How Do Consumers Read and Encode a Price?

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Do consumers really read a price from left to right, as assumed in past research? Or does price reading operate like word reading, with a single fixation toward the middle? Three eye-tracking lab studies reject both theories, revealing instead a distinct reading pattern: multiple fixations, with the first located on average between the first third and middle of the price; the first eye movement is usually to the left; and subsequent eye movements are as often to the left as to the right. Overall, consumers pay as much attention to cents as euros, with the cents part influencing how prices are encoded in memory, as evidenced by an in-store price-recall survey. The reading process identifies whether to encode a price verbally as is or replace it with a shorter substitute that is easier to memorize and turns out to be well correlated with the actual price ($r = 0.952$). When consumers compare two prices, eye movements and the subsequent subjective estimation of the price difference depend on whether or not the prices have identical integer parts. The combined findings of four studies suggest that consumers have developed a reliable, efficient ability to read and encode prices, despite limitations of their visual span and working memory.

Keywords: price reading, eye tracking, price encoding, numerical cognition, triple code for numbers, psychological prices

INTRODUCTION

How do consumers read a price? What eye movements do they make when reading a posted price, as in online or in a store? Intuitively, most people might assume the answer to both questions is "from left to right," that is, from the leftmost to the rightmost digit. This assumption has guided consumer research on price (Bizer and Schindler 2005; Coulter 2001; Coulter and Coulter 2007; Stiving and Winer 1997; Thomas and Morwitz 2005) and accords with early findings in numerical cognition (Poltrock and Schwartz 1984).

In contrast, neuroscience research (Adelman, Marquis, and Sabatos-DeVito 2010; Dehaene 2009) reveals, for words, the prevalence of parallel reading: for up to seven letters, people process all of them in parallel, most often with a single fixation located slightly to the left of the middle of the word (Rayner 1979). The ability to identify an isolated word or object is optimal when the eyes first fixate at its center (van der Linden and Vitu 2016). In turn, numerical cognition research offers evidence of parallel processing of consecutive digits in a number (Meyerhoff et al. 2012; Moeller et al. 2009; Nuerk, Weger, and Willmes 2001). Transposing these findings leads to an alternative set of hypotheses: reading a price might involve parallel processing of digits and start close to the center.

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The initial aim of the current research was to apply eye tracking to make a direct empirical comparison of these two alternative views on how consumers read prices: left to right versus in parallel. In all its activities, the human eye makes successive fixations (during a fixation, miniature eye movements stabilize the retina around a gaze point). Fixations are separated by longer, faster eye movements called saccades (Duchowski 2017, 40–44). Using three eye-tracking lab studies, we identify patterns of successive fixations and saccades when consumers read a price. We ask: where are fixations located? How many are there? What is the direction of saccades between fixations? Do they follow a left-to-right or different pattern?

Determining precisely how people read prices has theoretical importance but also critical practical implications. In the "from left-to-right" hypothesis, consumers pay limited or no attention to cents. In an extreme version, for a price like 2.99, consumers would not bother to read the cents. But if digits are processed in parallel, cents may receive as much attention as dollars, euros, or pounds, even if they are relatively economically inconsequential. They may then influence how the price is encoded to inform further price judgments and consumption decisions. Equally, "psychological" endings (e.g., 99) would benefit from the attention paid to cents in general, increasing sales (Anderson and Simester 2003; Schindler and Kibarian 1996), thereby remaining favored by retailers (Schindler and Kirby 1997).

The eye-tracking studies produced an unexpected outcome: when consumers read a price, their eye fixations do not correspond to either left-to-right reading or parallel reading but follow a distinct, original pattern. For prices comprising both euro digits and cents digits (our data come from European consumers), these two parts attracted about the same number of fixations, with participants allocating consistently half of their attention to the cents part.

We subsequently examined the possible substantive consequences of this attention on consumers' price encoding and price magnitude estimations. In the lab, we checked its influence on how consumers estimate the magnitude of the difference between two prices. In the store, we examined the effect in relation to how consumers encode the posted price before making their decision. On the basis of research into short-term memory (Baddeley 2012; Baddeley, Lewis, and Vallar 1984) and short-term recall of prices (Vanhuele, Laurent, and Drèze 2006), we anticipated that the initial attention to the cents part helps consumers identify whether the price can be easily encoded as posted or should instead be replaced by a simpler substitute, more manageable within the limitations of their short-term memory. In eight in-store surveys, consumers were asked, unexpectedly, to report the price of products they just put in their shopping cart. Indeed, the cents part of the posted price affects these consumer reports: whether the reports are perfectly accurate and, if not, what form they take.

In combination, the results of these four studies suggest that consumers have developed an efficient, reliable ability to handle the limitations of short-term memory when reading and encoding prices with a cents part. The eyes scan the price completely, euros and cents, and identify whether it is easy to remember. If not, the actual price gets replaced by a substitute that is almost perfectly correlated with it and easier to remember, as it is about half the length.

In the next section, we review research on left-to-right reading and parallel reading, deriving opposite hypotheses that can be tested empirically. We then report three eye-tracking studies with different protocols, analyzing fixations and saccades while participants read prices. In one, we also examine the links between price characteristics, eye movements, and the perceived magnitude of price differences. Next, we develop new hypotheses about price encoding and test them in a store setting. In the discussion, we propose a novel theory of how consumers read and encode prices with a cents part, complemented by a review of our contributions and proposals for further research.

THEORETICAL BACKGROUND

Left-to-Right Reading: Results from Consumer Behavior and Numerical Cognition

An intuitive assumption holds that, when reading a price, the eyes move from left to right because, when reading a text, people read successive words in a line from left to right (but right to left in, for instance, Hebrew or Arabic). It seems natural to infer that they read the letters in each word from left to right and, similarly, that they read the digits in a price from left to right. In addition, left-to-right reading of prices would be functional, due to the relatively lesser economic importance of cents.

Consumer research on price largely reflects this assumption. Stiving and Winer (1997, 58) compare brand-choice models that capture different assumptions about how the price digits are processed and conclude that "consumers process prices digit by digit, beginning with the left-hand digits and frequently ignoring right-hand digits." However, they also find indications that people notice price endings of 0 and 9 and acknowledge that they cannot rule out alternative explanations of their findings, because they only have indirect evidence. Thomas and Morwitz (2005) examine "when and why nine-ending prices are perceived to be smaller than a price one cent higher" (idem, abstract). They call this underestimation the "left-digit effect" and explain it as a result of left-to-right reading in combination with magnitude coding of the first digit: "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'" (idem, 55). Similarly, Coulter (2001, 276) concludes that "left-to-right digit encoding may be a necessary condition for higher than expected demand" for psychological prices. Sokolova, Seenivasan, and Thomas (2020) also assume that evaluations of presented prices are carried out digit by digit.

None of these studies collect data on the actual pattern of eye fixations and saccades that occurs during price reading. Nevertheless, their conclusions, consistent with left-to-right reading assumptions, imply three hypotheses on eye movements, which we designate with "a" to specify a left-to-right hypothesis:

> **H1a:** Price reading requires multiple consecutive eye fixations.
>
> **H2a:** The first fixation on a price targets its leftmost digit.
>
> **H3a:** Eye movements between consecutive fixations are from left to right.

However, research on numerical cognition challenges the notion of left-to-right reading of digits. In particular, the "unit–decade compatibility effect" offers evidence of parallel processing of different digits of a number. For example, if people must compare two two-digit numbers with different first digits to determine which is larger, reading these first digits should be sufficient for the processing, according to the left-to-right reading theory. However, Nuerk et al. (2001) instead find that the second digit influences response times. The respondents take longer to compare 47 with 92 than to compare 42 and 97. The larger second digit 7 slows down the realization that 4 is smaller than 9, even though the second digit of each number is task-irrelevant and could be ignored. To clarify this unit–decade compatibility effect, Moeller et al. (2009) examine the underlying process by comparing the number of fixations that people make on each digit in different conditions; they find evidence of parallel processing of the tens and units of two-digit numbers. Meyerhoff et al. (2012) extend this work to four- and six-digit numbers and conclude that for large numbers, sequential and parallel processing combine. The numbers are divided into shorter chunks of two to four digits. Digits within a chunk are processed in parallel; chunks are processed sequentially.

Fixating First on the Middle: Findings on Word Reading

Research on word reading also questions the notion of left-to-right reading. People read successive words in a text using successive fixations, ordered from left to right, but they read most words of normal length (up to seven letters) in a single fixation, during which they recognize all letters simultaneously, not in a sequence (Adelman et al. 2010; Dehaene 2009). In only a few cases (10–15%) do readers need a second fixation or move their eyes back (regress) to previously read material, and those regressions increase with the difficulty of the text (Rayner 2009). If a single fixation is sufficient to identify all the letters in a word of normal length, it also likely should be enough to identify four digits in a short price, up to 99,99 €. With another set of hypotheses, denoted with "b," we offer alternatives to the preceding predictions.

> **H1b:** Reading a short price requires a single eye fixation.

This transposition from word reading to price reading may be inaccurate, though. Word reading involves recognition of the observed combination of letters from a dictionary of words stored in long-term memory (Dehaene 2009). For prices, there is no equivalent to this dictionary, because all combinations of digits are possible. Therefore, people's ability to read in a single fixation may be limited for prices, as it is when deciphering a previously unknown word (e.g., a geographical name like Bohorkortea). Prices may then produce more regressions than words do.

Research on text reading also examines the location of the eye's first fixation on a word, referred to as the landing position, which tends to be halfway between the beginning and the middle of the word (Rayner 1998). In experiments, Vitu, O'Regan, and Mittau (1990) manipulate this landing position for isolated words and identify an optimal landing position, near the middle, at which the probability of having to refixate on the word decreases, and the average duration of the fixation is larger. A price tag is an object. When van der Linden and Vitu (2016) examine the impact of manipulated landing positions for identifying isolated objects and reading isolated words, they locate the optimal viewing position in the center for objects and slightly to the left of the middle for words. We thus predict:

> **H2b:** The first fixation on a posted price is located in its middle.

Both sets of hypotheses, hypotheses 1a–3a and hypotheses 1b and 2b, pertain to the location of the first fixation and the number and relative locations of additional fixations, so we can use empirical evidence to test their contrasting predictions. Studies 1–3 analyze eye-tracking data across different reading conditions.

STUDY 1: EYE MOVEMENTS WHILE READING A PRICE

Procedure

Because we aim to examine natural reading, for most of study 1, we instructed participants "to read presented prices like they would in a store," telling them that questions would be asked about some of those prices. During their reading, we collected eye-tracking data using a Tobii Pro TX300 oculometer at a 300-Hz frequency (accuracy: 0.4°, precision: 0.07°). We used actual prices encountered in stores or on the Internet, on a range of products from fast-moving consumer goods to apartments, with a variety of price endings. Stimuli and answers were in French, the respondents' native language.

Participants were seated 60 cm away from the screen. Each screen displayed both a product name (top of screen) and its price (bottom), both centered on the left–right axis (web appendices A–C describe the stimuli for all three eye-movement studies in detail). We presented prices in the French everyday (and legal) format, such as "42,70 €." After reading a price, participants had to press the F10 key to move to the next price.

