare the brands Avalon and Aprilla in three different categories of writing instruments: fountain pens, ballpoint pens, and pencils. Target price level was manipulated within subjects at three different levels (\$3.20 vs. \$3.00 vs. \$2.80); these target price levels were chosen such that the price ending manipulation changed the leftmost dollar digit only when the price level was \$3.00/\$2.99; at the other two price levels, the dollar digit remained unchanged in both price ending conditions (\$3.20/\$3.19 and \$2.80/\$2.79). The comparison standard was \$4.00 across conditions. Thus in each condition, the participants saw six different prices (see table 2).

Results

Since the order manipulation and product counterbalancing effects were not significant ($F < 1$), the data were collapsed across these manipulations. Target pen magnitude

TABLE 2

STIMULI USED IN STUDY 1B

	Nine-ending condition ($)	Zero-ending condition ($)
Pair 1 (nine-ending target has same left digit):		
Target	2.79	2.80
Standard	4.00	4.00
Pair 2 (nine-ending target has lower left digit):		
Target	2.99	3.00
Standard	4.00	4.00
Pair 3 (nine-ending target has same left digit):		
Target	3.19	3.20
Standard	4.00	4.00

perceptions were submitted to a 3 × 2 mixed factorial ANOVA with target price levels ($3.20 vs. $3.00 vs. $2.80) as the within subjects factor and target price ending (nine vs. zero) as the between-subjects factor. There was a significant target price level by target price ending interaction ($F(2, 122) = 5.29, p < .01, \eta^2 = .08$). The results were consistent with the left-digit-effect hypothesis. When the target level was $3.00 such that the nine-ending condition (i.e., $2.99) resulted in a lower dollar digit, then the nine-ending price was perceived to be significantly lower ($M_0 = 55.8$ vs. $M_9 = 35.6$; $F(1, 122) = 20.92$, $p < .01$, $\eta^2 = .15$). However, when the target level was $2.80 such that the nine-ending condition (i.e., $2.79) did not change the dollar digit, then the nine-ending price had no effect ($M_0 = 44.4$ vs. $M_9 = 42.8$; $F < 1$). Similarly, when the target level was $3.20 such that the nine-ending condition (i.e., $3.19) did not change the dollar digit, then, again, the nine-ending price had no effect ($M_0 = 43.7$ vs. $M_9 = 47.7$; $F < 1$). These results are similar to those obtained in study 1a. The left-digit manipulation had no effect on the magnitude perceptions for the comparison standards ($F < 1$).

Discussion

Results from studies 1a and 1b support the left-digit effect hypothesis. They show that lowering a price by one cent to a 99 ending affects magnitude perceptions when the left digit changes (e.g., $3.00 to $2.99) but does not affect magnitude perceptions when the left digit is unchanged ($3.20 to $3.19 or $2.80 to $2.79). These studies, contrary to some of the earlier views (e.g., Gabor 1977; Knauth 1949), provide experimental evidence that nine-ending prices are perceived to be smaller than a price one cent higher. These experimental results also corroborate Stiving and Winer's (1997) finding, using scanner data, that the left digit exerts a stronger influence than the right digits in price evaluation. Study 1b also showed that distance between target number and the comparison standard has no effect on magnitude perceptions when the left digit remains unchanged. In the following study we test the effect of distance between two numbers being compared when the left digit of one of the two numbers changes.

STUDY 2: ANALOG MAPPING AND THE DISTANCE EFFECT

The process of mapping from numerical symbols to mental magnitudes imposes a cost on the speed of mental calculations (Shepard and Podgorny 1978). The closer the numbers being compared, the greater the effort required for their comparison. This ease of comparison manifests in the response latency for these comparisons. Moyer and Landauer (1967) measured the time participants took in comparing two Arabic numbers and found that as the numerical distance between them decreased, the response time for the comparison task increased, a phenomenon which has come to be known as the distance effect. The distance effect has been cited as evidence for holistic or analogical encoding of numbers. Dehaene (1997, 76) wrote, "The only explanation I can think (for the distance effect) is that our brain apprehends a two-digit numeral as a whole and transforms it mentally into an internal quantity or magnitude. At this stage, it forgets about the precise digits that led to this quantity." The distance effect has been shown to be a robust phenomenon not only in humans but also in chimpanzees and pigeons. Further, this effect extends to multidigit numerals, resists training and is present at 6 yrs. of age, the earliest age at which it has been tested (cf. Dehaene 1997).

