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Count on the €uro! Interference between the size and the value of the coins in the judgment of the monetary value

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ABSTRACT
Coins are used for everyday economic exchanges. The present work examines the relation between the size and monetary value of coins within large coin sets. European participants were asked to decide whether the monetary sum of a set of euro coins was smaller/larger than a given reference value. The results showed that this monetary value judgment was improved when the semantic information of the coins was congruent with their visual size in the real world, compared with judgments based on incongruent (uniform or inverted) information. Distinguishing between units (€0.01, €0.02, €0.05), tens (€0.1, €0.2, €0.5) and mixed categories, we further found that the size congruency effect depended on stimulus characteristics. The positive correlation between coin size and value, leading to improved monetary judgments, supports the existence of a sensory integration of the monetary and physical properties of coins.

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KEYWORDS
Number sense; enumeration; estimation; money; judgement task

The processing of numbers and numerical information is an inextricable part of human commerce, as people all over the world process prices and handle cash in the form of bills and coins on a daily basis. Part of the process of a cash transaction is counting and adding up the values of the bills and coins to arrive at the desired amount. In some situations, for example, when a person receives a small change after a purchase at the market, they may want to quickly know the approximate value of what they have received without wasting time counting all the coins one by one. To do this, we surmise that such a person can make monetary estimates based on the numerical (e.g. the number of coins and the number printed on them) and physical (e.g. the size, colour, or weight of the coins) information available to them. In this study, we examine how adults with experience of money use these physical and numerical properties to quickly estimate the monetary value of a set of coins. But before doing so, we describe in the following sections how individuals make numerical and monetary estimates.

Numerical judgments

Human beings have a singular ability to directly grasp the exact number of objects in small sets (i.e. up to four) with remarkable accuracy and precision (Bourdon, 1908; Jevons, 1871). This ability captures the essence of sudden access to exact cardinal values and is called "subitizing" (from Kaufman et al., 1949). Subitising is a cognitive ability based on general processes of attention and object tracking (Burr et al., 2010) that appears very early in development: subitising is already observed in toddlers before they have mastered verbal counting (at the age of two, Starkey & Cooper, 1980). Interestingly, it should be noted that humans can process multiple tiny sets (i.e. each within the subitising range) in parallel (Wege et al., 2022), a phenomenon coined as "groupitizing" by Starkey and McCandliss (2014). Beyond four elements, individuals can't easily and quickly grasp the cardinality of a set and must either count (slow but accurate) or estimate (fast but imprecise).

Dehaene (2001) proposed that individuals possess and use their *number sense* to quickly represent, manipulate, and estimate large numerical quantities. This cognitive ability has been operationally described as an *Approximate Number System* (ANS), which enables the approximate but rapid estimation of large non-symbolic quantities (Feigenson et al., 2004). The system's name emphasises the approximate nature of the number

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sense, implying that mental representations of numbers are not always exact. These representations would indeed follow the Weber-Fechner law, so that the larger the quantities, the more imprecise the corresponding mental representations, and consequently the higher their approximation (Dehaene, 2003). In addition, the ANS framework proposes that humans possess a direct model of number perception, capable of extracting the meaningful value of number (however imprecise) as an abstract property from any appropriately perceived stimulus (see Dehaene & Changeux, 1993).

However, a growing body of research shows that physical properties influence numerical judgments, even when the former are irrelevant to the decision (e.g. Gebuis & Reynvoet, 2013; Guillaume et al., 2016; Leibovich et al., 2017; Norris & Castronovo, 2016). For instance, in numerical comparison tasks with Arabic digits, participants' responses are faster when the larger digit has a larger font (i.e. "congruent condition") than when the digits have the same font size (i.e. "neutral condition"). Further, when smaller digits are printed in larger fonts (i.e. "incongruent conditions"), participants are even slower and less accurate (Gebuis et al., 2009; Gebuis et al., 2010; Henik & Tzelgov, 1982). For dot arrays, studies reported similar in congruency effects since many physical properties, such as dot size (Gebuis & Reynvoet, 2012a; Hurewitz et al., 2006), density (Gebuis & Reynvoet, 2012b; Hendryckx et al., 2021), or convex hull (Clayton et al., 2015; Gilmore et al., 2016; Shilat et al., 2021) interfered with numerical estimates when these properties were incongruent with the cardinality of the set. These results provide evidence that numerical judgments are spontaneously affected by non-numerical information (see Leibovich et al., 2017, for a discussion). One interesting implication of this spontaneous effect is that individuals can and will use non-numerical information to make numerical judgments (see Roquet & Lemaire, 2019).

Monetary judgments

Much research has been devoted to how individuals perceive the monetary value of banknotes (Di Muro & Noseworthy, 2013; Giuliani et al., 2018; Macizo & Herrera, 2013; Macizo & Morales, 2015; Manippa et al., 2021; Mishra et al., 2006; Raghubir & Srivastava, 2009; Ruiz et al., 2017). Beyond their monetary value, the format in which banknotes are presented influences their perceived economic value. For example, people place a higher value on banknotes that look new than those that are old and worn (Di Muro & Noseworthy, 2013) and on banknotes that are more familiar to them than those that are less familiar (Alter & Oppenheimer, 2008). In addition, how individuals perceive and spend their money depends on how monetary value is presented. Specifically, people are more likely to spend their money when it is presented in smaller bills (e.g. €20, 20€, €10) than in a single bill of larger value (e.g. €50, Mishra et al., 2006; Raghubir & Srivastava, 2009). Finally, the visual processing of money appears to have specific characteristics, as €100 bills were recognised faster than €5 bills when displayed in the right visual field, a difference that was not found in the left visual field (Giuliani et al., 2018).