After a training task (on four prices), we presented respondents with a total of 44 screens with product–price pairs. The appendix details the conditions used in studies 1–3. We first instructed respondents to read in silence 8 screens showing prices comprising 2 euro digits and 2 cents digits, followed by 10 screens showing prices with 5–7 euro digits but no cents part. In a second phase, they were asked to read aloud the same number of screens for each type of price, this time with different prices. This second phase allowed us to verify that all the digits were effectively read, which is not possible with silent reading. The experimenter verified that respondents always reported prices perfectly accurately. When the prices included a cents component, the spontaneous oral report always had two parts: the verbal form of the euros followed by the verbal form of the cents. Research on text reading shows that with oral reading saccades are smaller (Rayner 1998) and fixations are longer. The eyes move faster than the reader can produce the words and should not get too far ahead of the voice. If we find that price reading requires multiple fixations (hypothesis 1a), we should also find more fixations for oral reading.

In a third and final phase, on eight additional prices with cents, respondents were asked, before being shown the price, a question about either the euro part (is it above or below 50 €?) or the cents part (is it a psychological price, ending in 95 or 99, or not?). The objective here was to examine whether eye movements differ when participants' attention is directed to specific digits, as opposed to normal reading of the price, as for all preceding stimuli.

Data were collected from 21 staff employees at a French business school. We excluded four respondents for whom the raw data were missing for 22% of observations or more. This produced a total of 4,973 fixations for analysis.

To identify fixations, we rely on the BIT program (van der Lans, Wedel, and Pieters 2011), requiring a fixation to be at least 80 ms long, which corresponds to the minimum fixation time for information acquisition to take place. BIT takes no account of screen changes when identifying fixations. When a fixation begins on a screen and ends on the next screen, we consider its first part (until the screen changes) as a fixation on the first screen. We do not consider its last part as a fixation on the second screen, because it did not occur as a reaction to that screen (Holmqvist and Andersson 2017, 9). Because we need to analyze only fixations on price (in the bottom half of the screen), we set aside fixations on product names, identified by their position in the top half.

Given our hypotheses, we analyze the precise horizontal location of each fixation (measured in pixels) (van der Linden and Vitu 2016; Vitu et al. 1990). Thus, we can precisely compare this location with that of the posted digits and compute an exact horizontal distance between two successive fixations (how many pixels to the right or left?). These data are more precise than if we defined an a priori area of interest (AOI) for each posted digit (Meyerhoff et al. 2012; Wedel and Pieters 2006), which would allow only approximate measures of fixation locations and eye movements and ignore fixations outside these AOIs, which may be relevant for understanding reading behavior.

Results

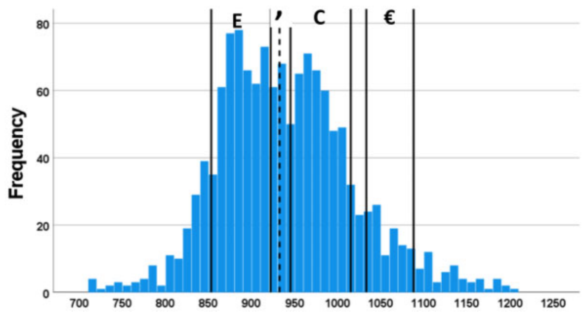
We present the detailed results when participants are asked to simply read, aloud or silently, prices comprising two euro digits and two cents digits. We obtain similar results when participants read prices with no cents part or answer a question about the price, and we mention some of those results.

Overall Distribution of Fixations' Horizontal Locations. Only the cone cells at the center of the human retina (the fovea) have the ability to decipher small symbols, such as digits or letters (Holmqvist and Andersson 2017, 13). They can do so within an angle of about 2° around the gaze point. Given the distance of 60 cm between the eye and the screen in our studies, 2° corresponds to about 80 pixels. Thus, we expect to observe fixations not only over the posted price but also within 1° (40 pixels) around its limits. Figure 1 displays the distribution of fixations. The total horizontal length of the four digits (including the comma) is 162 pixels, with 35 pixels per digit. Most of the fixations are within the limits (83%, including the € symbol in the posted price), and only 5.8% deviate more than 40 pixels (3.1% on the left, 2.7% on the right). The distribution is continuous and "well-behaved" (Tukey 1976): there is no sudden drop in frequencies at the price limits. The frequencies decrease smoothly until they reach zero at both ends of the distribution, and we observe smooth transitions in the 40 pixels around the limits.

How Many Fixations on the Price?. Do consumers make multiple fixations (hypothesis 1a) or a single fixation (hypothesis 1b) on a price? To formally test these competing hypotheses, we use a mixed linear model with a number of fixations as the dependent variable and reading mode (silent vs. aloud) as the independent variable, treating the participant as a random factor. The effect of reading mode was significant ($F(1, 254) = 70.94$, $p < 10^{-14}$). The number of fixations was higher when participants had to read aloud ($M = 6.38$) than when they were reading in silence ($M = 3.51$). Both means were greater than 1

FIGURE 1

DISTRIBUTION OF THE HORIZONTAL LOCATION OF FIXATIONS



NOTES.— Vertical solid bars indicate the horizontal limits of the euro digits ("E"), the decimal comma (","), the cents digits ("C"), and the euro sign ("€"). The dotted vertical bar indicates the median of the distribution.

($p < 10^{-7}$ and $p < 10^{-15}$), indicating that participants made more than one fixation. Using another indicator, they make more than one fixation on the price in 89.0% of the cases when reading in silence and in 98.5% of the cases when reading aloud. With the same mixed linear model, we obtain a similarly large difference when participants read long prices with no cents part but five to seven euro digits: estimated marginal means of 4.45 fixations (silent) versus 11.58 (aloud) ($F(1, 338) = 32.71, p < 10^{-7}$).

Given these large numbers of fixations, a proper analysis of price reading cannot be restricted to the first fixation on each price. In figure 2, we compare the horizontal locations of the first fixation, second fixation, and further fixations (third and beyond) for prices with two euro digits and two cents digits.

Location of the First Fixation. Table 1 (top two lines) displays the observed median location of the first fixation on each price with a cents part and translates this median into a standardized left-to-right indicator from 0% to 100%, in which 0% indicates the left of the first digit and 100% indicates the right of the last digit. This indicator takes a value of 48% for silent reading (location on the decimal comma) and 38% for reading aloud (on the second euro digit). Thus, the median first fixation is not located on the leftmost digit, but between one-third and one half along the posted price, like in word reading, supporting hypothesis 2b rather than hypothesis 2a. We obtain similar results for prices comprising no cents but five to seven euro digits, with the left-to-right indicator varying between 29% and 43% over the three numbers of digits and two reading modes.

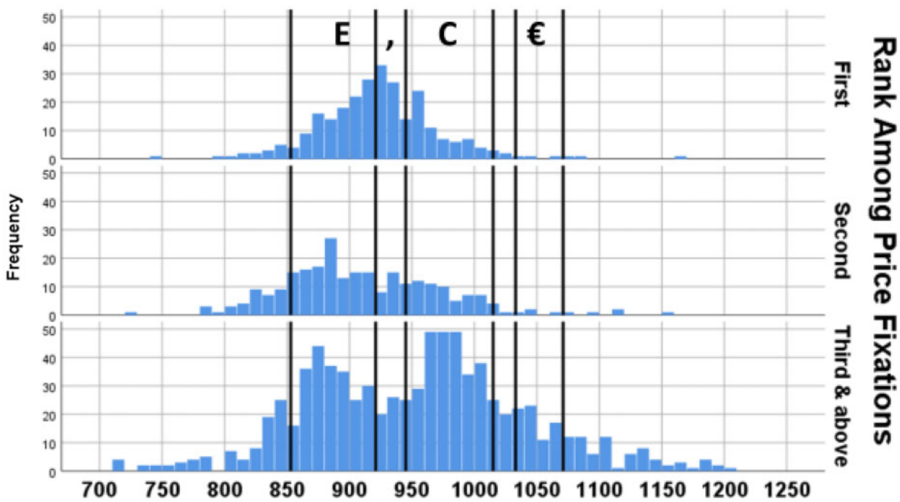
Table 1 also reports the mean location of the first fixation, estimated by a mixed model explaining fixation location by the fixation rank (1, 2, 3+), with the participant as a random factor. In addition, we use a mixed linear model to test the difference between the average position of the first fixation and the midpoint of the leftmost digit (located at 870 pixels), with the participant as a random factor. The difference is significant ($t = 8.32$ for silent reading, $t = 7.21$ for reading aloud, with *ps* below 10^{-7}).

Location of Subsequent Fixations. As shown in figure 2, the mode of the second fixation is on the euro part. Further fixations have a bimodal distribution, with one mode on the first euro digit and the other on the cents digits. To test whether a fixation is located to the left or to the right of the comma, we use a mixed logit model with the location (1 left, 0 right) as the dependent variable and fixation rank as a fixed factor, with the participant as a random factor. We find that 67% of second fixations are situated to the left of the comma (33% to the right) versus 66%/34% for the first fixation and 40%/60% for further fixations. Across all fixations ($n = 1{,}346$), cents benefit from as much attention as euros: a mixed logit model estimates that 49.5% of fixations are located to the right of the comma.

Direction of Saccades between Consecutive Fixations. To test whether participants read prices from left to right (hypothesis 3a), we analyze saccades between two consecutive fixations. Of course, we must analyze only saccades between two fixations on price, excluding saccades from price to product name or vice versa. Fortunately, when participants read prices with both euro and cents digits, all fixations on price follow one another in a single sequence in 63% of participant–screen combinations, and in another 33%, they occur in just two sequences. We use a mixed logit model in which the dependent variable takes value 1 if the move is left to right and 0 if right to left, with first versus further saccades as a fixed factor and participant as a random factor. The first saccade is most often (71%) from right to left. Of further saccades, 60% are from left to right (z for the difference is 7.62, $p < 10^{-13}$). Are consecutive saccades from one digit to the next? We analyze their lengths with a mixed linear model, with the move direction as a fixed factor and the participant as a random factor. Both moves to the right and to the left have large absolute lengths (respectively, $M = 79.5$, $SE = 2.6$, median = 76 and $M = -65.3$, $SE = 2.8$, median = −51). Thus, saccades are much longer than the width of one posted digit (about 35 pixels), traveling on average over two or three posted digits. Finally, we analyze whether two consecutive saccades move in the same direction, as predicted by left-to-right reading. We use a mixed logit model, with the direction of the given saccade (left or right) as a dependent variable, the direction of the previous saccade as a fixed factor, and the participant as a random factor. After a move to the left, 73% of moves are in the opposite direction, whereas after a move to the right, 49% of moves are in the opposite direction. This does not fit the left-to-right hypothesis.

FIGURE 2

DISTRIBUTION OF FIXATIONS FOR FIRST, SECOND, AND FURTHER FIXATIONS



NOTES.— The location of the first fixation is in 6.3% of cases on the left of the first euro digit, 12.9% on the first euro digit, 29.5% on the second euro digit, 23.2% on the comma zone, 17.3% on the first cents digit, 6.6% on the second cents digit, and 4.1% on the right of the second cents digit.

TABLE 1

LOCATION (IN PIXELS) OF THE FIRST EYE FIXATION WHEN READING A PRICE WITH TWO EURO AND TWO CENTS DIGITS

Task	Mean location (95% conf. interval)	Median location	Standardized left-to-right indicator (0–100%)	Median location (in words)
Silent reading	935 (922–947)	931	48	Decimal comma
Reading aloud	914 (902–927)	914	38	Second euro digit
Question about euros	864 (847–882)	886	21	First euro digit
Question about cents	885 (857–913)	944	56	First cents digit

NOTES.— The price digits were positioned as follows on screen: first € digit 853–887 pixels; second € digit 887–922; decimal comma 922–945; first cents digit 945–980; and second cents digit 980–1,015. In terms of our standardized left-to-right indicator, the first euro digit is positioned from 0% to 21%, the second euro digit from 21% to 43%, the comma zone from 43% to 57%, the first cents digit from 57% to 78%, and the second cents digit from 78% to 100%.