The distance effect suggests that encoding the magnitude of a price is more cognitively taxing when an available comparison standard is closer to the target price. The distance effect should then exacerbate the primacy effect of left digits. The closer the prices being compared, the higher the cognitive load, and therefore the greater would be the error in encoding their magnitudes. This argument is also consistent with the notion that under higher cognitive load, individuals will be more likely to rely on a simplifying heuristic for relative magnitude judgments. Study 2 tests whether numerical distance moderates the underestimation effect caused by a lower left digit (hypothesis 2).

Method

Design. This study employed a 2 × 2 × 2 fully factorial design. Distance between the target and comparison standard ($1 vs. $2), comparison standard level (higher vs. lower) and the price ending of the target price (zero vs. nine) were manipulated. The stimuli were a subset of those used in studies 1a and 1b. Each participant saw two ballpoint pens (see table 3). One pen served as the target while the other served as the comparison standard. We manipulated the target brand's price ending ($3.99 or $4.00) and the comparison standard's price level ($2.00, $3.00, $5.00 or $6.00). The comparison standards were selected such that they were either $2 higher ($6) or lower ($2) or $1 higher ($5) or lower ($3) than the target price. This resulted in two

TABLE 3

STIMULI USED IN STUDY 2

	Target price higher than standard ($)		Target price lower than standard ($)	
	$2 higher	$1 higher	$1 lower	$2 lower
Zero-ending target price conditions:				
Target	4.00	4.00	4.00	4.00
Standard	2.00	3.00	5.00	6.00
Nine-ending target price conditions:				
Target	3.99	3.99	3.99	3.99
Standard	2.00	3.00	5.00	6.00

levels of distances between the comparison standards and the target price ($1 or $2).

Procedure. One hundred and fifty-four undergraduate students participated in this study. They were told to evaluate two brands of pen sold by an online company. Participants were given a booklet that showed advertisements for both pens and the response scales. We used the same two fictitious brands of ballpoint pens, Avalon and Aprilla, as in study 1. Avalon served as the target brand and Aprilla as the comparison standard. The same dependent measure of perceived price magnitude employed in study 1a was used in this study.

Results

Perceived price magnitude was subjected to three-way ANOVA with comparison standard level, price ending, and distance as between-subject factors. There was a main effect of price ending ($F(1, 145) = 8.09$, $p < .01$, $\eta^2 = .05$). For all levels of comparison standard, nine-ending target prices were perceived to have lower magnitude than zero-ending ones ($M_9 = 2.73$ vs. $M_0 = 3.24$). This main effect was qualified by a significant price ending by distance interaction ($F(1, 145) = 4.67$, $p < .05$, $\eta^2 = .03$), supporting hypothesis 2. The effect of price endings on perceived price magnitude was greater when distance was small. When the distance between the target and the comparison standard was $1, there was a significant difference in the magnitude perceptions of nine- and zero-ending prices ($M_9 = 2.50$ vs. $M_0 = 3.39$; $F(1, 145) = 12.81$, $p < .01$, $\eta^2 = .08$). However, there was no significant difference between these prices when the distance was $2 ($M_9 = 2.96$ vs. $M_0 = 3.09$; $F < 1$). There was also a main effect of comparison standard level such that the target price was perceived to be smaller when it was lower than the comparison standard ($M_{low} = 2.59$ vs. $M_{high} = 3.38$; $F(1, 145) = 19.2$, $p < .01$, $\eta^2 = .12$). No other effect reached significance. We also estimated the mean perceived price magnitude separately for the four levels of comparison standard (see fig. 2). The effect of price ending was significant only when the target price was $1 lower or higher than the comparison standard and not in the other two conditions.

Discussion

The results of this study are consistent with the predictions of the analog model and with our assertion that the underestimation caused by the left-digit effect occurs during the magnitude encoding process. When the magnitude encoding was made easier by increasing the numerical distance between the two prices, then the effect of left-digit change on magnitude encoding was weakened.

