

Consumers' Immediate Memory for Prices

MARC VANHUELE

GILLES LAURENT

XAVIER DRÈZE*

*Marc Vanhuele is Associate Professor of Marketing at the HEC School of Management, Paris (GREGHEC), Marketing Department, 78351 Jouy-en-Josas, France (vanhuele@hec.fr). Gilles Laurent is the Carrefour Professor of Marketing at the HEC School of Management, Paris (GREGHEC), Marketing Department, 78351 Jouy-en-Josas, France (laurent@hec.fr). Xavier Drèze is Assistant Professor of Marketing, the Wharton School of Business, University of Pennsylvania, Philadelphia 19104-6340 (xdreze@wharton.upenn.edu). The authors thank Zsofia Kenesei and Sandor Czellar for their help with the data collection and Wes Hutchinson, David Luna, and Eric Yorkston for their comments on a previous draft.

Abstract

We examine the cognitive mechanics involved in keeping prices in short-term memory for subsequent recall. Consumers code and store prices verbally, visually, and in terms of their magnitude. The encoding used influences immediate recall performance. The memorability of prices depends on their verbal length, usualness, and overall magnitude. We find that the performance of consumers is affected by their pronunciation speed and price abbreviation habits. Overall, consumers recall prices better than what previous digit span studies with simple numbers have suggested.

Keywords: consumer behavior, numerical cognition, price memory

Consumers make price-based decisions on a daily basis. They routinely observe and compare prices and make purchase decisions based on spot prices. Their accumulated price knowledge helps them determine whether a price they observe in a store, on a flyer, or in an advertisement is high or low. However, research has shown that consumers' price knowledge with regard to packaged goods tends to be lower than what one might expect intuitively from the prevalence of customer-price interactions (Vanhuele and Drèze 2002). Even a couple of seconds after they pick up a product from the shelves, only 47% to 55% of consumers are able to recall its correct price (Dickson and Sawyer 1990; Le Boutillier, Le Boutillier, and Neslin 1994; Wakefield and Inman 1993). This low recall level may be due to a lack of attention and motivation by the consumer or to distractions in the store environment, but part of the explanation may also include the cognitive challenge posed by the need to store pairs of prices and product identifiers in memory and retrieve them.

Little is known about the cognitive processes involved in the encoding, storage, updating, and retrieval of prices. Although conceptual models of the grocery shopper's treatment of price information have been proposed (e.g., Dickson and Sawyer 1990; Monroe and Lee 1999), past research has focused on the output of the process; looking at the level of short or long-term recall that different types of consumers have for different products. The cognitive processes themselves have not been examined. Reference price research (e.g., Briesch et al. 1997) gives indirect evidence of these processes but, as pointed out by Kalyanaram and Winer (1995), "we cannot be certain that consumers actually form reference prices, only that they act as if they did." To advance our understanding of the price memory phenomena observed in the marketplace, we propose a detailed analysis of the cognitive processes involved. The logical starting point is the encoding phase.

We have a double objective. First, we want to identify an appropriate conceptual framework that relies on cognitive psychology and verify that this framework effectively

applies to price memory tasks that consumers typically engage in. Second, we study the cognitive processes involved in price encoding with realistic stimuli and in a setting relevant for typical consumer price interactions. In this research, we consider a consumer who is motivated to learn the prices of specific products and concentrates on the learning task. We then examine the cognitive mechanics involved in the storage and short-term recall of prices when a paired product serves as the recall cue. We are particularly interested in the capacity limits of working memory and the effects of these limits for short-term price recall. How many prices, and of what level of complexity, can consumers handle? For which type of prices are errors more likely? How do consumers differ in their capacity to retain prices in their memory for a couple of seconds? To answer these questions we put the participants of our experiments in the best possible learning conditions

Our analysis of consumers' immediate recall of prices stems from two fields of research in cognitive psychology: numerical cognition and the architecture of working memory. In the field of numerical cognition, a sub-domain of cognitive psychology, consensus is emerging about the way the human cognitive system deals with numerical information through a dedicated cognitive subsystem (Ashcraft 1992; Dehaene 1992, 1997). If prices are treated as numbers, memory performance for prices should reflect the architecture and processing characteristics of that cognitive system dedicated to number processing. Beyond its theoretical interest, this proposition also has practical importance in that it implies that specific prices will be more or less likely to be recalled accurately according to the way they are treated by the numerical cognitive subsystem. Recall errors therefore would contain a systematic component in addition to a random component. To examine this proposition, we test a series of hypotheses derived from numerical cognition and Baddeley's (1992) theory of working memory.

The second theoretical basis for our work pertains to the architecture of working memory (Baddeley 1992, 2001). In a classic article, Miller (1956) proposed that the capacity of short-term memory has a fixed limit of approximately seven “chunks” or units of information. Baddeley shows, however, that immediate memory span is not constant in the number of units but rather depends on the phonological length of the words to be recalled. Many studies have confirmed Baddeley’s initial demonstrations that a person’s memory span for words equals the number of words that person can read aloud in 1.5 to 2 seconds (Baddeley 2001). Using Baddeley’s work as a starting point, we examine the capacity limitations of working memory for pricing information.

The applicability of past research on numerical cognition and working memory to price knowledge may be questioned because of the specific stimuli used in psychological experiments—typically, one-digit (sometimes two) integer stimuli without contextual meaning. The prices consumers typically encounter in the marketplace differ from these stimuli in at least four respects. First, most prices are much more complex. In the terminology of numerical cognition, in addition to the lexical dimension (i.e. the number “vocabulary”), the combination of multiple digits involves a syntactical dimension (i.e., how individual elements are combined; 5 and 7 take a different meaning in \$57 than in \$572, McCloskey and Macaruso 1995). Second, to our knowledge, no work in psychology studies stimuli that combine an integer and a fractional part, that is a combination of dollar and cents (though this topic has received considerable attention in marketing; cf., Thomas and Morwitz 2005). Third, most consumers will rely on their contextual knowledge when asked for the price of a product, while psychological studies study numbers in a contextual vacuum. Fourth, a price is always the price of something. To be useful as information, this price must be stored in a pair with the corresponding product. In conclusion, it is clear that we cannot blindly apply the findings of past psychological research to a pricing context.