With regard to the physical size of banknotes, Coulter and Coulter (2005) have shown that banknote size influences their processing in price comparison tasks, showing that physical properties are spontaneously processed. The congruence between the value of a banknote and its physical size increases accuracy in a monetary comparison task (Ruiz et al., 2017). This phenomenon parallels the physical size effect found in numerical judgments (e.g. Henik & Tzelgov, 1982; Hurewitz et al., 2006). Ojedo and Macizo (2023) analyzed the results of three monetary comparison tasks in which three different banknote properties (size, colour, and pattern) were manipulated. The authors found a combination of facilitation and interference effects and concluded that physical size was the most important feature for accessing the monetary value of banknotes, followed by colour.

As far as coins are concerned, several studies have shown that their physical appearance can also influence our perception of their value and our economic behaviour. Physical size is also essential for estimating the monetary value of coins, as surface detail and raw characteristics (i.e. size, weight, colour, edge) provide information for coin identification and discrimination (Horner & Comstock, 2005). Coins are indeed designed to favour the distinction between each of them (e.g. European Central Bank, 2007; Pavlek et al., 2020). In general, high-value coins tend to be larger and heavier than low-value coins. This is the case for euro coins (see Figure 1). In line with the preference for bigger stimuli over smaller ones in the context of aesthetic judgments (Silvera et al., 2002), oversized coins are generally perceived as more valuable than their original counterpart and could have a positive effect on participants' motivation to save (Peetz & Soliman, 2016). Nonetheless, coins are generally perceived as less valuable than banknotes, which promotes different financial decisions (Tessari et al., 2011).

Several studies have examined the relation between physical features and monetary value in coins (Fitousi, 2010; Goldman et al., 2012; Hasegawa, 2020; Peetz &

Category	Units			Tens			Euros	
Diameter (mm)	16.25	18.75	21.25	19.75	22.25	24.25	23.25	25.75
Mass (g)	2.30	3.06	3.92	4.10	5.74	7.80	7.50	8.50
Color	copper			gold			Outer: Gold Inner: Silver	Outer: Silver Inner: Gold
Composition	Copper-steel			Nordic gold			Inner: nickel-brass Outer: copper-nickel	Inner: copper-nickel Outer: nickel-brass

Figure 1. Physical size, weight, colour, and composition of euro coins, adapted from the European Central Bank website (https://www.ecb.europa.eu/euro/coins/html/index.en.html).

Soliman, 2016; Tessari et al., 2011). In the study by Goldman and colleagues (2012), participants' performance in numerical and monetary judgment tasks was affected by incongruence with the physical size of coins. Conversely and interestingly, in a physical size judgment task, participants performed less well when low-value coins were presented as large and when high-value coins were presented as small (Hasegawa, 2020). These findings replicate and extend the size congruency effect found in numerical judgment tasks (e.g. Henik & Tzelgov, 1982; Hurewitz et al., 2006).

Critically, most studies have explored the relation between size and monetary values using experimental tasks that require an explicit comparison between two stimuli (for example, which of two banknotes/coins has the greater value). However, direct comparison involves visual and decision-making processes for which the weight of visual properties could be overestimated compared to simple estimation (Guillaume et al., 2016; Krajcsi & Szűcs, 2022; Rodríguez & Ferreira, 2023). In other words, when comparing two sets, participants may rely more often on directly comparable specific visual properties (such as size) to make their decision. In the present study, we aimed to design a new monetary estimation task in which participants must estimate whether the value of a visual set of euro coins is higher or lower than a reference value that won't be displayed (thus without direct visual comparison to the former). We explain our current study in the following section.

The current study

We explore whether we could find the size congruency effect in monetary judgments in a monetary estimation task involving a single set of euro coins. This investigation would provide better insights into whether humans extract symbolic numerals (monetary value) from non-numerical and non-monetary properties (physical size). We chose euro coins due to their usage across the entire eurozone in 20 countries, broadening the study's implications beyond a country-specific currency. In our design, we grouped the coins into three categories: units (0.01€, 0.02€, 0.05€), tens (0.10€, 0.20€, 0.50€), and a third mixed category (0.02€, 0.20€, and 2€).

We used a referent-target paradigm in which participants must decide whether the total value of the displayed coins is smaller or larger than a reference value. We manipulated within each block the size of the coins in each set as follows. In the congruent condition, we displayed pictures of euro coins in their real-world size. In the incongruent *inversion* condition, no euro coin was displayed at its original size. Finally, in an incongruent *uniform* condition, all coin sizes had the same diameter. We expect to replicate and extend the congruency effects found in comparison tasks (Goldman et al., 2012; Hasewaga, 2020).