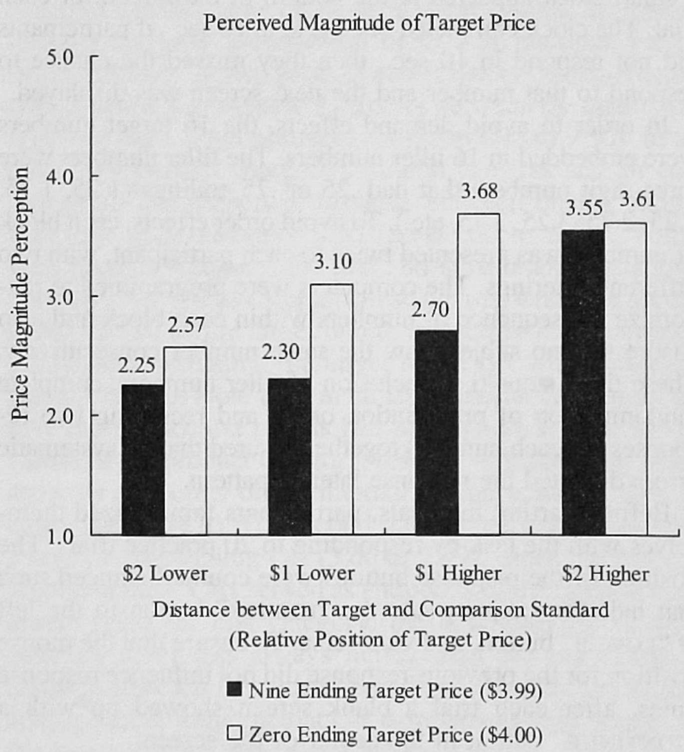
STUDY 3: RESPONSE LATENCY PATTERNS

This study was designed to (1) gain insight into the cognitive encoding process underlying the left-digit effect using response latencies and (2) test whether the left-digit effect manifests in nonprice domains. Thus this study seeks support for both hypothesis 2 and hypothesis 3.

Since self-reports about encoding and processing of numerical stimuli are not reliable, numerical cognition researchers have traditionally relied on response time patterns to make deductions about the underlying cognitive process (Dehaene 1997; Hinrichs et al. 1981; Moyer and Landauer 1967). In this study we adopt the experimental paradigm used by Hinrichs et al. (1981), with minor modifications. Participants judged whether a given three-digit number, between 1.00 and 9.00, was lower or higher than 5.50. (Hinrichs et al. 1981 used numbers between 10 and 100 with 55 as the comparison standard.) Drawing on past findings,

FIGURE 2

DISTANCE MODERATES THE EFFECT OF LEFT DIGIT ON PRICE MAGNITUDE PERCEPTIONS



we predicted that participants would take significantly more time to make magnitude judgments when the target number was close to 5.50 than when it was farther away from 5.50. More importantly, we also examined how the response times varied for nine-ending numbers.

Method

Design. Sixteen numbers were chosen as target numbers, half with nine and half with zero endings. The chosen target numbers were 1.99, 2.00, 2.99, 3.00, 3.99, 4.00, 4.99, 5.00, 5.99, 6.00, 6.99, 7.00, 7.99, 8.00, 8.99, and 9.00. These numbers were symmetric around the comparison standard, 5.50, such that eight of the target numbers were lower and eight were higher than it.

Participants. Fifty-three undergraduate students from a large northeastern university, all with normal or corrected vision, served as participants in partial fulfillment of course requirements.

Procedure. Participants judged whether a target number presented on a computer screen was higher or lower than the comparison standard 5.50. The comparison standard was not presented on the screen; only the target numbers were. Thus participants encoded each target number relative to a memory based comparison standard. The target numbers were displayed at the center of the screen. Below the target number were two buttons labeled "HIGHER" and "LOWER." The computer recorded the time participants took to click on one of these buttons with a mouse after the target number was flashed on the screen.

Participants were told "accuracy and speed are equally important." Further, in order to ensure that they responded fast, a small clock appeared at the bottom of the screen for each trial. The clock completed one cycle in 10 sec.; if participants did not respond in 10 sec., then they missed the chance to respond to that number and the next screen was displayed.