Three main contributions emerge from our work. On the theoretical side, this is the first attempt, to our knowledge, to combine the dominant theories in numerical cognition and on working memory. These theories prove to be compatible with each other and, moreover, applicable to an information processing based analysis of price memory. Second, we show that these theories in combination generate predictions about the differences in memorability of different prices. They also predict how consumers differ in immediate memory performance (and therefore also in later long-term performance). As a third contribution, we test and confirm most of these predictions in an experimental context that is relevant to the way consumers often interact with price. We show that prices are encoded in different ways and that each form of encoding affects the way prices are remembered. Together, our contributions should provide the basis for future information processing driven research on price memory.

THEORETICAL BACKGROUND

The Triple-Code Model

Central to the domain of numerical cognition is the question of how numbers are represented in the cognitive system and what roles the formats of this representation play in numerical processing (Ashcraft 1992; McCloskey and Macaruso 1995). In a synthesis of the essential research findings, Dehaene (1992) develops a triple-code model in which he proposes that numbers can be mentally represented and manipulated in three different forms, depending on the task at hand. The *visual Arabic code* represents numbers on a spatial visual medium on the basis of their written form in Arabic numerals (e.g., 35). The *auditory verbal code* is generated through a phonological representation in which each number is represented

by a sequence of phonemes (e.g., /thirty/ /five/). Finally, the *analogue magnitude code* represents numbers as approximate quantities on an internal dimension termed the “number line” (e.g., about 35, slightly less than 40, or somewhere between 30 and 40). A representation in the analogue magnitude code apparently is generated automatically when a number is represented in the verbal or visual code. In addition, with the magnitude code, larger numbers are represented with less absolute precision than are smaller ones. The scale of the internal number line scale appears to be logarithmic.

Working Memory

Baddeley (1992, 2001) uses the term “working memory” to refer to the subsystem of the brain that temporarily stores and manipulates information. He proposes dividing working memory into three components: (1) the central executive that controls attention, (2) the visual-spatial sketch pad for manipulating visual information, and (3) the phonological loop, which consists of a phonological store to hold speech-based information for a duration of 1.5 to 2 seconds and an articulatory control process that can maintain data within the phonological store through subvocal repetition. Through the loop component, “subjects can generally remember as many words as they can say in 2 seconds” (Baddeley 1992, p. 558). Memory traces in the phonological store decay in approximately 2 seconds unless they are refreshed by sub-vocal rehearsal. Memory span in immediate recall tests then varies according to the length of the words used as stimuli (Baddeley, Thomson, and Buchanan 1975), because fewer long than short words can be rehearsed to refresh the phonological trace (Baddeley, Lewis, and Vallar 1984). Baddeley’s theory accounts well for the findings in an impressive number of studies on immediate recall (Baddeley 2001).

Hypotheses

Analyses of each of the three codes proposed in numerical cognition, in combination with Baddeley's work on the phonological loop, leads us to a set of predictions about the conditions under which consumers are likely to make errors when they attempt to memorize prices.

Auditory verbal code. An intriguing implication of the memory span limitation of 1.5 to 2 seconds is that prices that take longer to pronounce are less likely to fit in the phonological loop and therefore are less likely to be recalled accurately. Recording and measuring the pronunciation durations for each price for each subject in our empirical studies would be too cumbersome, so we use the number of syllables as proxy variable for most of our work (we demonstrate below that this is a good approximation). We therefore formulate our first hypothesis as follows:

H1a: The more syllables in a price; the less likely it will be recalled accurately.

Most research that links pronunciation duration to recall (e.g., Schweickert and Boruff 1986) focuses on the effect of word length and ignores differences between persons. We are, however, also interested in the effect of individual differences in pronunciation rates.

H1b: Consumers who speak more slowly are less likely to recall prices accurately.

Different people also have different verbal price coding habits. A price of 137 could be coded as one hundred thirty-seven (7 syllables), hundred thirty-seven (6), one thirty-seven (5), or one three seven (4). This habit variation leads us to formulate another hypothesis about individual differences.

H1c: Consumers who habitually shorten the verbal coding of prices will have better recall.

Visual Arabic code. In many countries, price endings tend to take common structures. In the United States, for example, the digits 0, 5, and 9 are overrepresented as the rightmost price digits (Schindler and Kirby 1997). We hypothesize that the visual Arabic code will be particularly sensitive to those prices that stand out because they do not respect such common endings. These unusual prices should attract visual attention and therefore be more likely to be encoded visually, even if they are encoded verbally. This double encoding should enhance recall (Chincotta et al. 1999; Frick 1984). Indeed, research on the eye movements that occur during reading (Rayner 1998) shows that when people fixate on the first letter of a word, the rest of the word (up to 14-15 letters to the right) is also in the focal field and therefore processed. The maximum digit length of the prices in our studies is six. We can therefore assume that participants always perceive the prices in their entire visual pattern, even when they start by focusing on the first digit in order to start verbal coding.

H2a: Visually unusual patterns of prices will be recalled better than will visually usual patterns.

In addition to demonstrating the presence of visual coding and its effect on recall, we want to study the extent to which individual differences in visual memorization ability affect accuracy. Consumers have different abilities and preferences for visual versus verbal information processing (Childers, Houston, and Heckler 1985). In order to further explore the effect predicted by H2a, we will develop a measure of visual processing ability. It is natural to assume that price recall will be correlated with this ability. More importantly, we expect an interaction effect between usualness and visual processing ability. If consumers' recall of unusual prices is driven by visual processing, those who are good visual processors should perform better with unusual prices.

H2b: The recall advantage for visually unusual patterns of prices will be more pronounced for people with a better visual memory capacity.

Analog magnitude code. Numbers in the analog magnitude code are converted to approximate quantities and become less precise in absolute terms as the numbers get higher. In the context of price knowledge, this trend implies that smaller prices are coded with more absolute precision than are larger prices and, consequently, that absolute recall errors will increase as prices get larger. More precisely, researchers on numerical cognition believe the hypothetical internal number line for magnitudes is scaled such that error sizes increase in direct proportion to price levels, a property called “scalar variability” (Dehaene and Marques 2002). Therefore, when the analog magnitude code is used, the following should be true:

H3: Higher prices will lead to larger absolute deviations between the recalled and the actual price, and the deviations will be proportional to the price level.