Results with Other Tasks. When the question is whether the price is above or below 50 € so that the first euro digit holds the answer, the median location of the first fixation is at the limit between the first and second euro digits, with the standardized left-to-right indicator taking the value of 21% (table 1). When the question is whether the price is psychological (95 or 99 cents) so that the cents part holds the answer, the median first fixation is at the limit of the first cents digit, with the same indicator taking the value of 56%. To analyze, over all fixations, if they are on the left or right of the comma, we use a mixed logit with a binary dependent variable (1 left, 0 right) with the consumer task as a fixed factor and the participant as a random factor. For the question on euros (above/below 50 €?), 65% of fixations are on the left, well above 47% when the task is reading in silence ($t = 6.08$, $p < 10^{-8}$), and 52% when reading aloud ($t = 5.10$, $p < 10^{-6}$). That is, when participants must read a specific part of a price to answer a question, they are able to fixate on that part immediately. This implies that if they had wanted to start from the left digit when instructed to read a price as if they were in a store (as in most conditions of study 1), they could have done so, instead of locating their first fixation on average close to the middle of the price.

Main Findings. Study 1 does not find empirical support for either of the two groups of opposing hypotheses. Price reading starts with a fixation somewhere between the first third and the middle of the price, as in word reading and against the assumption of left-to-right reading. But unlike word reading, price reading involves multiple fixations and large saccades across two or three digits of the price. The saccades take both directions, not only left to right.

STUDY 2: READING A PRICE DISPLAYED AT DIFFERENT POSITIONS

Some of the unexpected patterns identified in study 1 need validation, because they may have been the result of the specific protocol used. First, prices and product names appeared on the same screen. The participants' gaze could go back and forth between product and price, which may have inflated the number of fixations on the price. Thus, study 2 presents the product name and price on successive screens. The product name appears in the upper part of the first screen, and the price is in the lower part of the next screen, at the same horizontal location.

Second, in study 1, the horizontal position of the price was always in the center of the screen, perhaps leading respondents to locate, screen after screen, their first fixation on average on the middle of the price. Thus, study 2 presents prices at different horizontal locations, as in a store setting where consumers might not be exactly in front of the posted price.

Third, for prices with no cents part, we use a more complete set of stimuli, with the number of digits varying from one to seven rather than only from five to seven as in study 1.

Procedure

We obtain eye-tracking data with the same Tobii Pro TX300 oculometer at a 300-Hz frequency and use the BIT algorithm for analysis. The general organization of study 2 is identical to that of study 1: a verbal introduction, four product–price pairs of training slides during which participants learn to use a mouse (rather than the F10 key as in study 1) to advance to the next screen and then the main stimuli (described subsequently). We locate each product–price pair randomly on the left of the screen, in the center, or on the right, using for each screen the same randomly chosen location for all participants.

The 28 respondents (25 usable, based on the same criteria as in study 1) are staff employees at a French business school. Stimuli and answers are in French. As in study 1, to induce normal reading, the posted prices are actual prices encountered in stores or on the Internet.

After the training task, the main experiment involves 66 screen pairs overall (appendix). We asked participants to read in silence 12 pairs in which the price comprises two euro digits and two cents digits, followed by 21 pairs in which the price has no cents part. Then, we asked them to read aloud the same number of screen pairs for each type with different prices (12 plus 21). The cents part features a variety of values, in random order: 3 psychological values (99 or 95), 3 zero values (00), 3 multiples of 10 (e.g., 30), and 3 other values (e.g., 57).

We treat overlapping fixations that begin when the monitor displays a screen with a product name and end when the monitor displays the next screen with a price like we did in study 1: we exclude the end part of these fixations from the analysis relative to the price screen. The resulting data set contains 14,371 fixations on price screens.

Results

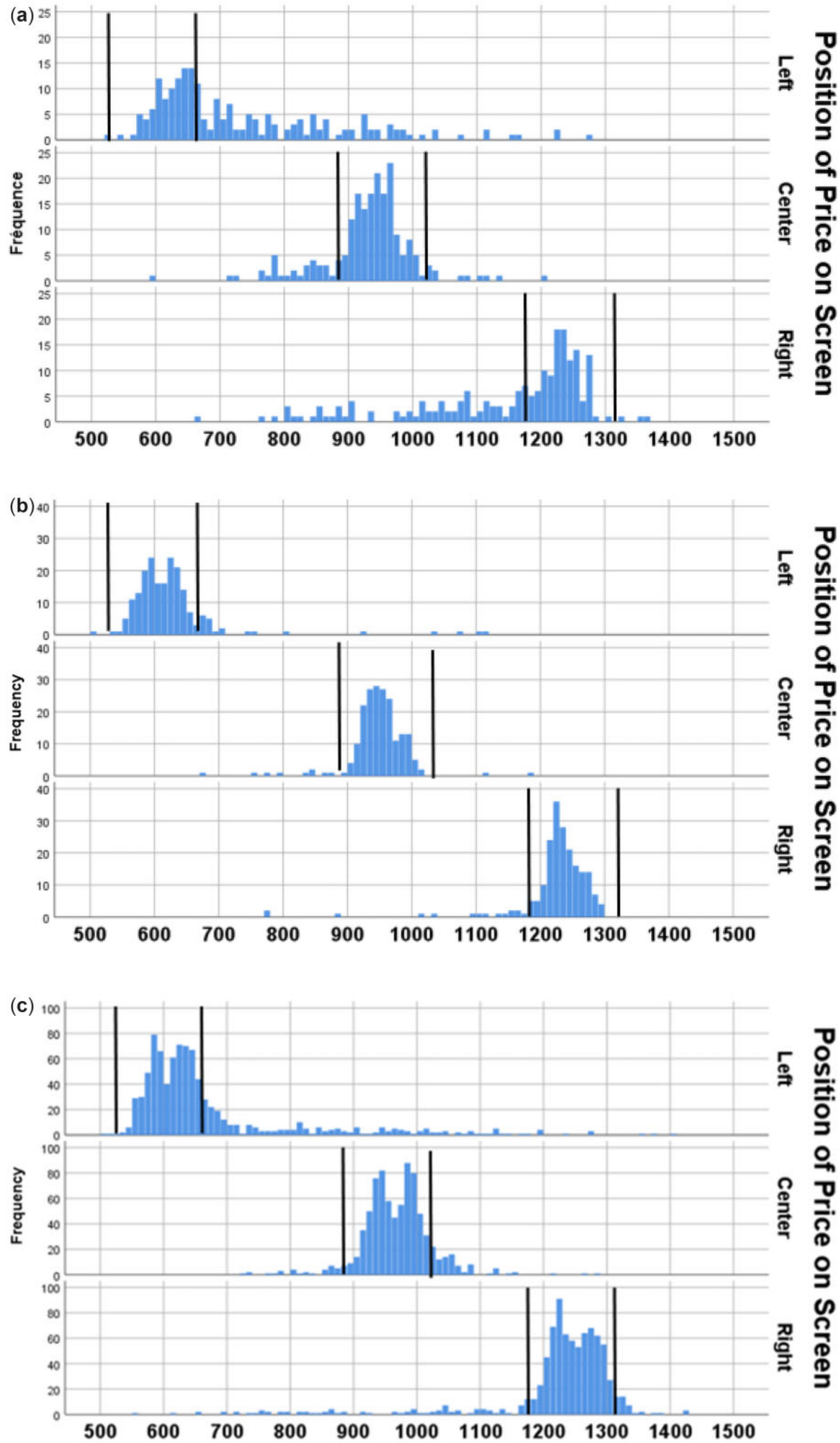
We present detailed results related to the tasks in which respondents read prices with two euro and two cents digits, and we briefly summarize the (similar) results for prices with no cents.

Location of the First and Second Fixations. When the price is posted in the center, study 2 replicates study 1's finding that the median first fixation is not located on the leftmost digit, but between the first third and the midpoint of the price, again supporting hypothesis 2b over hypothesis 2a (figure 3a). For prices with two euro and two cents digits, the standardized left-to-right indicator takes values of 39% (silent reading) and 33% (aloud); for prices with no cents, 57% (silent) and 31% (aloud). However, we observe an important effect of the horizontal position of the stimulus: when the price is presented on the left or right side of the screen, a large proportion of first fixations miss the target (i.e., the price stimulus) by more than 40 pixels (1°). We use a mixed logit in which missing the target in the first fixation is the binary dependent variable, with the position of the price as the fixed factor and the participant as a random factor. When the price is on the left, the probability of missing it is 42% and the mistargeted fixations are all located to the right of the price, toward the center of the screen. When the price is on the right, the probability is 33% and almost all the mistargeted fixations (68/70) are located to the left of the price, toward the screen's center. In contrast, when the price is located in the center, the probability of missing is only 12%. We find the same phenomenon for prices without a cents part. This result appears to be a manifestation of "central bias" (Tatler 2007), which might arise because an eye fixation in the center is optimal to start exploring a new scene in which the relevant information (here, the price) is located at a previously unknown position, or it could be due to a tendency to center the eye in its orbit.

The second fixation on the screen (figure 3b) is very rarely more than 40 pixels away from the stimulus: a similar mixed logit indicates a probability of 2.5% when the stimulus is on the left, 1.7% in the center, and 1.9% on the right. Thus, when the first fixation misses the target, the next eye movement appears to be a corrective saccade, allowing the eye to land its next fixation accurately on the actual price position (Becker and Fuchs 1969). In the

FIGURE 3

(a) HORIZONTAL LOCATION OF FIRST FIXATION. (b) HORIZONTAL LOCATION OF SECOND FIXATION. (c) HORIZONTAL LOCATION OF THIRD AND FURTHER FIXATIONS



NOTE.— Vertical bars indicate the limits of the price stimulus.

following analyses, when the first fixation on the screen is more than 40 pixels away from the price, we do not consider it a fixation on the price but rather a preliminary orientation fixation, such that the consumer acquires no information about the price itself, but only about the position of the price tag on the screen, that is, where to locate the next fixation. Accordingly, we exclude these preliminary, off-target fixations from the statistical analyses below. After this exclusion, the location of the first usable fixation still depends on the price position. For prices on left, 16% of those fixations are on the euro digits or to their left, 5% on the comma, and 79% on the cents digits or to their right; for prices in the center, the percentages are 63%, 8%, and 29%; and for prices on the right, they are 69%, 8%, and 23%.

Bimodal Distribution of Other Fixations. Irrespective of the position of the posted price, the distribution of further fixations (third fixation and beyond, figure 3c) replicates study 1, showing a bimodal distribution with a valley in the middle of the price, between the two modes. This repeated evidence indicates consumer attention to both the euros and the cents.

Reading a Price Involves Multiple Fixations. For prices with two euro digits and two cents digits, study 2 reveals multiple fixations as in study 1, supporting hypothesis 2a but not hypothesis 2b. A mixed linear model with the number of fixations as a dependent variable and the reading mode (silent/aloud) as a fixed factor, with the participant as a random factor, produces estimated marginal means of 5.94 (silent) and 6.45 fixations (aloud) ($F(1, 574) = 8.59, p = .0035$).