In order to avoid demand effects, the 16 target numbers were embedded in 16 filler numbers. The filler numbers were three-digit numbers that had .25 or .75 endings (1.25, 1.75, 2.25, 2.75, 3.25, 3.75, etc.). To avoid order effects, each block of numbers was presented twice to each participant, with two different orderings. The computers were programmed to randomize the sequence of numbers within each block and also ensure that no subject saw the same number consecutively. These three steps (i.e., inclusion of filler numbers, complete randomization of presentation order, and recording two responses for each number) together ensured that no systematic errors distorted the response latency pattern.

Before starting the trials, participants familiarized themselves with the task by responding to 20 practice trials. The position of the response buttons were counterbalanced such that half the subjects saw the "HIGHER" button to the left of "LOWER" button, and vice versa. To ensure that the mouse position for the previous response did not influence response times, after each trial a blank screen showed up with a "CONTINUE" button in the center of the screen.

Results

Participant's response times for the target numbers were submitted to an 8 × 2 within subjects' ANOVA.[2] The first factor, target level had eight levels: 2, 3, 4, 5, 6, 7, 8, and 9. The second factor was target number ending: zero versus nine ending.

There was a main effect of target level ($F(7,364) = 14.23$, $p < .01$, $\eta^2 = .21$). Participants took more time to make comparisons when the target numbers were close to the comparison standard. For numbers lower than 5.50, as the magnitude increased toward 5.50, the response latency (in milliseconds) also increased: $M_2 = 781$ ms, $M_3 = 818$ ms, $M_4 = 838$ ms, $M_5 = 935$ ms. A linear contrast of these four means was significant confirming a systematic pattern of increase in response latencies ($F(1,364) = 68.15$, $p < .01$, $\eta^2 = .16$). For numbers higher than 5.50, the response latency systematically decreased as the magnitude increased away from 5.50: $M_6 = 888$ ms, $M_7 = 853$ ms, $M_8 = 793$ ms, $M_9 = 822$ ms. Again, a linear contrast of these four means was significant ($F(1,364) = 11.37$, $p < .01$, $\eta^2 = .03$). These observations suggest that the closer the number to the comparison standard, the greater the difficulty in magnitude comparisons.

More interesting was the significant interaction between distance and number ending ($F(7,364) = 4.36$, $p < .01$, $\eta^2 = .08$). The pattern of means supported the hypothesis that nine-ending numbers tend to affect response times only when the distance between the target number and the comparison standard is small. First consider the numbers lower than the comparison standard. When the magnitudes of the target numbers were four or lower, then nine endings did not affect response times ($p > .25$). However in the case of 4.99 versus 5.00, a change in left digit significantly reduced the response time ($M_0 = 1{,}067$ ms to $M_9 = 903$ ms, $F(1,364) = 22.80$, $p < .01$, $\eta^2 = .06$). The response time for the nine-ending number was lower because its left digit led to a perception that it was farther from the comparison standard (see fig. 3). A similar pattern emerged for numbers higher than the comparison standard. When the magnitudes of target numbers were seven or higher, then nine endings did not affect response times ($p > .31$). However in the case of 5.99 versus 6.00, response time was significantly higher for the nine-ending number ($M_0 = 853$ ms to $M_9 = 923$ ms, $F(1,364) = 4.12$, $p < .05$, $\eta^2 = .01$). In this case, the response time for the nine-ending number was higher because its left digit led to a perception that it was closer to the comparison standard.

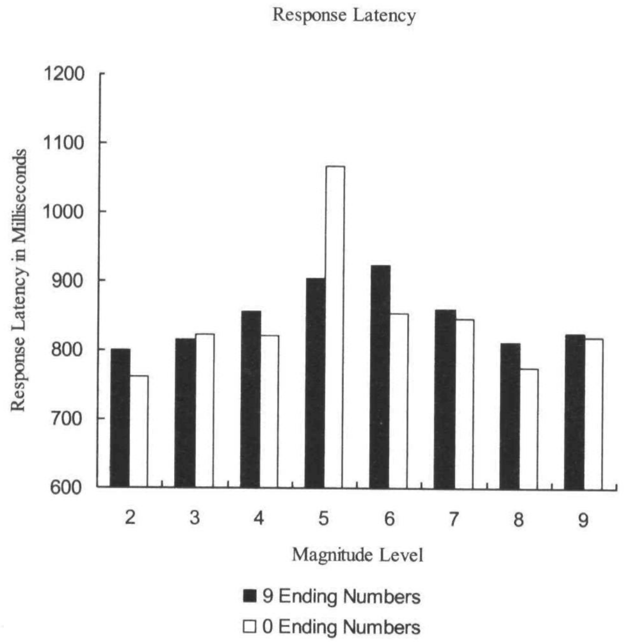
Discussion

The results of this experiment show that the left-digit effect on response time is more likely to manifest when the nine-ending numbers are close to the comparison standard. This provides support for our proposition that nine endings

[2]We repeated this analysis with log transforms of response times, and obtained similar results (interaction $p < .05$).