Most evidence of the existence of magnitude coding is indirect (e.g., reaction times in number comparison tasks, Hinrichs, Yurko, and Hu 1981), but Dehaene and Marques (2002) show that when consumers must choose the typical price of a product category from a series of seven proposed prices, their answers display scalar variability, as predicted by magnitude coding. In addition, Marques and Dehaene (2004) provide a series of similar demonstrations with a free price estimation task. We take these demonstrations a step further by examining the extent to which the magnitude code also operates in immediate recall. The notion of scalar variability may be important in consumer research because it provides the theoretical basis for a number of findings. Grewal and Marmorstein (1994), for instance, demonstrate that consumers perceive the value of proposed savings not in absolute terms but instead relative to the price. Thomas and Morwitz (2005) also propose a magnitude coding–based explanation of the phenomenon in which consumers perceive prices that end in 9 as

significantly less costly than prices one cent higher. Finally, some research suggests the existence of reference price regions instead of price points (e.g., Kalyanaram and Little 1994). Magnitude coding provides a theoretical basis for the existence of these reference price regions.

In the remainder of this paper, we will test the hypotheses we just developed and examine how each of the three codes is involved in the encoding of prices. We present three main studies and two pilot studies that all share a common research approach inspired by in-store price comparison making. In study 1 we focus on the phonological loop constraint. Study 2 examines the effect of price usualness and the role of visual coding. In study 3 we zoom in on individual differences and test of the presence of magnitude coding.

Pronunciation Durations

When introducing H1 we proposed to use the number of syllables as proxy variable for the pronunciation duration of a price because measuring pronunciation time itself accurately is extremely time consuming. Before starting our experimental work, we verified that this is a good approximation. This test also was an opportunity to check whether the two-second limit of the phonological loop has any practical relevance for consumer research.

We asked five French consumers with different educational backgrounds and ages to read aloud a series of 24 prices that were up to seven syllables long. Their voices were digitally recorded. This allowed us to measure pronunciation duration with a millisecond-level accuracy.

Our measurements indicate that seven-syllable prices, which remain fairly short in terms of the number of digits (all prices were less than 100€), take an average of 1.60 seconds to pronounce. This duration does not include the product identifier that also must be stored.

Therefore, as soon as two such prices must be stored, the two-second limit of the phonological store is surpassed. We thus conclude that the two-second limit is a real constraint for consumers interested in memorizing prices. In addition, we ran a regression analysis to assess how good a proxy the number of syllables is for pronunciation duration. The adjusted R^2 of 0.79 demonstrated a reassuring level, and we decided to use the number of syllables as the variable to manipulate in our experiments instead of pronunciation duration as such.

STUDY 1: VERBAL CODING

Overall Research Approach

All our experiments share a common approach. Because we ultimately want to understand the short-term recall challenges for consumers in the marketplace, we used in-store price comparisons as the inspiration for the experimental task. To compare the prices of different products, the prices and product identifiers must be stored in the consumer's short-term memory (consumers typically do not write down prices in the supermarket). Memory researchers refer to this task as "paired-associate learning." To ensure that participants stored different price-product associations and not just a sequence of prices, we presented the product cues in the recall test one by one in random order.

To keep the task as realistic and engaging as possible, we used pictures of real products that exist in marketplace of the country in which we ran each study as stimuli. We took the actual prices as starting points to avoid confusing participants with unrealistic prices levels and then made modifications to operationalize the price length manipulation. One drawback of our decision to use pictures of real products is that we could not control the

memory space that the identification of the product itself requires. That is, we do not know whether subjects memorized the names of the products or took a mental picture of them; any variation in recall performance due to the identification of the product is therefore part of the experimental noise.

The instructions explained that the study was designed to examine the capacity of consumers to memorize prices. Two or three products and their prices would be presented together on a screen. Participants then would view the products again one by one, in random order, and be asked to recall the prices. They were told that they always had to give an answer. Before the actual experiment started, they watched a demonstration of a complete trial (with music CDs, a category not used in the tests), during which the instructions were repeated.

Pilot Study

We ran a pilot study to verify the feasibility of the task and experimental procedure. Thirty-nine graduate students from a French business school participated in the context of a classroom session. The instructions, study, and test screens were presented as a PowerPoint slide show, and the subjects wrote down their responses on a paper questionnaire. The products were shown in groups of two or three. The prices (in euros) varied in length from four to six syllables. Overall, this pilot test confirmed the feasibility of our experimental procedure. On average, 46% of recall responses were correct. We will come back to the results of this pilot when we relate recall performance and the number of syllables to be remembered across all our studies.

Design of Study 1

The main experimental variables of interest are the price length of the target product in number of syllables (3–8) and the price length of the other products on the study screen (3–8 syllables each). Recall performance might also be influenced by the number of products per study screen (2 or 3), the presentation order (from left to right, 1, 2, or 3), and the question order (1, 2, or 3), which affects the time the consumer has to rehearse an item before recalling it. Therefore, we introduce these factors as control variables.

We used three product categories: (1) candy, with prices that comprised one dollar-level digit and two cents digits (e.g., \$1.19); (2) DVDs with two dollar digits and two cents digits (e.g. \$12.95); and (3) digital cameras with three or four dollar digits and zero cents digits (e.g., \$345). To ensure that the price stimuli were realistic, we started with the actual price of the products, for realism, and then induced changes with minimal monetary impacts to attain the desired number of syllables. The resulting prices ranged from \$1.05 to \$3.95 for candy, from \$12.15 to \$72.26 for DVDs (and DVD collections), and from \$120 to \$2,390 for cameras. Product shots of each were downloaded from the Internet.