For prices with no cents part, the number of digits varies from one to seven, and reading can be silent or aloud. Over all these 14 conditions, it is very rare (0.7%) to observe reading in a single fixation. To examine the effect of the number of digits and the reading mode on the number of fixations, we use a mixed linear model predicting the number of fixations with the number of digits, the reading mode, and their interaction as fixed factors and the participant as a random factor. There is a significant impact of the reading mode ($F(1, 1007) = 30.63, p < 10^{-7}$), the number of digits ($F(6, 1007) = 55.70, p < 10^{-58}$), and their interaction ($F(6, 1007) = 11.36, p < 10^{-14}$). Table 2 reports the estimated marginal means for each of the 14 conditions. Reading aloud increases the number of fixations, but only for prices with at least three digits. The number of fixations increases about linearly with the number of digits but is not proportional to the number of digits, offering another indication that reading does not take place digit by digit.

Attention to the Right Part of the Price. When reading prices with two euro digits and two cents digits, participants targeted more fixations to the right of the comma (56%) than to its left (44%). However, these results differ drastically depending on the position of the posted price on the screen. Table 3 reports the results of a mixed logit predicting the probability of a fixation being on the right of the comma with two fixed factors, the position of the price on the screen and whether the fixation is the first on the screen, and the participant as a random factor. When the price is posted in the center, about half of fixations are on the right (46% or 54%); when posted on the left, as many as 71% or 77% of fixations are on the right; and when posted on the right, only 32% or 40% of fixations are on the right. The z-values for the difference with the center position are 11.78 on the left ($p < 10^{-15}$) and −7.03 on the right ($p < 10^{-11}$). The probability of being on the right of the comma is lower for the first fixation on the screen ($z = -3.29, p = .0010$).

For prices with no cents part, this directional bias is also influenced by the number of digits. Table 4 reports the results of a mixed logit estimating the probability of a fixation being to the right of each price's midpoint. The fixed factors are the number of digits, the price position on the screen, and their interaction, with the participant as a random factor. The larger the number of digits in the price, the lower the probability that fixations are on the right of the midpoint. Thus, reading is more likely to focus on the left part of the price for higher prices. In addition, the location of fixations differs drastically depending on the position of the posted price. As above, the probability of a fixation on the right part of the price is lowest when the price is posted on the right of the screen, intermediate

TABLE 2

NUMBER OF FIXATIONS BY NUMBER OF DIGITS IN THE PRICE

Number of digits	Mean (SE) when reading in silence	Mean (SE) when reading aloud
1	4.6 (0.37)	3.9 (0.37)
2	4.7 (0.37)	3.9 (0.37)
3	4.7 (0.37)	5.3 (0.38)
4	5.6 (0.37)	6.3 (0.37)
5	6.1 (0.37)	7.1 (0.37)
6	6.1 (0.37)	8.3 (0.37)
7	7.0 (0.37)	10.2 (0.37)

TABLE 3

ESTIMATED PROBABILITY OF FIXATIONS BEING ON THE RIGHT OF COMMA

	Price posted on left (%)	Price posted in center (%)	Price posted on right (%)
First fixation	71	46	32
Further fixations	77	54	40

TABLE 4

ESTIMATED PROBABILITY OF FIXATIONS BEING TO THE RIGHT OF PRICE MIDPOINT FOR PRICES WITH NO CENTS PART

Number of digits in price	Stimulus on left (%)	Stimulus in center (%)	Stimulus on right (%)
1	96	71	49
2	96	77	57
3	89	63	45
4	79	59	50
5	74	48	32
6	56	39	32
7	57	40	32

when it is in the center, and highest when it is on the left of the screen. Thus, we note again a tendency of the eye to fixate on the middle of the screen (Tatler 2007).

Direction of Saccades between Two Consecutive Fixations. To examine whether the finding in study 1 that successive saccades tend to counterbalance one another is confirmed, we use a mixed logit in which the dependent variable is the saccade direction (1: left to right, 0: right to left) with the price position and the direction of previous saccade as fixed factors and the participant as a random factor. After a move to the right, the probability of the next move being to the right is 40%; after a move to the left, 62% ($z = 11.61$ $p < 10^{-15}$). There is no significant impact of the price position on this counterbalancing movement ($z = -2.30$ and $z = 0.95$). The results for prices with no cents part are similar.

Main Findings. Study 2 replicates all the main results of study 1 and, in addition, shows an important influence of the horizontal position of the price on fixations and saccades. There is a pronounced central bias such that the right (left) side of prices presented to the left (right) of the viewer receives more initial and total fixations. For prices without cents (and therefore without decimal point), we find that the more digits a price has, the less attention its right part receives.

STUDY 3: EYE MOVEMENTS WHEN COMPARING TWO PRICES AND ESTIMATING THE MAGNITUDE OF THEIR DIFFERENCE

For all experimental conditions in studies 1 and 2, participants read a single price. For most, they did so without any specific purpose other than being able to answer questions that were not specified a priori. Study 3 assesses the generalizability of our findings in different task conditions. During their everyday shopping, consumers often read two (or more) prices from the same product category with the specific objective of comparing them.

This poses two questions. First, to what extent do consumers, to read each price, follow the same patterns of eye movements as those observed in studies 1 and 2? It could be that consumers selectively limit their attention to information they consider relevant for the task. For instance, would they pay attention to cents when a knowledge of the euros would be enough to make the comparison? To answer this first question, we simply test the same hypotheses as in studies 1 and 2 by replicating, separately for each of the two prices that are compared, the same analyses. A second question is how consumers allocate fixations across the two prices during the comparison process.

We also examine if and, if so, how eye movements are linked to the outcome of the comparison process, in particular the estimated magnitude of the price difference.

Procedure

We obtain eye-tracking data through a Tobii Pro TX300 oculometer at a 120-Hz frequency (accuracy: 0.4°, precision: 0.24°) at an academic lab located in a major French city, which we analyze using the BIT algorithm. The stimuli and answers were in French. The 40 respondents were recruited according to diversified age, gender, and occupation quotas. Ages varied from 20 to 80 years ($M = 45$, $SD = 17$); the sample included 20 women and 20 men; and 26 participants had jobs, 4 were looking for jobs, 6 people were retired, and 4 were students.

After four introductory slides, respondents had to read prices in six successive task conditions (web appendix A): (i) indicate by mouse-clicking the cheaper of two prices displayed on the left and right of the screen at the same ordinate (23 screens); (ii) the same task for two prices displayed on the top and bottom of the screen at the same abscissa (23 screens); (iii) read a price on a first screen, memorize it, then read a price on a second screen, and indicate whether it is cheaper than the first one (five pairs of screens); (iv) read two prices displayed on the left and right and judge how large the difference is by clicking on a continuous scale with the digits 1–7 as anchor points and the labels "negligible" (1) and "very large" (7) (22 screens) at the extremes; (v) the same task with two prices displayed on the top and bottom of the screen (22 screens); and (vi) read and memorize three prices displayed under three product pictures from the same category and then recall each price orally to the experimenter when shown the product picture on separate screens, in the same random order for all respondents (five successive sets of three products). Using the same criteria as in previous studies, we set aside six respondents who had 22% or more missing values in raw data.

To permit comparisons with studies 1 and 2, we mostly use prices with two euro digits and two cents digits (with a few additional prices with no cents part, which we do not analyze below; see web appendix). Since we wish to assess eye movements over a large variety of prices and price pairs, we manipulate both euros and cents.

A key finding of studies 1 and 2 is that consumers pay about as much attention to cents as to euros and have back-and-forth moves between them. Furthermore, we know from these studies that when asked to read a price aloud, consumers produce spontaneously a two-part verbal form, the verbalization of euros and then the verbalization of cents. Consumers may therefore, when comparing prices, compare the verbal forms of the euro parts and cents parts separately. The comparison process may then differ, depending on whether the two prices have identical euro parts. For example, we can expect fewer fixations on cents when the euros differ, since cents are not really informative for the comparison. According to the left-to-right reading account, they would not even be read. This needs to be verified empirically, and we therefore make sure that our stimuli include price pairs with identical euro parts (in which the comparison requires assessing both the euro part and the cents part) and pairs with different euro parts (in which an assessment of the euro parts could be sufficient).

Concretely, in each of tasks (i), (ii), (iv), and (v), we have, among the 20 pairs of prices with cents, 8 price pairs with the same euro part and 12 price pairs with different euro parts. We also vary the cents parts. This manipulation of both euros and cents produces, over the 40 price pairs for which participants have to estimate the magnitude of the difference, 34 different objective price differences, varying from 2 cents to 27.01 €, in percentages from 0.02% to 100.1% (web appendix C). Obviously, the objective price differences are smaller for pairs with the same euro part (varying from 2 cents to 99 cents) than for pairs with different euro parts (from 39 cents to 27.01 €). For tasks (i), (ii), (iv), and (v), the higher price is displayed on the left (top) in half the price pairs, and on the right (bottom) in the other half.

As in our previous studies, we exclude from the analysis the end part of the fixations that begin on one screen and end on the next screen. As in study 2, we also exclude first fixations on a screen, which miss the target, with a horizontal location of more than 1° (40 pixels) away from either of the two prices. This leaves for analysis 17,905 usable fixations on the price zones of the screens displaying two prices in tasks (i), (ii), (iv), and (v).

Eye Movements on Each of the Two Prices

For tasks (i), (ii), (iv), and (v), in which respondents had to compare two prices displayed simultaneously, we perform, separately for each of these prices, the tests from studies 1 and 2. Thus, we do not consider here the saccades through which consumers move their attention from one price to the other (we do it below). Table 5 presents separate results for the eight conditions defined by three fixed factors: the task (identify the cheaper price vs. estimate the magnitude of the price difference), the display (horizontal vs. vertical), and the price position (left or top vs. right or bottom). The results are consistent across conditions and replicate those from studies 1 and 2.

To examine if price reading requires one or multiple fixations, we ran an ANOVA with the number of fixations on the prices as a dependent variable and three fixed factors (task, display, position), with the participant as a random factor. The adjusted R^2 is 0.153 (vs. 0.091 with the random factor alone). The estimated number of fixations on each price varies from 2.49 to 2.98 when the task is to identify the cheaper price and from 3.24 to 4.44 when participants have to evaluate the magnitude of the price difference, in accord with the hypothesis of multiple fixations. A formal test of the difference of the number of fixations with 1, using a mixed analysis with the participant as a random factor, produces t-values varying between 9.82 and 22.73 over the eight conditions in table 5, with p-values below 10^{-13}. For task (iii), when consumers had to memorize the first displayed price, the number of fixations is considerably higher: 10.42 ($t = 20.49$, $p < 10^{-46}$), likely reflecting their memorization efforts.

Next, we test if the first fixation is on the leftmost digit (hypothesis 2a) or close to the center of the price (hypothesis 2b). We use the same standardized left-to-right indicator as above (0% at the left limit of the first euro digit, 100% at the right limit of the second cents digit). When the two prices are located on the left and right of the screen (horizontal display), the first location tends to be biased toward the center of the screen as in study 2: the indicator is at 58% or 68% (cents zone) for the first fixation on the left price, whereas it is at 44% or 26% for the first fixation on the right price. This tendency disappears for further fixations. It also is absent when the two prices are located above and below each other (vertical display): the first fixation is at the center of the price for price comparisons and slightly left of center for the magnitude-estimation task. Across the eight cases in table 5, the standardized left-to-right indicator over all fixations is always between 36% and 57%, close to the center of the price. For task (iii), we find similar results (indicator at 65% for the first fixation and at 51% across all fixations).