Our paradigm additionally controls for several confounding factors that are usually observed in numerical judgment tasks: the monetary distance from the target, and the set size. We expect to find a monetary distance effect that would mirror the well-known numerical distance effect (Henik & Tzelgov, 1982; Moyer & Landauer, 1967). In other words, the monetary judgments should be easier when the displayed value is further away from the reference value, while conversely, they should be harder when the displayed value is closer to the reference value. We hypothesise that the size-congruency effect interacts with the monetary distance since studies have previously shown this (Faulkenberry et al., 2016; Kaufmann et al., 2005; Schwarz & Ischebeck, 2003), though the direction of the relation depends on the task (Kaufmann et al., 2005). We expect that the size-congruency effect increases as the numerical distance decreases, as this direction is found in tasks where participants have to make judgments on numerical value (Kaufmann et al., 2005; Schwarz & Ischebeck, 2003). One possible explanation for this effect is that small numerical distance trials are harder; so that participants might thus leverage all available visual information to tackle the difficulty, which would make their judgment more sensitive to the physical size of the coins.

We also expect to find a set size effect, reflecting a processing advantage for small cardinal values compared to large values (Kaufman et al., 1949). In our study, we expect our participants to perform better in the small set size condition where we used sets of coins in the subitising range, which allows for groupitizing processes (Anobile et al., 2020; Guillaume et al., 2023; Starkey & McCandliss, 2014; Wege et al., 2022). If groupitizing successfully occurs, then participants should be more accurate and faster to estimate the small set size condition in comparison to the large set size condition.

Finally, we hypothesise finding different levels of interference (from the size-congruency effect) in each coin category (units, tens, or mixed), depending on whether the value of coins can be predicted from one or multiple visual properties (units and tens vs. mixed), and whether participants were making judgments on coins with a single or double-digit number (units vs. tens). Particularly, we predict that the congruency effect will be smaller when one can predict the value from multiple visual cues (e.g. the colour can help us distinguish units and tens and facilitate judgment). According to the reasoning described above, multiple consistent cues should make the monetary judgment easier and thus reduce the congruency effect. Furthermore, we predict a total-value size effect such as that the congruency effect will be smaller for coins with single-digit values, because single-digit values add up to a smaller total than 2-digit values do.

Method

Participants

Based on the reviewed literature, we anticipated lower performance with incongruent inversion trials and larger set sizes. Therefore, using G*Power (Faul et al., 2009) we opted for a one-tailed t-test and obtained a sample size of 45 participants, to detect a moderate effect size of $d = 0.5$ with 95% power. Because of the extraordinary situation caused by COVID-19 precautions at the time of data collection, we were able to recruit and test in person only 39 adults (31 women, mean age: 26.9 years) during the study period. Twenty participants were recruited at the Technische Universität (TU) Dresden in Germany and eighteen participants were recruited at the University of Luxembourg (UNI), in Luxembourg.

Eligibility criteria were that individuals (1) were born and raised in a country that is part of the eurozone (thus ensuring familiarity with the Euro currency); (2) had no reported history of numerical or neurological disorders; and (3) had normal or corrected-to-normal vision as determined by a standardised Lindolt vision test (Bennett, 1965). Prior to data analysis, we used the MAD procedure (Leys et al., 2013) and excluded four participants whose performance differed by more than three standard deviations from the median performance. The final sample size was 35 participants (29 women, mean age: 27.6 years). We followed APA ethical standards to conduct the present study. Written consent from the participant was obtained before the start of every session. The study was approved by the Ethics Review Panel from the University of Luxembourg (ERP 23-030 EURO).

Apparatus and material

The experiment was designed with Psychtoolbox-3 (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997) and run on MATLAB (The MathWorks). Participants were individually tested in a quiet room in our university laboratories providing a consistent set-up. Participants seated at approximately 65 cm from the monitor. We used a Dell U2211H (22-inch) with a resolution of 1920×1080 pixels. The participants used a keyboard to respond. The stimuli were images of sets of euro coins with the denomination of the monetary value apparent. Euro coin images were downloaded from the website of the European Central Bank (https://www.ecb.europa.eu/euro/coins/html/index.en.html). Using an adapted version of NASCO (Guillaume et al., 2020), we generated 750×750 px images of coin sets (material available on https://osf.io/7chkj/). We scaled up the raw pixel diameters (as mentioned on the European Central Bank website) to match the real-world sizes of the coins when displayed on a 22-inch screen.

Because the metal alloy of euro coins differs in colour (e.g. copper, silver, and gold), a change in monetary value corresponds not only to a change in size but also to a change in colour. To dissociate the change in monetary value due to a change in size from the change due to a change in colour, we divided the stimulus set into three categories: the *Unit* category (0.01€, 0.02€, 0.05€), the *Ten* category (0.10€, 0.20€, 0.50€), and a third *Mixed* category (0.02 €, 0.20€, and 2€), in which colour varies with size. In addition to this categorisation, we manipulated the numerosity range (i.e. number of coins) for each coin value to compare subitising/groupitizing and estimation processes. We distinguished between small sets (1–3 coins per coin value) and large sets (5–7 coins per coin value).