To counterbalance the presentation order and keep the number of syllables of a given price independent of that of the other price(s) on a particular study screen, we used the following procedure: For each product, we created a price we labeled “short” (S) and another we labeled “long” (L). For study screens that displayed two products, we used the following four price/length combinations: SS, SL, LS, and LS. For three-product screens, we provided eight combinations from SSS to LLL. Each subject viewed all 12 price/length combinations for a given product category, which resulted in a total 32 product–price pairs (four two-product screens, eight three-product screens). Our database contained 32 visuals for each

product category, and each visual corresponded to a “short” and a “long” price. For each subject, we randomly assigned products to two- and three-product screens and to a price length condition and then selected the appropriate price (short or long).

To limit the length of the task, we used a fractional factorial design in which we showed each subject only two of the three product categories and asked for answers in digits for half of the price/length combinations (for both the two- and three-product screens) and in words for the other half. Each subject therefore viewed a total of 24 screens with 64 product–price pairs to recall, and the product sequence, price length conditions were randomized for each subject.

Procedure

Ninety-one U.S. undergraduate business students participated for course credit in this online experiment. Because this experiment focuses on the role of the verbal length of a price, we instructed participants to read prices to themselves during the study phase “without speaking out loud.” This reflects the way they read prices in a store environment.

The introductory instructions explained that the objective of the study was to examine the capacity of consumers to hold prices in their memories for a couple of seconds. Participants were instructed specifically to read each price to themselves and then rehearse those prices internally to keep them in memory. They also were told that their answer had to be as accurate as possible.

The trial started with a two-second announcement of the product category, followed by a nine-second presentation of the product–price pairs, a three-second masking of the prices (to clear the visual sensory buffer; see Breitmeyer and Ogmen 2000; Sperling 1960), a 2-second blank screen, and then the random presentations of each product for recall. After

typing their responses, participants clicked a continue button to move to the next test presentation.

Analysis

We coded recall performance as a binary variable (correct or incorrect) and used logistic regression to test our hypotheses. Overall, 49.8% of the responses were correct. The logistic regression explains 22% of the variance in recall. The parameter tests (see Table 1) show that prices with more syllables are less likely to be recalled. This is demonstrated by the significant parameter for the number of syllables in the focal item ($\chi^2(1) = 95.60, p < .01$) and provides support for H1a. The effect size is considerable as each additional syllable in the focal item reduces the odds of recall by 20% (exponent of the parameter). Moreover, each additional syllable in the other item(s) leads to another reduction of 12% ($\chi^2(1) = 51.18, p < .01$). These effects operate in addition to the effect of the number of product–price pairs presented. Presenting three prices to remember, instead of two, almost triples the odds of a recall error. Each of these three effects captures part of the effect of the phonological loop constraint.

Insert table 1 about here

The first question asked has a much higher chance of producing a correct answer than do either the second or the third ($\chi^2(1) = 26.69, p < .01$). The order effect probably results from the passage of time, the ensuing decay of the memory trace in short-term memory, and the increase of interference among prices. These effects therefore may be considered as additional reflections of the limitations of the phonological loop (see Cowan et al. 1992).

Indeed, a longer output time forces a participant to rehearse an item for a longer period of time and makes interferences and/or decay more likely. Finally, there is a significant effect of product category ($\chi^2(2) = 121.80, p < .01$), in that recall for cameras is best, followed by that for candy and then for DVDs. These recall differences, however, may be attributed to various factors, including the number of digits, the presence or absence of cents, price levels, problems of visual identification, and recall of the product identification.

STUDY 2: VISUAL MEMORY

Our second study has two objectives. First, we test H2a and H2b regarding the effect of visual memory. Second, given our previous demonstration of the effect of the number of syllables of the price on price recall, we are interested in examining how consumers in countries with currencies with high face value deal with the challenges of price recall. Our two previous recall tests used monetary units with comparable face values—the euro and the dollar—but in some other currencies, the prices of the products include many more digits. The Hungarian marketplace is ideal to examine both dimensions. The Hungarian forint is pegged to the euro at an exchange rate of approximately 250 forint per euro (202 forint per dollar at the time of the study). In addition, price endings in Hungary follow a restricted number of patterns, which enables us to manipulate the visual “usualness” of prices in the Arabic format. Hungarian prices do not use decimals, and though coins of 1, 2, and 5 forint exist, unit prices that are three digits long (e.g., for the candy product category used in our study) always end in a 5 or 9. Prices with five or six digits (e.g., digital cameras) always end in 90 or 00.

Design and Procedure

The experimental instructions were identical to those of Study 1. Participants were directed to use verbal coding and rehearse the prices verbally. Thus, if visual coding nevertheless plays a role in this study, it represents a strong demonstration of the role of visual memory. Due to practical constraints participants could not be tested individually and were tested in groups, which precluded a full randomization of prices across word lengths and presentation and test orders. Participants viewed a PowerPoint slide show with the instructions, study, and test screens. The price usualness manipulation was between-subjects. One group only saw prices with usual endings, and the other saw a mix of prices with usual and unusual endings. We will subsequently refer to them as the usual and unusual groups respectively. Two product categories were used; candy and cameras. Within each category we used the staircase method in which the total number of syllables to be remembered on each subsequent screen increases (Baddeley, Thomson, and Buchanan 1975). The first trials for candy contained 8 syllables and those for cameras 17 syllables. The last trials had, respectively, 21 and 42 syllables. The first three screens for each category included two stimuli, and the final three had three. Each screen for the unusual group provided one unusual price with an equal number of syllables as the corresponding price for the usual group (e.g., 137 instead of 135—in Hungarian, 137 and 135 have the same number of syllables).

Scale for Visual Memory Capacity

In addition to testing for the main effect of price usualness, we also test its interaction with the participants' visual memory capacity. To measure this capacity we developed a modified version of the Corsi block-tapping test, which was designed to assess visual

memory span and has often been used in neuropsychological research (Berch, Krikorian, and Huha 1998). In the first part of the test, participants successively viewed six tables with four columns and four rows each, with some cells colored black and others in white. After they considered each table, subjects marked, on paper, an “empty” table with crosses to indicate which cells were black. In the second part of the test, they were shown sequences of four or five tables; each with a black cell. Subjects were asked to replicate the sequence in which the black cells appeared by numbering the cells of an empty table.