Contrary to the hypothesis of left-to-right reading (hypothesis 3a), saccades between consecutive fixations on the same price are not always from left to right. We use a mixed logit model predicting whether the saccade is left to right (1) or right to left (0), with display, comparison task, and price location as fixed factors and the participant as a random factor. For prices located on the left or on top of the screen (the prices that participants are observed to almost always read first), the estimated percentage of saccades that go from left to right is slightly below one half, between 36% and 38%. For prices located on the right or

TABLE 5

NUMBER AND LOCATION OF FIXATIONS AND DIRECTION OF SACCADES

(A) Results for tasks (i) and (iv) (horizontal price display)

Task		Left price zone	Right price zone
Which is cheaper?	Number of fixations (SE)	2.98 (0.084)	2.82 (0.084)
	Median location first fixation (standardized indicator)	58%	44%
	Median location all fixations (standardized indicator)	57%	49%
	% saccades from left to right between consecutive fixations	37%	55%
	% fixations right of comma	62%	50%
Assess price difference	Number of fixations (SE)	4.44 (0.084)	3.71 (0.084)
	Median location first fixation (standardized indicator)	68%	26%
	Median location all fixations (standardized indicator)	55%	36%
	% saccades from left to right between consecutive fixations	38%	56%
	% fixations right of comma	53%	41%

(B) Results for tasks (ii) and (v) (vertical price display)

Task		Top price zone	Bottom price zone
Which is cheaper?	Number of fixations (SE)	2.81 (0.084)	2.49 (0.084)
	Median location first fixation (standardized indicator)	47%	45%
	Median location all fixations (standardized indicator)	49%	50%
	% saccades from left to right between consecutive fixations	36%	54%
	% fixations right of comma	55%	43%
Assess price difference	Number of fixations (SE)	3.85 (0.084)	3.24 (0.084)
	Median location first fixation (standardized indicator)	41%	35%
	Median location all fixations (standardized indicator)	42%	38%
	% saccades from left to right between consecutive fixations	37%	55%
	% fixations right of comma	46%	34%

on the bottom of the screen, this percentage is slightly above one half, between 54% and 56%. As in studies 1 and 2, respondents pay overall a lot of attention to the cents part (46% of all fixations on prices).

Allocation of Eye Fixations across the Two Prices

To replicate studies 1 and 2, the analyses above examine separately eye movements on each of the two displayed prices. However, participants were asked to compare the two prices. A complete understanding of the price-reading process during a comparison task therefore requires also investigating the history of eye movements across the two prices, and its impact on the quality of the outcome: how well is the subjective estimate related to the actual price differences? (We cannot carry out the latter analysis for the task of identifying the cheaper of the two prices because participants identify it accurately in 99.1% of the cases.)

As indicated above, we manipulated both the euros and the cents of the price pairs. Consider first the impact of the euro manipulation on consumer attention. For each of four conditions (two displays, vertical/horizontal, and two comparison tasks, identify cheaper/evaluate magnitude), we have 8 price pairs with the same euro part and 12 price pairs with different euro parts. We expect fewer fixations on cents when the euros differ, since they are not really informative for the comparison (according to the left-to-right reading account, they would not even be read). We estimate a mixed logit using as fixed factors whether the euro part is different, display, comparison task, and price location, plus the participant as a random factor (table 6).

As expected, cents attract less attention when the euro parts are different ($z = -13.60$, $p < 10^{-15}$). Yet, they still attract a sizable percentage of fixations: 30–57%, depending on task, display, and price position. The effects of the three other factors (not reported in detail due to page constraints) remain similar to those obtained with the mixed logit above.

Furthermore, we observe that the proportion of fixations devoted to cents (vs. euros) varies over time during the reading process and that this variation depends on whether the two prices have identical euro parts. Respondents are free to choose to which of the two prices they will pay attention first. We observe that they typically make an initial series of consecutive fixations on the first attended price (such a series of consecutive fixations on a zone is called a "dwell" in the eye-tracking literature), before making a dwell on the other price, and then completing their information search with additional dwells on the two prices. Table 7 reports the probability of a fixation being on the euro digits (rather than on the cents digits), as estimated

TABLE 6

ESTIMATED PERCENTAGE OF FIXATIONS ON THE CENTS PART AS A FUNCTION OF TASK AND SIMILARITY BETWEEN EUROS

	Horizontal display (%)				Vertical display (%)			
	Which is cheaper?		Assess price difference		Which is cheaper?		Assess price difference	
	Left	Right	Left	Right	Top	Bottom	Top	Bottom
The two prices have different euro parts	57	44	49	37	49	37	41	30
The two prices have the same euro parts	69	57	62	50	61	49	54	42

TABLE 7

PERCENTAGE OF FIXATIONS ON CENTS FOR SUCCESSIVE DWELLS

	Predicted percentage of fixations on the cents part	
	Price pairs with different euros	Price pairs with same euros
First price dwell	47.8	48.0
Second price dwell	31.0	44.2
Third and further price dwells	15.8	28.7

by a mixed logit explaining this likelihood by two fixed factors—whether the euro parts are identical and the particular stage (dwell: 1, 2, 3+) in the reading process—and their interaction, with the participant as a random factor.

For the first dwell, the likelihood of fixating on the euro digits is similar (47.8% vs. 48.0%), regardless of whether the two prices have different euro parts or the same euro part ($z = -0.09$, $p = .93$). This can be explained by the fact that consumers cannot adapt their eye movements to the characteristics of a price pair before they have at least a first look at both prices. In the subsequent dwells, consumers adapt their information search to the characteristics of the price pair. In the second dwell (the initial series of consecutive fixations on the other price), there is already an interaction effect with a lower tendency (31.0% vs. 44.2%) to focus on the cents digits when the two prices have different euro parts than when they have the same euro part ($z = -9.10$, $p < 10^{-15}$). In further dwells (third and beyond), we observe the same interaction effect, 15.8% versus 28.7% ($z = -19.07$ $p < 10^{-15}$).

In summary, depending on whether or not the two posted prices have identical euro parts, consumers tend to allocate more of their eye fixations to the parts of the prices (euros vs. cents) that contain the more relevant information. This differentiated attention does not occur at the beginning of the comparison process (in the first dwell, the initial fixations) but occurs later, because the first two dwells allow one to identify where the useful information is so that the fixations in the second dwell and later (in the third dwell and beyond) can be directed there.

Evaluating the Magnitude of the Price Difference

Building on the results above showing the impact of euro similarity on attention, we now examine whether the link between the actual price difference and its subjective evaluation also depends on whether the two prices have the same euro parts. Dehaene's classical "triple code" model (1992) posits that a number perceived in visual code as a series of digits is automatically transcoded into two other forms: a verbal code and an analog code (a position on an underlying "number line"). The analog transcoding is a logarithmic (rather than linear) function of the original number. Accordingly, in the present comparison task, the analog code of each of the two prices should be a function of its logarithm. This leads us to expect that the perception of the price difference should be a function of the difference between the *logarithms* of the two prices, rather than of the raw difference between them. To check this expectation, we plot in figure 4 the average estimated magnitude of the price difference (ordinate) against the actual price difference in euros (abscissa), for each of the 34 objective price differences in our sample (varying from 2 cents to 27.01 €). This aggregate graphical analysis indeed confirms that the scale score varies as a logarithmic, rather than linear, function of the actual price difference.

We already know that, while participants acquire information on both parts of the prices (table 5), they acquire more information on the part that is more relevant to compare the prices: the euros when the euro parts differ, the cents when the euros are identical (tables 6 and 8). This difference in information acquisition suggests that, similarly, the process of subjectively estimating the magnitude of the price difference, and its outcome, should differ depending on whether euros differ or are identical.

To test this empirically, we use a mixed model that can detect such a difference, if it exists. The dependent variable in this model is the subjective estimated magnitude on the 1–7 scale, and the independent variables include the actual difference between the logarithms of the two prices, but also two predictors that together could detect the effect of the euro similarity: a binary indicator (1 if same euros, 0 if not) and its interaction with the difference between the log prices, with the participant as a random factor. Table 8

FIGURE 4

MAGNITUDE ESTIMATION IN FUNCTION OF ACTUAL PRICE DIFFERENCE

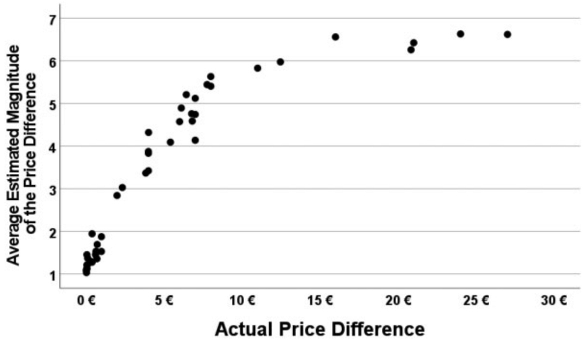


TABLE 8

MIXED MODEL COEFFICIENTS FOR MAGNITUDE ESTIMATION

Type of price pair	Constant			Difference between log prices		
	Beta	*t*	*p*	Beta	*t*	*p*
Same euros	1.16	8.32	$<10^{-10}$	24.40	3.92	$<10^{-4}$
Different euros	3.04	22.54	$<10^{-24}$	6.02	35.92	$<10^{-200}$

shows, as expected, that the mixed model coefficients differ depending on when the euros are identical or different.[1] The gap between them is 1.88 ($t = 22.30$, $p < 10^{-94}$) for the coefficients of the constant term and 18.38 ($t = 2.95$, $p = .0032$) for the coefficients of the difference between the log prices.

Of course, one should be very cautious when comparing the two sets of coefficients because the key predictor, the actual difference between the logs of the two prices, varies from 0.008 to 0.69 across pairs with different euros, but only from 0.00035 to 0.030 across pairs with the same euro values; there is therefore little overlap between the two series of price differences. Nevertheless, the coefficients obtained separately for the two conditions produce consistent predictions in the following sense: the dependent variable (the subjective magnitude estimate on the 1–7 scale, predicted using the coefficients above) takes values dispersed over most of the scale range (between 3.08 and 7.21) when the euro parts differ, but it takes values on a narrow range at the bottom of the scale (between 1.16 and 1.88) when the euro parts are the same.

These coefficients have an interesting implication regarding the effect of nine-ending prices. Consider two pairs of prices with a one-cent difference: one with the same euro parts (48.00 and 48.01[2]), the other with different euro parts (47.99 and 48.00). Based on the coefficients above, the predicted magnitude estimate would be 1.16 for the former pair, but 3.04 for the latter. Consider another example, with a 99-cents difference: the predicted magnitude estimate would be 1.66 when the euro parts are the same (47.00 and 47.99), but 3.16 when they differ (47.60 and 48.59). This generalizes to all possible actual price differences between 1 and 99 cents: the estimated coefficients suggest a tendency to generate a subjective estimate of the price difference in a higher range of the scale when the euros differ than when they are the same. Such a tendency could provide an alternative mechanism to explain the left-digit effect, according to which nine-ending prices are perceived to be significantly lower than prices that are one cent higher (Thomas and Morwitz 2005). Obviously, more research is needed to confirm and further examine this tendency for other ranges of prices. We analyze price pairs with two euro digits with either identical or different euro parts, whereas Stiving and Winer (1997) analyze prices below one dollar, and Thomas and Morwitz (2005) analyze prices with a single dollar digit that differs across the two prices.