By crossing stimulus category (unit, ten, or mixed) and numerosity range (small vs. large), we constructed six block categories (see Figure 2A). Within each block, we considered each combination of coins in the numerosity range and calculated the median value. The median values were 0.16€ in the small unit condition, 1.60€ in the small ten condition, 4.44€ in the small mixed condition, 0.48€ in the large unit condition, 4.80 € in the large ten condition, and 13.32€ in the large mixed condition. These median values were used as reference values for the monetary estimation decision in our experiment. We also labelled each set according to the distance between its total monetary value and the corresponding median value in one of three distance groups (small, medium, or large).

Finally, and critically for the purpose of this study, we manipulated the physical size of the coins under three conditions (see Figure 2B). In the congruent condition, all coins matched their exact physical size in the real world. In the incongruent *inversion* condition, coins

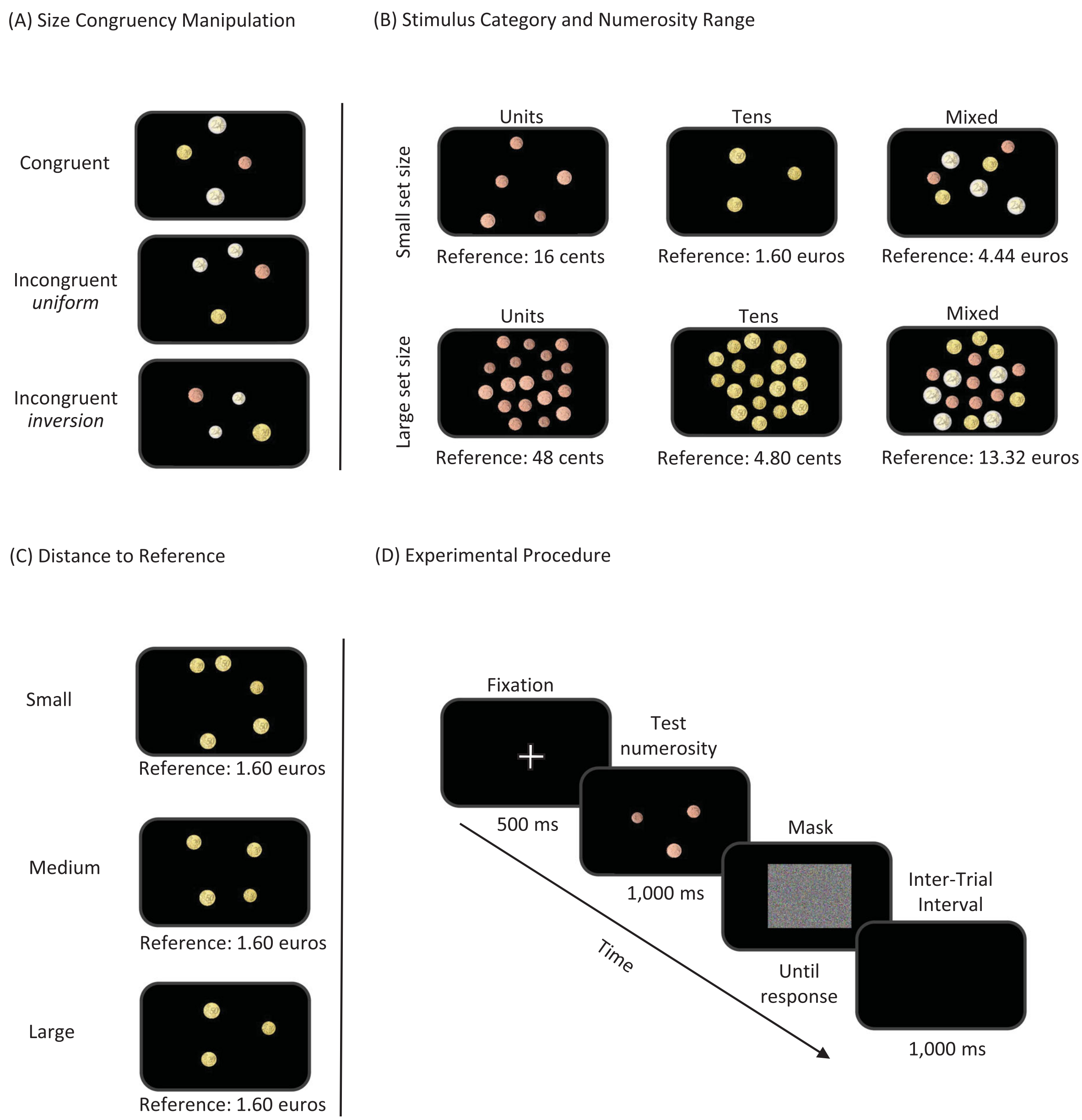

Figure 2. Illustrations of the stimulus set and the experimental design.

Note: (A) Example of one set of coins for every condition resulting from the crossing of the stimulus category (unit, ten, or mixed) and the numerosity range (small or large), (B) Illustration of the manipulation of the size congruency (congruent, incongruent uniform, and incongruent inversion), (C) Example illustrating the manipulation of distance from the reference value (€1.60): small (€1.80), medium (€1.00), large (€0.80), (D) Illustration of the procedure.

matched the physical size of another coin, so the coins never matched their exact physical size. In the incongruent *uniform* condition, coins all had the same size; the chosen size was the average size of the coins and did not correspond to any physical size.