We checked the internal validity of our measure and its relationship with recall in a pilot study with fifty-five French-speaking Swiss undergraduate business students. The recall part of this study used the same stairwise procedure as study 2 and was followed by the modified Corsi test. We discuss the recall test results for this Swiss sample when we compare the different studies. The Corsi test provided sufficient reliability for use in the Hungarian test (Cronbach’s alpha = 0.71).

Analysis

Due to the design of the Hungarian study, there is a high correlation between the number of syllables of the target and other price(s) in a given trial (candy prices are three digits long; camera prices are six digits). In the logistic regression (see Table 2), we therefore used only one variable for syllable length to code the total syllable length of all prices in a given trial. The logistic regression overall explains 40% of the variance in recall. We replicated the results of the U.S. study for syllable length, presentation order, and question order. We also find support for our key prediction (H2a) that unusual prices have a recall advantage. Indeed, unusual prices increase the recall odds by 69% ($\chi^2(1) = 7.94, p < .01$). However, participants who viewed a mix of usual and unusual price endings were not better

in their overall recall performance than were those who only saw usual price endings. Probably the most plausible explanation for this pattern of results is that unusual prices draw attention, to the detriment of recall of usual prices.

Insert table 2 about here

We attribute the observed recall advantage for unusual prices to visual encoding that complements verbal encoding (H2b). To test this explanation, we introduced our modified version of the Corsi test. Visual memory ability plays a significant positive role in overall memory performance ($\chi^2(1) = 8.92, p < .01$; note that our measure of visual memory ability is expressed as the number of errors). Whereas H2b implies an interaction effect between performance on the Corsi test and type of price—that is, people with good visual memory ability should perform especially well with unusual prices—the results showed the opposite effect ($\chi^2(1) = 3.87, p < .05$) and therefore do not support H2b.

STUDY 3: INDIVIDUAL DIFFERENCES IN RECALL STRATEGY

In our third study, we focus on the differences in recall strategies and performance across subjects by testing H1b regarding speech rates, H1c about verbal coding habits, and H3 pertaining to magnitude coding. We also examine the extent to which immediate price recall is driven by processing according to verbal, visual, and magnitude codes.

Ninety-eight American students participated in return for course credit. The price recall part of the experiment was identical to Study 1 except that we did not give any instructions about how the prices were to be coded or rehearsed (but the answers had to be given in digits). Participants therefore use their personal “natural” encoding strategies.

Following the price recall part of the study, five sections focused on individual differences. First, we measured the participants' habitual way of pronouncing prices by giving them four 3- and 4-digit prices, asking them to read the prices to themselves, and then presenting them with alternative ways to pronounce the price (e.g., 1290 as twelve ninety, twelve-hundred ninety, one thousand two hundred ninety). The participant also had the option of writing another pronunciation in words in a box labeled "other." We counted the total number of syllables in each participant's habitual pronunciation across the three prices. This was followed by the modified Corsi test with six fixed and six dynamic tables (Cronbach's alpha = 0.83), an auditory recall test, a visual magnitude estimation test, and a measure of the participant's speed of pronunciation.

To measure verbal memory ability, we used auditory recall to exclude the interference of visual memory. Our test was similar to the classical Wechsler (1958) test, which is widely used in clinical diagnoses, but we used letters instead of numbers. The computer played sound files of someone reading strings of letters at a rate of one letter per second. In the first part, participants were to memorize the letters and simply enter them into the computer in the same order. In the second part, they had to enter the letters in reverse sequence. For each part, an ascending number of letters was presented (from 5 to 8), and there were two strings for each string size. We used the total number of correct answers to score participants (Cronbach's alpha = 0.68).

To assess pronunciation rate, we measured the length of time the subjects needed to read to themselves two 1-page lists with 45 prices from the recall part of the test. The correlation between the two time measures across persons was 0.75.

By including three product categories with different price levels, we obtained a broad spread of prices, which enabled us to create a better test of the scalar variability than if we had used just one product category.

Because we did not find any established tests to estimate people's ability to develop good magnitude estimates, we developed our own, in which we present people with pictures of a set of identical objects that are too numerous to count during the presentation time. Because the obtained estimates are not normally distributed, we rescale them by taking the logarithm of the ratio of the estimate to the actual value before adding them and checking the reliability of our scale (Cronbach's alpha = 0.79). In the logistic regression, we classified respondents into three groups based on the size and direction of their estimation errors: the 25% who give the largest underestimates, the 25% who give the largest overestimates, and the rest, whom we use as a reference category.

Logistic Regression

The logistic regression explained 26% of the variance. In Table 3, we show the replication of the results for the price length effect and the primacy effects for presentation and question order. The effect of speech rate (H1b) is significant though small in size ($\chi^2(1) = 4.21, p < .05$). Each additional ten seconds needed to read 45 prices corresponds to a 3% decrease in accuracy. Subjects who habitually use more syllables to read a price present a lower recall performance (H1c, $\chi^2(1) = 4.45, p < .05$). The effect size is almost identical to that of the word length effect; for each extra syllable in coding, there is a 9% reduction in recall odds. By including the participants' verbal, visual, and magnitude coding abilities in our logistic regression, we establish how they explain individual differences in recall performance.

Insert table 3 about here

Subjects' performance on the auditory memory test is a strong positive predictor of price recall performance (despite the limited reliability of our measure). Visual memory ability also plays a significant positive role in price recall. However, our visual magnitude estimation test does not have significant predictive power for recall. The parameter estimates suggest that over- and under-estimators suffer a lower recall level, but the effects are not significant.

Analysis of Magnitude Coding

Our final hypothesis, H3, is based on the assumption that some form of magnitude coding takes place, which should be reflected in recall error sizes that are proportional to the price level. This hypothesis motivated our selection of product categories with clearly different price levels. In Figure 1, we link the level of the recalled prices (abscissa) to the standard deviation of these prices (the logarithm has been taken for both variables). As that figure shows, the standard deviation in recall errors is proportional to the price level. We also carried out a more formal test, as proposed by Dehaene and Marques (2002), by running a log-log regression. Scalar variability predicts a slope of 1. With its value of 1.06, the slope is close to 1, although the standard error of the estimate (0.019) makes it significantly different from the predicted value. In conclusion, the pattern of results indicates the presence of magnitude coding.