FIGURE 3

CHANGE IN LEFT DIGIT AFFECTS RESPONSE LATENCY ONLY WHEN THE DISTANCE FROM COMPARISON STANDARD IS SMALL



NOTE.—The nine-ending numbers are 1.99, 2.99, 3.99, 4.99, 5.99, 6.99, 7.99, and 8.99. The corresponding zero-ending numbers are 2.00, 3.00, 4.00, 5.00, 6.00, 7.00, 8.00, and 9.00. These numbers were compared with 5.50.

affect magnitude perceptions because of the manner in which they are encoded. Further, these effects manifested with numbers with no domain specification, suggesting that the left-digit and distance effects are not restricted to prices.

STUDY 4: REFERENCE FRAMES AND PSYCHOLOGICAL DISTANCE

The numerical cognition literature suggests that the psychological distance between numbers affects how they are processed. The psychological distance between numerical stimuli depends on the reference frame (Janiszewski and Lichtenstein 1999; Niedrich et al. 2001; Parducci 1965; Roggeveen and Johar 2004). Volkmann (1951) suggested that it is primarily the endpoints of the stimulus range that control perceptions of magnitude and distance. The intermediate points in the stimulus range are judged relative to these endpoints. Sherif and Hovland (1961) also suggested that when no explicit standard is introduced within a series of stimuli then the endpoints are used as standards for judgment. For instance, in the absence of accessible internal standards, whether the number five is perceived to be high or low will depend on whether the stimulus range is 0–6 or 4–10 (Lynch, Chakravarti, and Mitra 1991). It follows that the psychological distance between stimuli will also depend on the endpoints of the stimulus range.

The idea that reference frame can manipulate psychological distance motivates two interesting propositions. First, making a stimulus the upper endpoint of a series will cause its perceived magnitude to be higher (than its magnitude in the absence of the frame). For instance, when consumers are comparing two products with quality ratings (QR) 2.99 and 3.50, introducing a product with a 3.25 QR will increase the perceived distance between 2.99 and 3.50. Since consumers tend to use the end stimuli as standards, they will map 2.99 as the lowest and 3.50 as the highest standard on their internal analog scale while making product quality judgments (Sherif and Hovland 1961; Volkmann 1951). Second, adding an upper endpoint to a series will cause the perceived magnitude of the internal points to be lower (than their perceived magnitude in the absence of an upper endpoint). For instance, when consumers compare two products with QRs of 2.99 and 9.25, introducing a product with a 9.50 QR can decrease the perceived distance between 2.99 and 9.25. Thus, a small number can be framed as relatively large by presenting that number as the highest endpoint in the range, and a large number can be framed as relatively small by introducing a larger endpoint in the range.

In the following experiment, we manipulate framing to examine the effect of psychological distance (hypothesis 2). Further, we examine these effects in yet another non-price domain, namely, product quality ratings (hypothesis 3).

Method

Design. Three factors—nine endings in QR ratings (nine vs. zero), numerical distance (low vs. high), and psychological distance (low vs. high)—were manipulated within subjects. Participants saw quality ratings of three different brands in each of four different product categories. Product category presentation order was manipulated between subjects. In two product categories (web cameras and refrigerators) the numerical distance between the quality ratings was high, approximately six (2.99/3.00 to 9.50). In the other two product categories (digital cameras and air conditioners), the numerical distance between quality ratings was low, approximately 0.50 (2.99/3.00 to 3.50). Within each product category, the first and third brands (as shown in table 4) served as comparison standards, while the second brand served as the target brand. In each product category, participants compared the target brand QR with both comparison brands. Note that, in all four product categories, the first and the second brands had the highest and the lowest values in the product category, respectively, and thus would serve as endpoints of the internal analog scale for the category (see table 4). The second (i.e., target) brand had either a zero or nine-ending QR (3.00 or 2.99). Since the first and second brands' QRs served as endpoints of the internal magnitude scale for that category, the psychological distance between them was always higher than the psychological distance between the second brand and the third brand. The analog model suggests that QR comparisons will happen on the internal magnitude scale relevant to that product cate-