We also observe a second phenomenon in the magnitude estimations: consumers in our sample react with a higher sensitivity to an increase of the explanatory variable (the difference between the logs of the two prices) when the two prices share the same euro part (beta = 24.40) than when the euro parts differ (beta = 6.02). It is as if consumers have developed a "bifocal magnifying lens": the lens that assesses an increase in the difference between two prices that have identical euro parts has a higher magnification factor than the lens that assesses the same increase in the difference between two prices that have different euro parts.

All these results are consequences of the equal overall attention paid to cents and euros—a key finding of this article—in combination with consumers' differentiated allocation of attention to euros and cents, depending on whether the two prices share the same euro part.

Another Impact of the Cents Part: Accuracy of Price Recall

In task (vi), we examine the possible effect of the attention to cents on price memorization. Consumers see simultaneously three product icons from a category with their prices, after being told that they would be asked to recall these prices. They then see the icons successively, one by one, in a different order, and are asked to recall the corresponding prices. We manipulate the complexity of the

1 We replicate the mixed model estimation by inverting the binary coding to obtain both lines of coefficients in table 8.

2 We use 47 € and 48 € as examples, as they are closest to the average euro value in stimuli for study 3.

cents part of the three prices: no cents part (00 posted in one condition, no posted cents in another), a condition with a simple cents part (just one syllable in French, e.g., 10), and two conditions with a complex cents part (four or five syllables, e.g., 78 or 99). We estimate a mixed logit explaining recall accuracy (1 accurate, 0 inaccurate) by the complexity of the cents part and the order in which the icons are shown for recall, with the participant as a random factor. The estimates of the fixed effect of cents complexity are 88% of correct recall for prices with no cents part, 61% for prices with a simple cents part, and only 24% for prices with a complex cents part. These results provide additional evidence that the cents digits are read and, moreover, that their complexity affects recall performance. Study 4 tests this impact of cents reading on price recall in the natural setting of store shopping, with no advance warning of the recall test.

Main Findings

When comparing two prices to identify the cheaper one or to assess their difference, consumers read each of them largely in the same way they read single prices without a precise objective: they pay separate attention to euros and cents, with cents receiving on average 47% of the fixations. Furthermore, they pay less attention to the cents parts of the two prices when their euro parts differ than when they are identical. Relatedly, results on the subjective estimate of the magnitude of the price difference show that, while this estimate always depends on the difference between the logarithms of the two actual prices, the precise form of the relationship (represented by the mixed models' coefficients) differs markedly depending on whether the euro parts of the prices are identical or not. Importantly, we find that consumers, when they estimate the price difference on the 1–7 scale, use a different, lower and narrower part of the scale if the two prices have the same euro part than if they have different euro parts. In this narrower range, however, they react more strongly to variations in the price difference.

DISCUSSION OF STUDIES 1–3

When consumers read a price, their eye movements (saccades) and fixations follow an original pattern that does not match either the left-to-right hypotheses suggested by consumer behavior research or the alternative predictions stemming from studies on word reading and object viewing in cognitive psychology. Instead, we find that reading a price implies multiple fixations even for the shortest prices (single euro digit and no cents). Thus, the number of fixations when reading a price is much greater than when reading a word in a text or recognizing an isolated word or object. The number of fixations is smallest when asking consumers to read the price in silence, "as you would in a store." It increases markedly when they read the price aloud, when they need to judge how large the difference between two prices is, or when they memorize prices. Even if the number of fixations and process duration vary markedly across tasks, the pattern of saccades remains the same, with alternating saccades over the two parts of the price. When making judgments or memorizing, the eyes keep fixating in the price zone, suggesting that when the brain is engaged in other mental operations while reading, the posted price may serve as an external memory store.

When the price is posted directly in front of the participant in the center of the screen or always at the same horizontal position (with only variations in the ordinate), the average location of the first fixation is not on the first digit but between the first third and the middle of the posted price. This is consistent with the concept of an optimal landing position for reading an isolated word or object (van der Linden and Vitu 2016).

Saccades between consecutive fixations are not organized left to right. When reading a price with cents, the first saccade (from the first fixation on price to the second) instead mostly occurs from right to left. Over all saccades, we observe a pattern of counterbalancing moves, in which moves to the left are as frequent as moves to the right. These saccades have large absolute lengths, corresponding to the width of two or three posted digits, which contradicts the idea of reading one digit after the other. Further contesting this digit-by-digit account, the number of fixations and the total reading time are not proportional to the number of digits.

In contrast with the first fixation, which has its mode in the center, fixations beyond the first two have a bimodal distribution, with the two modes on the euro part and on the cents part, but few fixations on the center of the posted price. Across all fixations, people attend to cents as much as to euros, which is surprising considering their relatively smaller economic value.

Finally, when the price is posted on the left or right of the screen, rather than just in front of the participant, we often observe that the first fixation on the screen is not yet located on the price itself and remains closer to the center of the screen. Even when it lands on the price, it is skewed toward the center of the screen, offering an example of the central bias (Tatler 2007).

STUDY 4: HOW CENTS INFLUENCE PRICE ENCODING IN THE STORE

The most surprising result of our eye-tracking studies is that cents attract about as much attention as euros, despite their comparatively limited economic importance. In this study, we seek to identify the possible role in price encoding of this attention paid to cents. During the reading process, the price elements displayed visually as digits are encoded in verbal form in short-term memory. We rely on previous research in cognitive psychology and consumer behavior to develop hypotheses about the role of the cents part of prices in that process, as reflected in the price as memorized and reported by consumers. The related predictions cannot be tested with eye tracking, so we instead analyze in-store data by asking consumers, unexpectedly, to report the price of a product they have just put in their shopping cart. Their answer is the best possible measure of the encoded price that just informed their purchase decision.

Conceptual Framework and Hypotheses

Reading a price posted in visual code (Arabic numerals plus points or commas) involves transcoding it to both an analog code and a verbal code, even if the latter is not spoken aloud but remains subvocal (Dehaene 1992). During this process, people suffer the general limitations of the phonological loop, a component of working memory needed to store and rehearse verbal information, such that they generally "are able to remember as many words as they can articulate in two seconds" (Baddeley 2012, 8).

For prices, Vanhuele et al. (2006) found that for a constant number of Arabic digits, each additional syllable in the verbal form of a price decreases the chances of accurate immediate recall, even in ideal learning conditions in the lab. This should also occur in more difficult real shopping situations. On the basis of the results in studies 1–3, we predict that consumers fixate attention on the cents part and attempt to transcode it in verbal form. Thus, actual prices in which cents have a longer verbal form (in the number of syllables) should be less likely to be transcoded accurately.

> **H4:** The length of verbal forms of the actual cents part has a negative impact on the probability of accurate memorization of the full posted price.

Note that the left-to-right approach leads to an opposite hypothesis: consumers would ignore the cents part from the outset (e.g., retaining the 3 from prices like 3.99, 3.37, or 3.01 and neglecting 99, 37, or 01). If that is the case, the verbal length of the cents part should have no effect on the probability of reporting the price accurately.

Hypothesis 4 entails a corollary. If limitations of the phonological loop make accurate memorization less likely for prices with longer cents parts, then inaccurate substitute price reports should be easier to memorize than the corresponding actual prices, because they would be shorter. This corollary is easy to test empirically. If verified, it would be consistent with the principle of least effort, namely, "The work of uttering a longer word is greater than the work of uttering a shorter one" (Zipf 1949, 63), and we could extend this notion to cases in which consumers process and memorize prices without uttering them aloud.

A simple way to shorten the verbal length of a price is to round it either to the lower euro (e.g., 7 € for an actual price of 7.55 €) or the upper euro (e.g., 8 €). Does the actual cents part influence whether the rounding moves up or down? In a left-to-right theoretical view, many consumers would round to the lower euro, because they read and remember the posted euro value while ignoring the cents part. Other consumers might always round up, independent of the cents value, perhaps to stay within budget (Van Ittersum, Pennings, and Wansink 2010). But in either case, the actual cents value would have no impact. In contrast, if consumers process the cents part of the posted price, the probability of rounding up should increase with its value. Formally:

> **H5:** When the posted price is rounded to the euro above or below, the probability of rounding up (vs. down) increases with the value of the posted cents part.

In another form of shorter, inaccurate memorization, shoppers may report the true euro value while reporting erroneously the cents part as a multiple of 10 cents. As in English, in French, multiples of 10 always have a shorter verbal length than cents values ending with a non-zero digit. We can therefore develop a similar hypothesis.

> **H6:** When the cents part of a posted price is rounded to a multiple of 10, the value of the encoded cents part increases with the value of the actual cents part.

Methodology

To assess how shoppers encode and memorize prices in the store, the most valid procedure is to interview them immediately and unexpectedly just after their product choice. Dickson and Sawyer's (1990) in-store, in-aisle research protocol meets this criterion and has been applied by various authors, including Wakefield and Inman (1993), Vanhuele and Drèze (2002), and Jensen and Grunert (2014). Researchers randomly intercept consumers just after they have put an item from the product category of interest in their shopping cart and ask about the price of that product (without allowing respondents to look at the price tag). Obviously, it is possible to interview each consumer only once, about a single product. The random selection is obtained by skipping, between two interviews, a fixed number of category shoppers. Consumers may report the actual price accurately or inaccurately or provide no answer. This protocol thus leaves shoppers free to not to look at the price.

We obtained data from eight separate in-aisle price-knowledge studies, each pertaining to a specific product, carried out in France by a major market research company, all using this same protocol (4,373 observations).

Respondents were first asked to identify the brand and size (or volume) of the product and to indicate whether it was on promotion or not. The price-recall question then followed. Due to the random selection of respondents, we can treat this sample of observations as the result of a series of natural experiments with a representative sample of products and prices in each category. We excluded 31 observations from the initial 4,373 (0.7%), because the ratio of the reported price to the actual price was either greater than 10 or less than 0.12. This gap probably reflects transcription errors: 30 of these 31 observations came from 2 studies and generally follow each other in the data file.

The actual prices, in euro, differ in their verbal length, the number of digits, the presence of round endings, and so forth (table 9). Following Vanhuele et al. (2006), we measure the verbal length of the prices by the number of syllables.

Results

Among 4,342 usable observations, 1,176 shoppers report the actual price accurately (40.9%), 1,863 provide an inaccurate report, that is, a price that differs from the one posted (42.9%), and 703 shoppers provide no report (16.2%). These values are similar to those in Dickson and Sawyer (1990), that is, 47%, 32%, and 21%, respectively.

Does the Likelihood of an Accurate Report Depend on the Verbal Length of the Cents Part?. To answer this question, we estimate a logistic regression in which the dependent variable is report accuracy (1: accurate, 0: inaccurate or no report), using as predictors the verbal lengths (number of syllables) of the cents part and the euro part. The global fit is significant ($\chi^2 = 20.27$, 2 d.f., $p < 10^{-4}$). The probability of an accurate report indeed decreases with the length of the cents part ($\beta = -0.087$, Wald $= 12.05$, $p < .001$), supporting hypothesis 4. Thus, posted prices have a higher chance of being memorized accurately when their cents parts have a shorter verbal form. The length of the euro part also has a negative influence ($\beta = -0.208$, Wald $= 8.07$, $p = .0045$). These effects are even stronger when we set aside non-responses in the analysis (1: accurate report, 0: inaccurate report).