Insert figure 1 about here

ESTIMATING IMMEDIATE MEMORY CAPACITY

Insert figure 2 about here

In Figure 2, we compare the average recall performance of our participants in the three main studies and two pilot tests by plotting recall as a function of the number of syllables of the price. These five studies share a common overall experimental procedure but also have their specificities. The French, Hungarian, and Swiss participants were tested in groups while the American respondents participated individually. The average word length of the prices, total number of prices in the study and duration of the study also differed. The pattern of results is nevertheless remarkably similar for the French, Swiss and two American studies.

Memory span usually is defined as the number of items for which the probability of a correctly ordered recall in serial recall tasks is at least 50% (Schweickert and Boruff 1986). Using this criterion, the memory span in the French, Swiss, and U.S. studies is, on average, 12 syllables. In contrast, the performance of the Hungarian participants is startlingly high. They have a digit span of 24 syllables; double that of the participants in other countries. To compare these studies on a more equal basis, we could base our estimate of the Hungarian digit span on just the “usual price” condition, but this only reduces their span to 19.5 syllables. How can we explain the large difference between Hungarian participants and those of other countries?

One possibility is that Hungarians speak faster. Research on the memory span across different languages has suggested that languages that use more syllables on average per word

tend to be spoken at a faster rate, possibly to attain “an optimum rate of information flow ... to suit the human capacity for message transmission and reception” (Naveh-Benjamin and Ayres 1986, p. 749). In other words, speakers of languages that require more syllables per message, and that therefore might suffer more from the constraints of the phonological loop, apparently compensate for this limit by speaking faster. Because we did not find any published work on speech rate or language “length” that included Hungarian participants, we compared the pronunciation speed between Hungarian and French participants for the prices used in the previous studies to test the speech rate explanation.

In our recall experiments in France and Hungary, participants read and rehearsed prices sub-vocally. We therefore took time measures for the same type of reading, in which we asked 10 people in both countries to read sub-vocally three samples of the prices used in the previous study in their country. The total pronunciation time was then divided by the number of syllables, which resulted in an average sub-vocal reading time per syllable of 0.198 seconds for the Hungarians and 0.251 seconds for the French. Thus, the Hungarians clearly are faster speakers, but the question remains whether speech rate explains the differences in immediate recall performance. If we multiply the sub-vocal reading time per syllable by the observed memory span, in terms of the number of syllables in the recall studies, we obtain a measure of memory span that has been corrected for differences in speech rate. For French speakers, memory span for prices is 3.01 seconds, whereas for Hungarian speakers, it is 3.86 seconds for usual prices.

In conclusion, we can explain only part of the performance differences observed in Figure 2 through the differences in pronunciation speed. Hungarians still enjoy a 28% higher recall performance after controlling for this difference. There are at least two explanations for the remaining advantage. First, all people may pronounce longer prices more quickly than they do shorter prices. The difference we observed then would be due simply to the

difference in the stimulus material across the studies. We note, however, that this difference is not an artifact of our experiment; it corresponds to differences in currency exchange rates. If it were to be validated, it would imply that consumers who consistently face longer prices are not as handicapped by the constraints of the phonological loop as theory would predict, because they compensate for the limit by pronouncing prices faster.

Second, it may be that Hungarians do not have to code the entire price verbally because the marketplace (and our study) uses only a couple of price endings. If they remember the visual ending pattern, they may gain a recall advantage that operates beyond the constraints of verbal memory. Regardless, a full explanation of the Hungarian recall advantage clearly requires a separate series of studies and is beyond the scope of this article.

In addition to explaining part of the performance difference between Hungarian and French participants, our measures of pronunciation duration also highlight that the immediate recall of prices is far superior to that for single digits, as documented in memory span research, even though our recall task is more difficult for participants. In the typical memory span test, participants are exposed to a list of items that they must feed back immediately in the correct order. Our immediate recall procedure is more demanding because it includes more material to remember and, on average, must be retained in memory for a longer time (i.e., while the first recalled price is entered, the second, and possibly third, must be rehearsed). The memory span for single digits has been estimated at approximately seven (e.g., Schweickert and Boruff, Figure 2), which corresponds to 7.77 syllables in English (one for each digit except 7; in French, it corresponds to seven syllables). Although we found considerable evidence of the dominance of verbal coding, recall performance clearly transcends the constraints of the phonological loop. Hulme et al. (1995) offer a possible explanation that relies on the use of long-term memory representations: Partially decayed short-term phonological traces can be reconstructed with phonologically representations from

long-term memory. Most prices in our studies used numbers that consumers have encountered frequently in their lives (at least if we consider a price with decimals as a concatenation of two numbers). Some phonological representation of these numbers therefore may exist in long-term memory. Hulme et al.'s explanation then may explain the high level of recall performance in our studies.

DISCUSSION

Summary of Main Contributions

Consumer researchers have shown active interest in measuring the extent to which consumers can recall prices (for a review, see Monroe and Lee 1999). However, very little work has examined the memory processes that account for observed levels of performance. We focus on these cognitive processes by asking consumers to perform a realistic task (memorizing the prices of two or three competing products in the same category) and observing how their recall performance varies as a function of the price stimuli. Because so little work has been done on price memory, we examine immediate or short-term recall as the first step. Our project has nevertheless also implications for long-term recall phenomena. Presence in the short-term store is a prerequisite for long-term storage and the latter form of storage should be a reflection of the way a price was represented in the short-term store.

The combination of Dehaene's triple-code model and Baddeley's description of the architecture of working memory proves to be very productive for the study of immediate memory of prices. Baddeley's work describes the "hardware" components that operate at the encoding side for the three memory codes proposed by Dehaene. Overall, we find that variations in immediate recall performance reflect the cognitive mechanisms that researchers

in numerical cognition and working memory have posited. Interestingly, our analysis in the context of pricing highlights the role of two factors that these researchers have not considered in the past: the structural features of numbers and the differences among individuals.