TABLE 4

STIMULI USED IN STUDY 4

Product category	Comparison standard 1	Target brand	Comparison standard 2
High numerical distance comparisons:			
Web cameras	Brand X = 9.50	Brand Y = 3.00	Brand Z = 9.25
Refrigerators	Brand A = 9.50	Brand B = 2.99	Brand C = 9.25
Low numerical distance comparisons:			
Digital cameras	Brand X = 3.50	Brand Y = 3.00	Brand Z = 3.25
Air conditioners	Brand A = 3.50	Brand B = 2.99	Brand C = 3.25

NOTE.—Comparison standard 1 > comparison standard 2 > target brand. Since comparison standard 1 and the target brand were the endpoints of the stimulus range in each product category, these comparisons served as the high psychological distance comparisons. Comparisons between comparison standard 2 and the target brand were the low psychological distance comparisons.

gory. Therefore, drawing on hypothesis 2 we predicted that psychological distance would moderate the effect of nine endings on magnitude comparisons of QRs.

Procedure. Twenty-seven undergraduate students participated in the experiment in return for partial course credit. The stimuli were presented in a booklet. Quality ratings and dependent measures for each category were presented on separate pages, to ensure participants used the relevant reference frame for each product category. Participants, who were randomly assigned to first see the low numerical distance categories, began by examining the quality ratings for digital cameras that had a zero-ending target brand QR. The quality ratings for the three brands were presented on a single line and in the same order as shown in table 4. The dependent variables were the perceived differences between the target and the two comparison standard brands. After responding to the quality evaluation questions for digital cameras, participants turned to the next page to see the quality ratings for air conditioners that had a nine-ending target brand QR. Next they saw the two categories with high numerical distances. The remaining participants who were first exposed to high numerical distance categories saw quality ratings for web cameras and refrigerators and then for the other two categories.

Dependent Variables. For each product category, participants reported two dependent measures: the perceived QR differences between the target brand and both comparison standards. Participants' responses were recorded on seven-point semantic differential scales anchored at "low" and "high" in response to the statement: "The difference between Brand X's (Z's) and Brand Y's Quality Ratings is ___."

Results

The perceived difference perceptions were subjected to a 2 × 2 × 2 × 2 mixed factorial ANOVA with QR ending (nine vs. zero), numerical distance (low vs. high) and psychological distance (low vs. high) as within subject factors and product presentation order as a between-subjects factor. Since the main effect of order, and the order with QR ending interaction were not significant, we collapsed across presentation order. As expected, the psychological distance by QR ending interaction was significant ($F(1, 26) = 15.04$, $p < .01$, $\eta^2 = .37$). When the psychological distance was low, then a nine ending in the target QR significantly increased the difference perception ($M_0 = 4.33$ vs. $M_9 = 4.85$, $F(1, 26) = 17.96$, $p < .01$, $\eta^2 = .41$). However, when the psychological distance was high, then a nine ending in the target QR did not affect the difference perception ($M_0 = 5.48$ vs. $M_9 = 5.46$, $F < 1$).

We analyzed the moderating effect of psychological distance on the underestimation of nine-ending numbers separately for high and low numerical distance. For low numerical distance, when the comparison standard level was 3.25, then a change in target QR from 3.00 to 2.99 caused a significant change in the perceived difference between the target and the comparison standard QR ($M_0 = 2.70$ vs. $M_9 = 3.37$; $F(1, 26) = 14.84$, $p < .01$, $\eta^2 = .36$). However, when the comparison standard level was 3.50, the effect of nine ending was not significant ($M_0 = 4.22$ vs. $M_9 = 4.25$, $F < 1$). Similarly, for high numerical distance, when the comparison standard level was 9.50, the effect of left-digit change was not significant ($M_0 = 6.74$ vs. $M_9 = 6.66$, $F < 1$). However, when the comparison standard level decreased to 9.25, then a change in target QR from 3.00 to 2.99 caused a significant change in the perceived difference between the target and comparison standard QR ($M_0 = 5.96$ vs. $M_9 = 6.33$; $F(1, 26) = 4.58$, $p < .05$, $\eta^2 = .15$). These results support hypothesis 2 and confirm that psychological distance moderated the left-digit effect.