Procedure

The experiment consisted of six blocks of 156 trials, for a total of approximately 60 min. In the task, participants had to determine as accurately and as fast as possible whether the total coin value (of the displayed set) amounts to a smaller or larger sum than a reference value. The reference value was different in every block. Participants were explicitly reminded to pay attention to the new reference value at the beginning of every new block. They were asked to remember this value for the duration of the block.

In each trial, after a fixation symbol lasting 500 ms, a set of coins was presented in the middle of the screen (see Figure 2C). After one second, the set disappeared to favour estimation rather than counting processes. After this, a dynamic mask was then displayed until the response. Participants were instructed to respond whether the combined monetary value of the coins in the set was fewer (pressing the "A" key) or greater (pressing the "L" key) than the reference value. Prior to the start of each block, participants completed five practice trials, during which they received visual reinforcement of the reference value and feedback on the accuracy of their response.

Analysis

We built two linear mixed-effects models to assess the significance of our findings using the *lme4* (Bates et al., 2015) package on the *R* software (R Development Core Team, 2020). One model predicted accuracy (using binomial logistic regression) and the other one predicted response times (selecting only correct trials). Both models were built with Congruency: (congruent, inversion, or uniform), Set size (small or large), Distance (small, medium, or large), Coin set (units, tens, or mixed), Lab setting (Luxembourg or Germany) and all first-order interactions as fixed-effects predictors, and with Participant and Item as random-effects predictors (for which we only considered random intercepts to reduce the complexity of the random slope computation). We estimated the degrees of freedom and the effect sizes using the Satterthwaite approximation method (Satterthwaite, 1946) and obtained *p*-values with the *lmerTest* (Kuznetsova et al., 2014) and *car* (Fox & Weisberg, 2019) packages, respectively for the response times and accuracy models.

Results

Overall performance

On average, participants correctly estimated the monetary value in .76 of the cases (Standard Deviation, SD = .05), making their decision in about 1,037 ms (Standard Deviation, $SD = 289$). We verified whether the lab setting could have biased our findings by comparing the performance of students in Luxembourg (mean accuracy = .74, $SD = .05$; mean latency = 1,125 ms, $SD = 351$) to the performance of students in Germany (mean accuracy = .77, $SD = .04$; mean latency = 963 ms, $SD = 206$). Our analysis revealed that the lab setting did not affect nor accuracy, $\chi^2(1) = 2.42$, $p = .12$, $\eta_p^2 = .07$, nor latency, $F(1, 35) = 2.92$, $p = .09$, $\eta_p^2 = .08$. This result supports that performance is similar and comparable in both subsets, though slight variations may still exist.

Regarding our main research question, participants estimated more correctly congruent coin sets (mean = .78, $SD = .05$) than uniform sets (mean = .76, $SD = .05$) and inversion sets (mean = .74, $SD = .05$). They were also faster at judging congruent sets (mean = 1,026, $SD = 288$) than uniform sets (mean = 1,049, $SD = 296$) and inversion sets (mean = 1,035, $SD = 284$). The Analyses of Variance (ANOVAs) on the built mixed-effects models confirmed that the congruency significantly affected both accuracy, $\chi^2(2) = 56.87$, $p < .001$, $\eta_p^2 = .01$, and latency, $F(2, 23439) = 8.34$, $p < .001$, $\eta_p^2 = .01$. Pairwise comparison tests (Tukey-corrected) revealed significant differences between all pairs for accuracy (largest p = .017), but significant differences only between congruent and uniform sets ($p < .001$) for latency.

We replicated the numerical distance effect and the size effect, which are commonly found in numerical estimation tasks, in our money judgment task. Participants were indeed better at evaluating sets with large distance from the reference value (mean accuracy = .85, $SD = .05$; mean latency = 966 ms, $SD = 259$) than sets with small distance from the reference value (mean accuracy = .62, $SD = .03$; mean latency = 1,154 ms, $SD = 349$), or sets with medium distance (mean accuracy = .79, SD = .05; mean latency = 1,029 ms, $SD = 280$), $\chi^2(2) = 1{,}361$, $p < .001$, $\eta_p^2 = .05$, and $F(2, 23446) = 366$, $p < .001$, $\eta_p^2 = .03$, for accuracy and latency respectively. Participants were also better at evaluating small sets (mean accuracy = .84, $SD = .04$; mean latency = 989 ms, $SD = 266$) than large sets (mean accuracy = .67, $SD = .05$; mean latency = 1,100 ms, $SD = 342$), $\chi^2(1) = 1{,}171$, $p < .001$, $\eta_p^2 = .04$, and $F(1, 23372) = 372$, $p < .001$, $\eta_p^2 = .02$, for accuracy and latency respectively.