We find evidence that consumers code prices in all three codes—verbal, visual, and magnitude—and that different consumers have different tendencies or abilities to rely on each code. The overwhelming evidence of verbal coding reveals itself most clearly in the effect of the time needed to pronounce a price on its likelihood of recall. This effect takes three different forms in our studies. First, each extra syllable in a price decreases its chances of being recalled by 20%. It should be noted here that the number of syllables for a given price in Arabic numerals often differs by language, and we therefore expect that the probability that a given price in digits will be recalled depends on the language the consumer uses (typically the native language). Second, consumers can literally use shortcuts to reduce the number of syllables they must pronounce; in the most extreme form, they can ignore syntactic conventions and read out multi-digit prices as a sequence of single digits. Third, there is some cognitive cost of pronouncing prices slowly because it leads to the inefficient use of the phonological loop. In addition to these three effects, we observe that good auditory coders have better recall performance.

We also find evidence of visual coding in two types of effects. First, we observe the attention effect that unusual prices generate. Second, we show that good visual coders perform better on the recall test. To detect the presence of magnitude coding, we used an indirect approach and demonstrate that recall errors are proportional to the price level, a prediction we derived from the hypothetical number line generated by magnitude coding, which gets compressed when numbers get higher and results in a degrading precision in coding.

Across our three experiments and two pilot studies, we find that immediate recall performance is higher than predicted by digit span studies, even when we ignore that, in addition to a price, a product identification also had to be kept in memory. This level of performance most likely can be attributed to the combined use of the three types of coding and to the intervention of long-term memory during the recall task, probably mainly at the auditory code level when incomplete fragments in the phonological store are complemented by previously stored and overlearned phonological representations. In addition, certain visual aspects of the price can provide additional cues that, again supported by long-term memory, help reconstruct the recalled price.

Implications

In-the-aisle price surveys indicate that consumers' level of price knowledge is lower than what most researchers and practitioners intuitively would expect. Our project puts these results in a new perspective. We find that immediate memory capacity as such is fairly strong, which suggests that when consumers cannot respond to an in-the-aisle price recall question, it is because they simply have not looked at the price or at least have not observed it at a sufficient level to code it, or have already erased it from the short-term store. At the same time, some responses in these studies are probably based on magnitude coding. Labeling them as inaccurate reveals only part of the actual price knowledge present in memory. Our research therefore also adds to the discussion about reference pricing (Kalyanaram and Winer 1995). Some researchers propose that reference prices may exist in the form of zones of price latitude instead of precise price points. The magnitude code represents the cognitive basis of this zone of latitude. Magnitude coding is automatic and effortless, which implies that some

rudimentary form of price knowledge is easily acquired, provided the consumer allows at least some attention to price labels.

Past research on the structural properties of prices has focused on price endings (e.g., Schindler and Kirby 1997). Our research adds two other important properties: the verbal length of the price stimulus and the usualness of its pattern. A very practical implication of our findings is that small price changes can affect the potential to recall prices. Marketers who want to stimulate recall of their prices, or impede it, can do so at minimal cost. The consumer, in turn, can augment his or her recall capacity for prices by using recall strategies that lighten the load for the phonological loop. A price of \$173 can, for example, be verbally coded as “one hundred and seventy-three,” “one hundred seventy-three,” “one seventy-three,” or “one seven three,” that is in four to eight syllables. All four responses are correct, but they differ in how much space they leave in the phonological loop for other pieces of information, such as the price of a competing product.

Future Research Directions

The experimental procedure used in this project focuses on accurate recall of prices displayed in front of consumers, the common situation in supermarket settings, and a form of memory that is referred to as explicit. Monroe and Lee (1999) draw attention to the fact that consumers may also acquire price knowledge based on implicit memory through an accumulation of experiences over time. To examine this type of learning, a different experimental paradigm would be needed; one in which consumers do not only intend to learn prices but also engage in other forms of information processing of prices. Indirect tasks then can assess the level of learning that takes place. Our conjecture is that magnitude coding will become more prominent but that the verbal and visual codes still will play an important role.

Even when participants have no intention to memorize prices, an indirect task involving these prices still requires storage in working memory and therefore is subject to its structural constraints.

The study procedure used in our experiments was inspired by in-store price comparisons, during which several prices must remain in short-term memory. This procedure may reduce the role of visual coding on the visual-spatial sketch relative to procedures that involve the storage of single numbers. Visual coding is probably more prevalent for the storage of single numbers.

Our estimates of short-term memory performance and capacity for prices are clearly upper limits, largely because the participants in our studies were business students in elite schools who most likely had developed a certain agility in dealing with numbers. Researchers who are more interested in the level of performance than in the mechanisms that drive such performance could use our experimental procedure with different populations of participants and use our studies as benchmarks.

By using three very different product categories, we manipulated the level and form (presence or absence of cents) of prices, but we only addressed certain price levels. More research is needed about the strategies consumers use to deal with long prices that exceed the two-second limit of the phonological store. Another issue for research to determine is how chunking (Miller 1956) can help people avoid the limits of their short-term stores. Chunking, which involves the use of long-term memory, may help consumers recall prices that surpass the limits of the short-term store.

Our project studied the encoding and immediate recall of prices. To examine these processes we showed that the triple-code model of Dehaene, combined with Baddeley's architecture of working memory provide a productive conceptual framework. Although prices are relatively complex stimuli, compared to the items used in psychological research,

we showed that the conceptual framework provides important insights into the cognitive processing of price information for immediate recall. In addition, our experimental approach with real products and prices and a task related to price comparison making gives an excellent balance of internal and external validity. We therefore assume that the same conceptual framework and experimental approach also apply to long-term memory phenomena and hope that our work will be the basis of future research in this direction.

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TABLE 1
 LOGISTIC REGRESSION ANALYSIS STUDY 1 (U.S.)

	B	Wald	Sig.	Exp(B)
Number of syllables of focal item	-.222	95.60	<.001	.801
Number of syllables of other items	-.121	51.18	<.001	.886
Number of items for trial	1.062	93.01	<.001	2.893
Presentation order		3.59	.167	
First	.134	2.77	.096	1.144
Second	.017	.04	.849	1.017
Question order		33.04	<.001	
First	.418	26.69	<.001	1.519
Second	.075	.74	.389	1.078
Product category*		121.80	<.001	
Candy	-.265	14.46	<.001	.767
DVD	-.772	120.38	<.001	.462
Intercept	1.865	77.93	<.001	6.457

N= 6248, R² = .22

*The reference category is Camera, third presentation, and third question order.