There were also main effects of numerical distance ($M_{low} = 3.63$ vs. $M_{high} = 6.42$; $F(1, 26) = 125.82$, $p < .01$, $\eta^2 = .83$), and psychological distance ($M_{low} = 4.59$ vs. $M_{high} = 5.47$; $F(1, 26) = 28.33$, $p < .01$, $\eta^2 = .52$). Further the interaction between numerical distance and psychological distance was significant ($F(1, 26) = 6.57$, $p < .01$, $\eta^2 = .20$). When the numerical distance was high and the comparison standard's QR increased from 9.25 to 9.50, the perceived difference between the comparison standard and target brand QRs increased ($M_{low} = 6.14$ vs. $M_{high} = 6.70$; $F(1, 26) = 20.62$, $p < .01$, $\eta^2 = .44$). When numerical distance was low, then an increase in the comparison standard's QR from 3.25 to 3.50 had a stronger effect ($M_{low} = 3.04$ vs. $M_{high} = 4.24$; $F(1, 26) = 96.78$, $p < .01$, $\eta^2 = .79$).

These results served as manipulation checks to suggest that both numerical distance and psychological distance affected perceived distance. However, since quality comparisons were done within the reference frame relevant to each product category, only psychological distance (manipulated within reference frames) moderated nine-ending effects, while numerical distance did not.

Discussion

These results have several important implications. First, they add to the empirical observations from study 3 to show that the left-digit effect is not restricted to the domain of prices. Second, these results suggest that the distance effect should be interpreted cautiously. In the context of left-digit effects, the psychological distance as perceived on the internal analog scale is of greater relevance than objective numerical distance.

GENERAL DISCUSSION

This research adds further evidence to the view echoed by previous researchers (Blattberg and Neslin 1990; Monroe 2003; Stiving and Winer 1997) that the decision whether or not to use nine-ending prices is an important one and deserves due attention. Importantly, we show that nine-ending prices may sometimes but not always be perceived to be lower than a price one cent higher. This perception is more likely to occur when introducing a nine ending in the price causes a change in the leftmost digit. Further, this perception is more likely when the nine-ending price is perceived to be close to the comparison standard price. Our studies show left-digit effects manifest in the domain of quality ratings and in the domain of unspecified general numbers. Thus there seems to be a domain invariant cognitive phenomenon behind the popularity of nine-ending prices.

A research question that remains unanswered is whether the primacy effect of left digits will manifest when the right-digits are not 99. Our studies examined only numbers that ended with 99. Dehaene et al. (1990) found that repetition of a digit in a number influenced the number comparison process. Therefore, it is possible that the processing of numbers that end in 99 differs from numbers that end in 98, 96, 95 or other digits. Thus, a potential research question emerges: will numbers such as 3.95 and 3.90 also be underestimated in the same way as 3.99? A related question is whether digits other than the leftmost in a multidigit number can influence that number's magnitude perception. In the studies examined in this research, there was only one digit to the left of the decimal point. In a pricing context, when there are two or more digits to the left of the decimal point, a nine-ending that changes the dollar digit, may or may not also change the 10's digit (e.g., $19.99 vs. $20.00 or $22.99 vs. $21.99). Future research should examine whether there are effects associated with such internal left-digit changes.

Following the approach suggested by Monroe and Lee (1999), we based our hypotheses on the analog model of multidigit number cognition. Our findings add to the evidence accumulating in favor of the analog model. However, the objective of this article was more to examine cognitive phenomena associated with nine-ending prices rather than to defend the analog model. Several other models of numerical cognition such as the digital model (Poltrock and Schwartz 1984; Stiving and Winer 1997) and the semantic coding model (Banks 1977) have been proposed. Some of these models also can predict and explain the empirical phenomenon presented in this article, although many researchers (Dehaene 1997) believe that the analog model postulates the most parsimonious explanation for the distance effect. Which of these models offer the most convincing account for the left-digit effect, the distance effect, and other effects in price cognition is a question worthy of future research.

[*Dawn Iacobucci served as editor and Kent Monroe served as associate editor for this article.*]

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