We also found a significant effect of coin set values on accuracy, $\chi^2(2) = 607$, $p < .001$, $\eta_p^2 = .02$, and latency, $F(2, 23374) = 319$, $p < .001$, $\eta_p^2 = .04$, respectively. Participants performed better when judging a mixed set of coins (mean accuracy = .82, $SD = .05$; mean latency = 960 ms, $SD = 270$) than the tens set (mean accuracy = .77, $SD = .05$; mean latency = 1,035 ms, $SD = 318$), which yielded better performance than the units set (mean accuracy = .68, $SD = .06$; mean latency = 1,150 ms, $SD = 354$). Pairwise comparison tests (Tukey-corrected) confirmed significant differences between all pairs for both accuracy and response times (all $ps < .001$).

Finally, we looked at the significance of all first-order interactions between congruency and the other predictors on performance. There was a significant interaction between congruency and distance for accuracy, $\chi^2(4) = 16.72$, $p = .002$, $\eta_p^2 = .01$, but not for correct response times, $F(4, 23453) < 1$, $\eta_p^2 = .01$. Congruency significantly interacted with set size, $\chi^2(2) = 36.21$, $p < .001$, $\eta_p^2 = .01$, and $F(2, 23452) = 3.81$, $p = .022$, $\eta_p^2 = .01$. Congruency also significantly interacted with coin set, $\chi^2(4) = 14.56$, $p = .005$, $\eta_p^2 = .01$, and $F(4, 23443) = 4.91$, $p < .001$, $\eta_p^2 = .01$, for both measures. We conducted tukey-corrected pairwise comparisons analyses to assess whether and how the size congruency effect was modulated by the other dimensions. In Figure 3, we illustrate the post-hoc comparisons for the significant interactions of Congruency and the other predictors. For readability, we only marked with an asterisk the significant comparisons (at $p < .05$) between the levels of Congruency (congruent, uniform, inverted) within each level of the other predictors. The complete result tables are available in Supplementary Material together with Figure 4, illustrating the variability of performance across all different conditions.

Discussion

Overall, we found that numerate adults use non-monetary information, such as physical size, to assess the monetary value of sets of euro coins. Indeed, our participants were faster and more accurate in their monetary judgments when coins were presented in their real-world size than in uniform or inverted size. Additionally, we replicated the well-established numerical distance and set size effects which have been observed in adults performing judgments based on numerical representations (e.g. Brysbaert, 1995; Dehaene, 1989; Dehaene et al., 1990; Dehaene & Akhavein, 1995). We also found an effect of set values as the performance of participants was better when evaluating a mixed set of coins compared to the set of tens, which, in turn, exhibited better results than the set of units. Finally, the size-congruency effect exhibited significant first-order interactions with distance affecting accuracy and with set size and coin set, affecting both the accuracy and latency of participants.

Effect of non-monetary information on monetary judgment

Studies that examine the relation between the monetary value of coins and their physical characteristics have

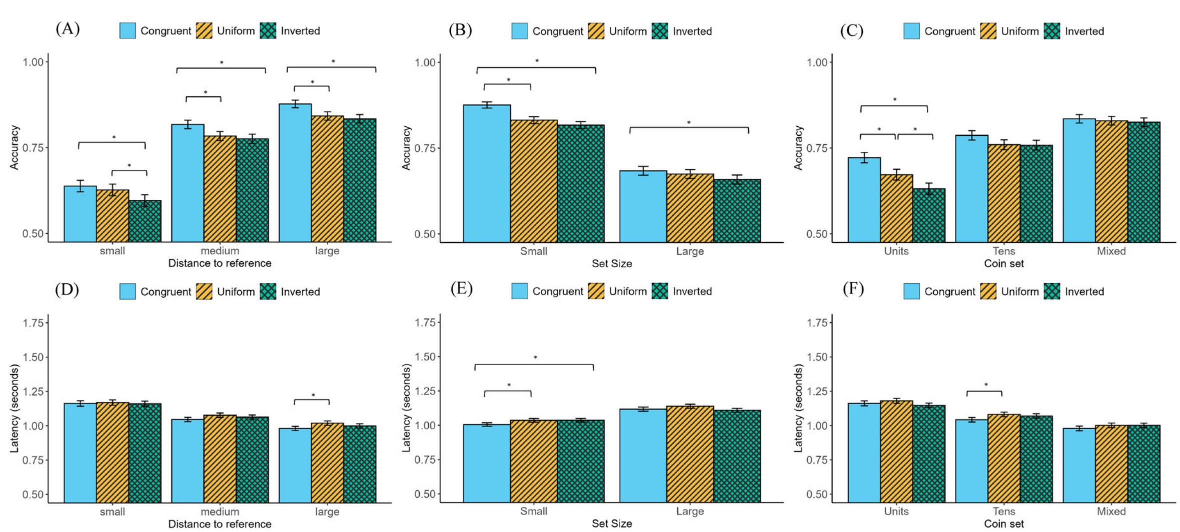

Figure 3. Performance (Upper Part: Accuracy, Lower Part: Latency) as a Function of Congruency: Congruent, Incongruent Uniform, or Incongruent Inversion and Either Distance to Reference (Small, Medium, or Large), Set Size (Small or Large), or Coin Set (Units, Tens, and Mixed).