This effect of the verbal length of the actual cents part entails the expected corollary that the average length of the inaccurate price reports ($n = 1{,}863$) is only about half the length of the corresponding actual prices: 2.01 syllables versus 3.91 (paired comparison $t = -46.00$, $p < 10^{-220}$). In these inaccurate responses, the reported cents part is shorter than the corresponding actual cents part by almost two-thirds: 0.98 syllables versus 2.88 ($t = -46.71$, $p < 10^{-220}$). In contrast, the average number of syllables in the euro part remains exactly the same, at 1.03.

Inaccurate Reports "Clean" the Cents Values. Shoppers report the posted cents part much less accurately than the euro part. The 1,863 inaccurate reports of the full price include 687 (36.9%) inaccuracies in both the euros and cents, 1,152 (61.8%) inaccuracies in only the cents, but just 24 (1.3%) inaccuracies in only the euros. Thus, among inaccurate reports, the cents part is inaccurate 98.7% of the time.

How are these inaccurate cents values generated? If they were due to errors, they should be the sum of the actual cents value plus a (presumably random) error term, leading to a diversified distribution of inaccurate cents reports. We observe a completely different pattern instead: a strong migration from complex to simple values. Figure 5, over the 1,863 inaccurate cents reports, compares the histograms of the actual cents values (panel a) and the corresponding inaccurate reports (panel b; note the different ordinate scales for this panel).

It is much more frequent for inaccurate cents reports than for the corresponding actual cents to end by a zero: 85% versus 20%. Notably, a "00" cents part appears in 59% of inaccurate reports versus in 1.2% of the corresponding actual prices. Values that are multiples of 10 also occur more frequently in inaccurate reports than in the actual prices. In turn, more complex cents values, with last digits other than zero, diminish in frequency: from 9% to 1.8% for psychological prices (95 and 99) and from 70% to 13% for the other values.

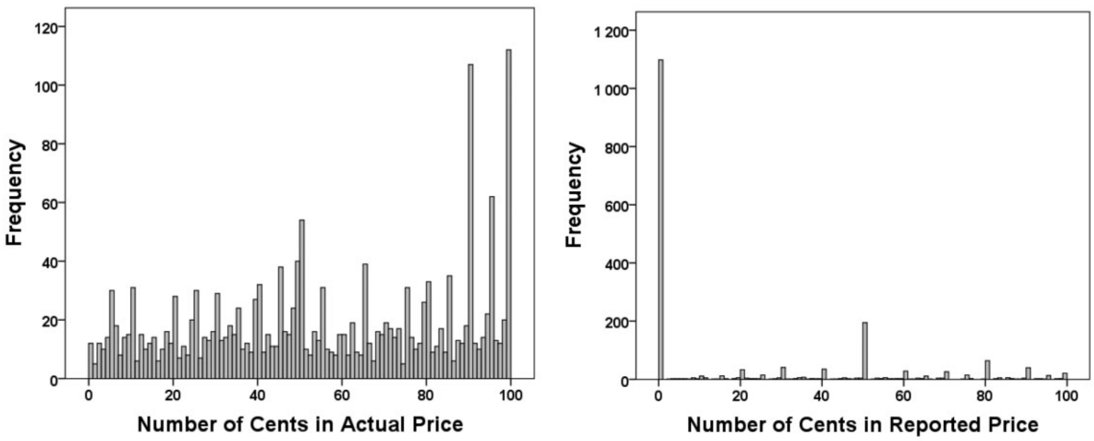
TABLE 9

PRODUCT CATEGORIES AND DESCRIPTIVE STATISTICS OF PRICE

Product category	Median price	Minimum price	Maximum price	% of prices with 2 (vs. 1) euro digits	Mean number of syllables in price	% of prices with 00 cents part	% of prices with 95 or 99 cents part	Number of observations
Candy	7.53 €	3.11 €	18.36 €	26	4.04	0	3.0	297
Cleaning products	5.77 €	1.43 €	17.76 €	28	4.00	5.3	2.6	408
Gardening	6.50 €	1.07 €	57.99 €	23	3.75	2.9	18	800
Crackers and chips	1.25 €	0.40 €	4.86 €	0	3.13	2.2	8.7	218
Soft drinks	1.52 €	0.09 €	12.30 €	0.2	3.37	2.8	3.8	843
Facial care	4.48 €	0.41 €	15.56 €	11	3.93	0	6.5	567
Pet food	2.61 €	0.03 €	22.82 €	3.7	3.57	0	0	965
Ink cartridges	20.90 €	2.00 €	78.45 €	92	5.61	2.9	23	244

FIGURE 5

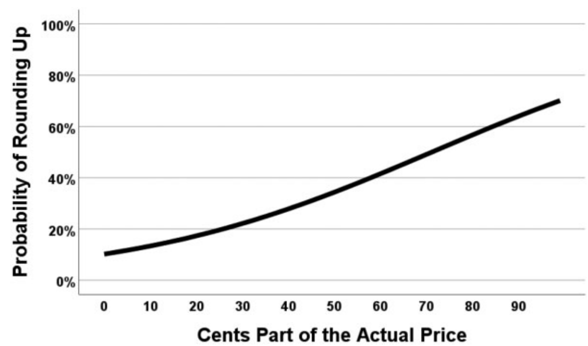
COMPARISON OF ACTUAL AND REPORTED NUMBER OF CENTS IN INACCURATE PRICE REPORTS



Value of the Actual Cents Part Influences Whether Rounding Occurs Up or Down. Rounding up or down to the next euro represents a large share (49.3%, $n = 918$) of the inaccurate reports. Among them, rounding down is more frequent (28.6%) than rounding up (20.7%). We use a binary logistic regression on these 918 cases to test whether the probability of rounding up depends on the value of the actual cents part (1 if rounding up, 0 if down). The overall result is significant ($\chi^2 = 164.70$, 2 d.f., $p < 10^{-35}$). As predicted (hypothesis 5), the probability of rounding up increases with the value of the posted cents ($\beta = 0.031$, Wald $= 135.39$, $p < 10^{-30}$). Figure 6 displays the estimated probability of rounding up as a function of the value of the actual cents (for a value of the actual euro part that is equal to its empirical average in the sample).

FIGURE 6

PROBABILITY OF ROUNDING UP AS FUNCTION OF ACTUAL CENTS PART



In a further 21.8% of inaccurate reports ($n = 406$), the euros are accurately reported, but the reported cents are, inaccurately, multiples of 10. If shoppers did not process the actual cents part, it should have no impact on which inaccurate multiple of 10 they report. Instead, there is a strong positive impact of the actual cents on the reported cents, as shown by a linear regression of the latter on the former on these 406 cases (adj$R^2 = 0.402$, $\beta = 0.512$, $t = 16.39$, $p < 10^{-45}$), while the actual euros have no impact ($t = -0.12$).

Discussion of Study 4

Influence of the Cents Part. The three eye-tracking studies indicate that the cents part of prices attracts as much attention as the euro part; study 4 affirms the influence of this cents part on price encoding and memorization. First, in line with the established limitations of the human phonological loop, shoppers are more likely to report posted prices accurately if they have a shorter cents part (i.e., fewer syllables in verbal form). Second, when shoppers report the price inaccurately by rounding it to the euro above or below (49% of erroneous reports), the likelihood of rounding up increases with the value of the actual cents part. Third, if they report the euros accurately but the cents inaccurately as a multiple of 10 cents (22% of erroneous reports), the actual cents value influences the inaccurate report positively. All three of these influences require shoppers to process the cents part.

Thus, processing the cents part of prices does not equate with memorizing them perfectly as posted. Conversely, not memorizing cents perfectly does not imply they are not being processed or are not affecting the memorization output. In a sort of paradox, the form of the inaccurate report of the cents part offers proof that it is being processed, because the true form of this part influences the erroneous outcome.

Efficiency and Validity of Memorized Prices. Given the high observed frequency of inaccurate price reports (49.2%), a key question remains whether, and if so to what extent, these inaccurately memorized prices offer a reliable basis for consumer decisions. To offer a valid basis, they must be close enough to the actual posted prices. To answer this question empirically, we compute the correlation between the inaccurate report and the corresponding actual price. Over all inaccurate reports, we observe an almost perfect agreement ($r = 0.952$, $n = 1{,}863$, $p < 10^{-220}$; figure 7). If we remember that, in addition, 40.9% of the reported prices are perfectly accurate, we can compute that, over both accurate and inaccurate reports, the correlation between the actual and encoded price is 0.968. Thus, both types of report provide shoppers with a reliable, useful basis for their purchase decisions. This is made possible by the role of the cents part in price reading and encoding.

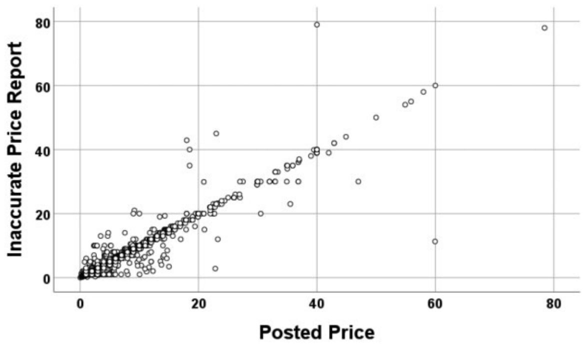
CONTRIBUTIONS AND FURTHER RESEARCH

Most previous consumer research on price processing rests on the assumption that price reading proceeds from left to right. This intuitive assumption is based on indirect empirical support in a study by Poltrock and Schwartz (1984), who used response latencies to infer reading patterns for multidigit integers. We use eye tracking to produce a direct analysis of price reading and show that it actually has its own peculiar, fairly complex pattern.

The most striking element in this pattern is that the cents part of prices (or more generally the right part) receives an unexpected amount of visual attention. This attention to the cents part then influences how people encode the price verbally and, specifically, whether and how they simplify it to shorten the verbal code in memory. It is this encoded price that then informs their purchase decision. Based on our findings, we first propose a theory of price reading and verbal encoding and then summarize more specific contributions to knowledge about consumer behavior.

FIGURE 7

INACCURATE REPORTS VERSUS ACTUAL PRICES



Price Reading and Verbal Encoding: A Novel Theory

A price is displayed in visual code as a series of Arabic digits, completed by points, commas, blank spaces, and often currency symbols, like € or $. When using this posted price in decision-making, consumers transcode it, as they transcode numbers in general, into both a verbal form and an analog form. Previous research documents limitations to human short-term memory (Baddeley 2012) and vision (Becker and Fuchs 1969; Holmqvist and Andersson 2017; Meyerhoff et al. 2012; van der Linden and Vitu 2016) that constrain the execution of verbal transcoding, but also abilities that mitigate the limitations, acquired in human activities unrelated to price reading.

Combining previous research with our empirical results, we advance a theory of price reading and verbal encoding as a six-step process that requires multiple visual fixations.