TABLE 2
 LOGISTIC REGRESSION ANALYSIS STUDY 2 (HUNGARY)

	B	Wald	Sig.	Exp(B)
Total number of syllables of items	-.131	418.17	<.001	.877
Viewing only usual prices*	.128	2.12	.146	1.136
Unusual focal prices**	.526	7.94	.005	1.692
Question order		9.93	.007	
First	.213	2.76	.097	1.237
Second	.364	9.12	.003	1.438
Presentation order		21.86	<.001	
First	.452	12.84	<.001	1.571
Second	.054	.21	.646	1.056
Candy	.217	4.55	.033	1.243
Errors Corsi test	-.013	8.92	.003	.987
Corsi test × unusual prices	.020	3.87	.049	1.020
Intercept	2.049	47.00	<.001	7.762

N = 4050, R² = .40

*The reference category is the subject group that viewed a mix of usual and unusual prices.

**The reference category is a focal usual price.

TABLE 3
LOGISTIC REGRESSION ANALYSIS STUDY 3 (U.S.)

	B	Wald	Sig.	Exp(B)
Number of syllables of focal item	-.099	18.46	<.001	.905
Number of syllables of other items	-.090	26.97	<.001	.914
Number of items for trial	1.282	126.30	<.001	3.603
Question order		17.62	<.001	
First	.306	17.10	<.001	1.358
Second	.141	3.63	.057	1.152
Presentation order		24.60	<.001	
First	.333	20.22	<.001	1.395
Second	.076	1.06	.304	1.079
Reading time for price tables	-.003	4.21	.040	.997
Syllable count with usual pronunciation	-.097	4.45	.035	.908
Performance auditory recall	.143	119.10	<.001	1.153
Errors Corsi test	-.080	17.61	<.001	.923
Performance magnitude estimation		.13	.936	
Underestimators	-.010	.02	.886	.990
Overestimators	-.029	.13	.722	.971
Product category*		235.15	<.001	
Candy	.042	.34	.561	1.043
DVD	-.978	181.94	<.001	.376
Intercept	1.131	11.30	<.001	3.098

N = 6278, R² = .26

*The reference category is a camera, third presentation and third question order, and the middle group in the magnitude estimation.

FIGURE 1

SCALAR VARIABILITY IN IMMEDIATE PRICE RECALL

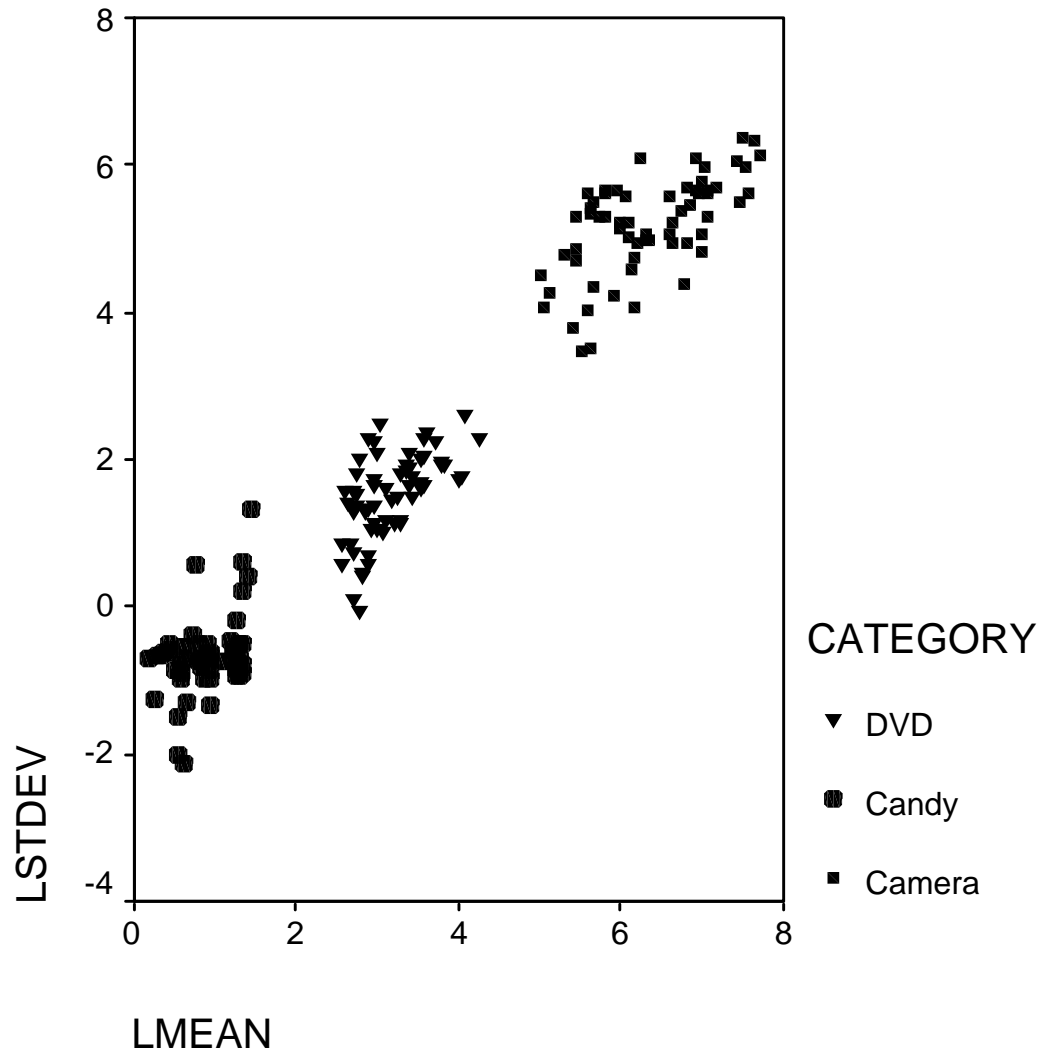


FIGURE 2

RECALL PERFORMANCE AS FUNCTION OF TOTAL NUMBER OF SYLLABLES TO
BE REMEMBERED