Note: Vertical Lines Depict 95% Confidence Intervals.

already demonstrated that people consider an object's physical size when judging its value (Goldman et al., 2012) and, reversely, they consider an object's value when judging its physical size (Hasegawa, 2020). Our study extends these findings by showing that the size-congruency effect occurs not only in direct comparison tasks (i.e. two sets displayed at the same time) but also in referent-target tasks (i.e. a single ensemble). This extension is crucial because comparison tasks typically require the explicit direct comparison of two target sets displayed at the same time, which influences the weight of visual properties in the comparison process (Guillaume et al., 2016; Krajcsi & Szűcs, 2022; Rodríguez & Ferreira, 2023). In our task, participants had to make their monetary decision in relation to an abstract referent that has no physical consistency, thus in a situation where no direct visual comparison is possible. Despite this, monetary decisions were significantly influenced by the congruency of the physical coin size. Detecting a size-congruency effect in a monetary judgment task thus supports the observation that we automatically access the real-world size of objects, even when this feature is task-irrelevant (Konkle & Oliva, 2012), and aligns with our preference of viewing objects in their typical, real-world size (Chen et al., 2022).

Recent discoveries about the capacity of visual working memory may partly explain the spontaneous effect of size congruency on monetary behaviour. These studies show that our ability to remember the physical characteristics of objects such as the colour (Chung, Brady, et al., 2023) and the shape (Chung, Tam, et al., 2023) depends on objects' meaningfulness. When people encounter familiar real-world objects, their prior knowledge about the objects' features (such as its size) helps optimise their processing. Here, a common association (i.e. larger size and higher value) may have facilitated efficient visual encoding in a quick "snapshot" (all at once) by enabling high capacity of visual working memory or long-term memory storage. The latter idea aligns with the results of Gabay et al. (2016) showing brain activation patterns illustrating that size information is integrated into objects' long-term memory representations. When visual objects do not follow these typical real-world associations (e.g. larger size but smaller value), individuals may resort to serial (individual) processing that impairs their performance. This could explain why our participants were slow to the same extent on both the uniform and inversion trials (compared with the congruent condition).

Furthermore, we expected to observe in our monetary task effects that are commonly found in numerical estimation tasks, such as the set size effect. In our data, there was indeed a clear difference in both accuracy and speed between judging small sets (up to 3 items) and larger sets (more than 4 items). This pattern aligns with many studies that support the idea that different mental processes are involved in quickly recognising small groups versus estimating larger numbers (Kaufman et al., 1949; Revkin et al., 2008; Starkey & McCandliss, 2014). Another well-known numerical effect that we found is the distance effect (Henik & Tzelgov, 1982; Moyer & Landauer, 1967); monetary values close to the reference values were much more difficult to judge than values far from the reference values. Overall, it's not so surprising to observe significant numerical effects in tasks related to monetary value, because these effects are inherent to the numerical representation of any magnitude, regardless of the specific context (following Dehaene, 2001; Feigenson et al., 2004).

Additionally, we contrasted different sets of coins (i.e. cent units, cent tens, and a mixed set) and found that our participants provided better estimates for the mixed set that included the 2-euro coin. This finding is consistent with the category effect found in Goldman et al. (2012), where the authors showed faster and more accurate judgments for the shekel (i.e. the main Israeli currency unit) than the agorot (the Israeli currency subunit). Further, a crucial point of discrepancy between the three conditions is the coin colour, which was consistent within the cent units (copper) and cent tens (gold) sets but varied within the mixed set. Ojedo and Macizo (2023) recently reported that colour is a relevant feature, following size, when one is trying to assess the monetary values of currency. Our participants could then have taken advantage of the colour of the coins and consequently obtained better performance in the mixed condition since we didn't manipulate this visual property in the sense that all the pieces were the same colour as in the real world. Furthermore, the 2-euro coin might not only have posed greater familiarity effects because it's more frequently used but also because according to the denomination effect found with banknotes (e.g. Raghubir & Srivastava, 2009), participants might perceive it as more valuable in comparison to the same monetary amount presented with smaller-value coins. Finally, the results do not support our total value size effect hypothesis. Within the cents, our participants were surprisingly better at estimating sets of tens than sets of units. One explanation for this unexpected result is that the cent conditions involved a less familiar and less ecologically relevant set of coins, which have been reported to pose problems of use and differentiation (European Commission, 2021) and have been withdrawn from certain EU-countries (Centrum für

Europäische Politik, 2014). Further studies are needed to confirm this interpretation.

The impact of visual cues on the size congruency effect in monetary judgments

The distance, set size and coin set effects showed significant interactions with the congruency effect on accuracy, while set size and coin set showed significant interactions with congruency on latency. Regarding accuracy, previous studies (Kaufmann et al., 2005; Schwarz & Ischebeck, 2003) have shown increased interference by an irrelevant factor (i.e. size) with smaller numerical distance. We also observed significant interference effects at small distances, supporting that the size dimension interfered more with accuracy when the task was harder (see Figure 3A). At medium and large distances, we found significant facilitation effects, suggesting that visual information was processed and used at the decision level even if the task was easier. As for response times, participants solved congruent faster than uniform trials (see Figure 3D), but the interaction effect was not significant overall. This may be due to the specific characteristics of our task, such as the difficulty level and the response time-window. Further research manipulating both numerical and physical size distance is needed to fully understand this interaction.