1. Locate and fixate on the price. The first fixation on a price tends to be near its middle, though it may be preceded by a preliminary, off-target fixation if the angular move from the previous fixation is great. In addition, the first fixation on the price is more likely to be on the right (left) part if that price is positioned to the left (right) of the consumer's view (central bias, Tatler 2007). In a store or on a computer screen, this bias may occur if the price tag is located on the left (right) of the consumer.
2. Identify the visual structure of the price. Are the digits organized in subgroups separated by commas, points, blank spaces, or currency units? In particular, does the price include a cents part? This identification may be facilitated by the middle position of the first fixation on price.
3. Transcode the digits in verbal form, with separate verbal forms for different digit subgroups. For example, when cents are present, separate verbal forms refer to euros (or dollars) and cents, consistent with the bimodal distribution of fixations.
4. Identify if the verbal transcode is short enough to be encoded as such or if a shorter substitute is necessary. This identification requires a knowledge of all parts of the price, which makes it functional to give cents the same attention as euros.
5. If necessary, create the shorter verbal substitute. For prices with cents, the cents part is the prime target for simplification. If shorter substitutes are to offer a valid basis for consumer decisions, they must correlate with actual prices. Study 4 reveals an extremely high correlation over a large sample of

prices with cents below 100 €. Lacking empirical data for very large prices with no cents part, we speculate that a similar process would occur, abbreviating mainly the rightmost, least important economically, part of the price.

6. Encode the result, either the accurate verbal transcode or the shorter substitute.

During this process, and associated cognitive tasks based on the price (like magnitude estimation of price differences that involves the analog code), the eyes typically remain fixated on the displayed digits or close to them. These fixations may play the role of an external memory store, useful for the associated cognitive task.

Other Contributions

Explaining the Underestimation of Psychological Prices. The effective and pervasive use of psychological prices (e.g., 99 as a cents part) by retailers, which has intrigued consumer researchers (Schindler and Kirby 1997) and sparked different explanations (Stiving and Winer 1997; Thomas and Morwitz 2005), is commonly attributed to an underestimation of those prices by consumers, often explained by left-to-right price reading. Our study finds support for three different mechanisms leading to such an underestimation.

The first mechanism is revealed in our results on magnitude estimation (study 3). We find that consumer estimations of the magnitude of a price difference depend on whether the two prices to be compared share the same euro part: the estimated magnitude is always larger when the euros differ than when they are the same. Thus, a one-cent difference will be perceived as larger if it entails a one-unit change in the euro part than if it does not.

The second mechanism derives from the result that prices with a more complex cents part are less likely to be encoded accurately and more likely to be rounded (study 4): for example, a price like 24.00 is most likely to be encoded perfectly, because its verbal form is extremely short (two syllables in French), whereas 23.99 is likely to be rounded, because its verbal form is long (seven syllables in French). When rounding, the consumer is more likely to round down (figure 6). Moreover, when rounding up a price ending in 99, the consumer overestimates the price paid by just one cent; when rounding down, the consumer underestimates it by 99 cents, a much larger error.

Third, it is often asserted that there is an image effect, according to which consumers have learned that a 99 ending signals a “good deal” (Schindler 2006; Snir and Levy 2021). For this effect to occur, consumers must detect this signal, that is, they must read the cents part of the posted price. A theory of left-to-right reading assumes that consumers often read only the left part of a price and neglect the rest: they would then not notice the 99 endings. In contrast, our key result, that cents are always attended to, indicates that consumers will always detect a 99 ending.

It is important to note that these three mechanisms are not in conflict with the evidence in previous research on the left-digit effect (Sokolova et al. 2020; Thomas and Morwitz 2005), which proposes still another mechanism, in the specific case of a one-cent price difference that leads to a one-unit change in the dollar part.

Effects of Price Precision. In study 2, we observed that attention to the right half of prices is not limited to prices with a decimal part but also applies to prices with up to seven digits. This finding may explain the existence of phenomena such as the price precision effect (buyers underestimating the magnitude of precise prices, like 395,425, compared to round prices like 395,000; Thomas, Simon, and Kadiyali 2010) or the positive impact of price roundedness on product evaluations (Wadhwa and Zhang 2015), which could not occur if the right half of long prices were not read.

Complex Prices and Consumer Welfare. The left-to-right price reading account implies that consumers will fall prey to the effect of psychological pricing if they do not make the extra effort of reading the cents part after the left digits. We show that in fact consumers devote as much attention to cents as to the left part and that it is the complexity of the cents part in psychological prices that generates inaccurate price encodings.

What we propose to call the “*hidden margin*” is this difference, when it exists, between the actual price, which retailers pocket, and the encoded price, which informs the consumer purchase decision. Such a difference occurs in about 40% of cases (42.9% in study 4), and consumers in all likelihood are not aware of the effect. Our analysis of price rounding reveals a hidden margin of 16 cents. Compared to an average price of 8,34 €, this amounts to 1.9%. Supermarket net margins at the time of our study were between 1% and 2% (Thoron 2019).

From a public policy perspective, our results suggest the potential value of regulating unnecessarily complex prices, such as those whose verbal form is very long while differing by only a negligible amount from a simpler round price just above them. Along these lines, regulation in Israel imposed “a legal change, effective on January 1, 2014, [that] prohibited using prices with non-zero endings (e.g., 5.99; 10.45), and only allowed the use of prices with ‘round,’ zero-endings (e.g., 7.60)” (Ater and Gerlitz 2016, 3). Our study also suggests combining two practical measures to guide the implementation of such a regulation, namely the difference between the number of syllables in the posted price and in the round price just above it, and the percentage difference between the values of these two prices.

Contributions to Numerical Cognition. A review of 45 eye-tracking studies involving numerical cognition (Mock et al. 2016) does not mention any studies of reading Arabic numbers as such. Most research on numerical cognition focuses on integer numbers, whereas in this article we analyze the treatment of numbers with decimal parts, separated from the integer component by a comma or point. Prices are a special but prevalent type of such numbers, and consumers face them constantly. Moeller et al. (2009) and Meyerhoff et al. (2012), as noted previously, display long series of digits with no separators and no preliminary understanding that the digits are parts of a price, whereas such an understanding likely guides reading in our case. Plus, they examine comparisons of multidigit numbers, not "pure" reading.

Another original contribution to numerical cognition is to reveal the differentiated and contingent verbal treatment of the integer part and the decimal part. This separate treatment confirms the chunking hypothesis of Meyerhoff et al. (2012).

In a different vein, we show consumers' ability to create substitute numbers that make memorization easier. This ability to simplify prices efficiently performs a function similar to ordinary people's ability to develop constantly abbreviated forms of common words (Cerquiligni 2019). Both are examples of the principle of least effort (Zipf 1949).

Dehaene (1992) proposed a "triple code" theory of the encoding in verbal and analog forms of numbers displayed visually as a series of digits. We extend this theory in two directions. First, we consider prices with euros and cents, instead of integers. Consumers asked to read a price aloud spontaneously create a double verbal code, for euros and for cents (studies 1 and 2), and study 4 shows that the length of the cents verbal code impacts the probability of reporting the price accurately. Second, Dehaene shows the logarithmic nature of the analog code of natural integers. Using numbers with a decimal part, we show that the subjective estimate of a price difference varies with the difference between the logarithms of the two prices (study 3).

Methodological Contributions. Our study is among the first to use eye-movement recording to examine the cognitive processing of prices. (Hodges and Chen [2022] already used the method to examine the effect of numeracy on price processing.) In addition, we demonstrate the benefits of precise analyses (at the pixel level) of fixations and saccades for eye-tracking data. Many of our findings would not have surfaced with analyses using the more frequent and convenient technique of predefining "Areas of Interest." These findings include results on the respective positions of stimuli and fixations, the bimodal distribution of fixations, and the exact length of saccades. We propose new practical indices, graphs, and statistical tests to summarize the fixations and saccades associated with reading and encoding a price.

We also demonstrate the benefits of investigating what might appear to be "errors" by consumers. Analyzing the discrepancies between an observed inaccurate consumer answer and the true value of a price can reveal at least partly the cognitive mechanisms underlying price encoding. Analyzing other types of consumer "errors" could prove equally fruitful.

Further Research

Price reading is a more complicated process than previously thought, so more research is needed to understand it, especially considering the challenge we issue to existing theoretical bases. We present two possible ideas for further consideration—first, a top-down effect: knowing the type of number that needs to be processed likely changes the way people process it. Our respondents knew that the posted sequence of four digits was a price, with a euro part and a cents part separated by a comma, and accordingly, they processed it in the very specific, well-adapted manner we describe. The processing might have been different if the number to read had a different substantive meaning (Santana, Thomas, and Morwitz 2020). Researchers might examine, for example, the treatment of large cardinal numbers when they are always multiples of 1,000 (e.g., altitude in feet) versus ending with non-zero digits (e.g., the exact number of COVID deaths in a country). Other potentially useful questions include how people process percentages that include a decimal part, such as an unemployment rate of 14.7% or a Dow decrease of 5.32%, and how these processes differ from the benchmark case in which all digits are equally important, as in a phone number.

Second, we propose that shoppers have developed a reliable and efficient ability to encode and memorize prices, which allows them to cope with the limitations of the phonological loop. It would be interesting to analyze how young people acquire this ability as they come of age and gain shopping experience. As a related public policy question, researchers might determine whether older people lose this ability as they age or retain it as a form of "crystallized intelligence" (Horn and Cattell 1967).

DATA COLLECTION INFORMATION

The two authors designed the data collection protocols for studies 1–3. The data for study 1 were collected in July 2018 by a research assistant at the HEC Paris eye-tracking lab, Jouy-en-Josas, France, under the supervision of the second author. The data for study 2 were collected in January 2019 by the first author at the same HEC Paris eye-tracking lab. The data for study 3 were collected in May 2021 at the INSEAD/Sorbonne Université behavioral

lab, Paris, France, by research assistants under the supervision of the first author. The eight data sets for study 4 were collected by IRI France between 2005 and 2009 for different clients and made available to the authors by Frédéric Nicolas, director Shopper Insights, IRI France. The data were analyzed by the first author, in constant interaction with the second author. All data are stored on the Open Science Framework.

APPENDIX

OVERVIEW OF EYE-TRACKING STUDIES 1–3

Study	Condition in study	Number of prices on screen	Type of price	Position of price on screen	Task	Replicates
1	1	1	2 + 2	Center	Read in silence “as in a store”	8
	2	1	No cents	Center	Read in silence “as in a store”	10
	3	1	2 + 2	Center	Read aloud	8
	4	1	No cents	Center	Read aloud	10
	5	1	2 + 2	Center	Is price above/below 50 €?	4
	6	1	Euros and cents	Center	Is price “psychological”?	4
2	1	1	2 + 2	Left, center, or right §	Read in silence “as in a store”	12
	2	1	No cents	Left, center, or right §	Read in silence “as in a store”	21
	3	1	2 + 2	Left, center, or right §	Read aloud	12
	4	1	No cents	Left, center, or right §	Read aloud	21
	5	1	2 + 2	Center	Is price above/below 50 €?	8
	6	1	2 + 2	Center	Estimate total cost for three units	8
3	1	2	2 + 2*	Left and right	Which price is cheaper?	23
	2	2	2 + 2*	Top and bottom	Which price is cheaper?	23
	3	1	2 + 2*	Center	Memorize the price then compare to price on next screen	5
	4	2	2 + 2*	Left and right	Judge magnitude of price difference	22
	5	2	2 + 2*	Top and bottom	Judge magnitude of price difference	22
	6	3	2 + 2*	Left, center, and right	Memorize the prices of three products then recall when cued with each product	5

NOTES.— 2 + 2 indicates a price with 2 euro digits and 2 cents digits; 2 + 2* indicates mostly prices with 2 euro digits and 2 cents digits, but a few prices with no cents; and § refers to prices presented in the same random position (left, center, or right) to all participants.

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