We additionally hypothesised that larger set sizes (harder tasks) would increase congruency effects, with greater interference from the irrelevant factor (size). For accuracy, we observed significant congruency effects with large set sizes as expected, but also significant facilitation effects with small set sizes (see Figure 3B). For latency, we only found significant congruency effects in the small set size condition (see Figure 3E). Contrary to our hypothesis, but similar to what we proposed about the interaction with distance, this finding suggests participants leveraged additional dimensions (size) more readily in easier tasks.

The interaction of congruency and coin set further strengthens the notion that task difficulty influences how individuals utilise additional dimensions. While our initial hypothesis predicted stronger congruency effects for harder tasks, the mixed condition, arguably the easiest due to its multiple visual cues, did not show congruency effects (see Figure 3C and F). This suggests that participants shifted their reliance from size, an additional dimension, to other visual cues when these were available. Furthermore, the presence of the more familiar 2-euro coin with a distinct colour and possibly the largest size difference in the mixed condition might have provided participants with readily available information useful for a quick decision. The colour cue might have been used by our participants as a grouping cue to process the set. Indeed, groupitizing is not limited to spatial grouping cues and can be elicited by colour cues too (Anobile et al., 2020). Finally, our hypothesis that smaller total values of units (assumed as an easier task based on the total-value size effect) would decrease congruency effects was not entirely supported. The results, showing significant congruency effects, suggest a potential shift of participants' focus away from numerical cues towards other dimensions, such as the size.

The first-order interactions of size-congruency and each of the distance, set size, and coin set effects could be interpreted based on both the shared representation and shared decision models, which have been suggested as possible explanations of the size-congruency effects (Santens & Verguts, 2011). For the interaction between size-congruency and the distance, the shared decision model predicts that the task is easier when the distance between the two targets to be judged is large, as the response from the numerical dimension is activated (Santens & Verguts, 2011). In congruent trials, when both decisions, from the numerical and physical dimensions, feed into the same response node, individuals' correct response is facilitated (heightened facilitation effects). On the other hand, based on the shared representation model, when the distance is small and the task is harder the numerical dimension cannot be activated, and both numerical and physical sizes are mapped onto a shared representation. Therefore, in incongruent *inversion* trials, the irrelevant dimension may pose a greater influence on the monetary value processing (heightened interference effects).

The interpretation of size-congruency and distance interaction effect can be extended to interactions between size-congruency and other visual cues (i.e. set size, coin set). These interactions might also imply a connection between task complexity and the size-congruency effect. Tasks with larger set sizes can be more challenging due to the numerical size effect and pose greater interference effects. Similarly, different familiarity levels between coins can make judgments about units more difficult than judgments about tens, which aligns with the observation of interference effects in this coin set category. Additionally, the interaction with the coin set could be attributed to the role of the stimulus characteristics. Units, distinct in colour and less common, might have prompted participants to recruit diverse estimation systems (exact vs. approximate). Although we suggest a link between task complexity and congruency effects, we acknowledge the possibility that the high accuracy rates in easier trials might have obscure these effects. To address this concern, future studies could incorporate a wider range of task difficulty levels to ensure enough variability in performance.

Limitations

Our research partially supports the sensory-integration theory, suggesting that, under certain conditions, people seem to estimate large numerical quantities by integrating various sensory cues (Gebuis et al., 2016). This is evident in ensemble perception tasks, where individuals discern numerical information (e.g. sum, average, range) from both realistic, meaningful objects and low-level features (e.g. size, colour, motion direction). However, due to our design we cannot distinguish between the main impact of colour cue and the interaction between colour and the number dimension. The lack of congruency effect in the mixed condition – containing the colour cue – suggests that participants might have adopted alternative strategies. They may have *groupitized* the coins based on their colour (see Anobile et al., 2020), and/or utilised size to make decisions.

In addition, we cannot exclude that participants, at least when the set was small, performed some arithmetic computations by adding the values printed on the coins, to make their judgment. Previous literature (e.g. Goldman et al., 2012; Hasewaga, 2020) indeed suggest that some arithmetic processes might have happened along with the processing of physical features. In our method, we tried reducing the use of counting and arithmetic strategies by masking the coin set after one second of display. But, on the other hand, this time limit might have impacted the assessment of the natural-ecological estimation of coins.

Finally, our study design didn't fully control for the impact of all non-numerical visual factors of the ensemble on monetary judgments. We utilised the NASCO method to minimise potential biases resulting from visual cues such as the convex hull and the density of the ensemble (Guillaume et al., 2020) and sequential modulations of congruency effects (Roquet et al., 2022). Future research should also focus on more refined control methods (DeWind et al., 2015) and investigate how these perceptual abilities vary across different age groups, considering developmental differences in processing non-symbolic stimuli (Roquet et al., 2022). The extent to which ensemble perception abilities are domain-specific or general remains unclear, with less meaningful objects possibly relying on general ensemble perception skills, while familiar objects using long-term memory. To further explore this, future studies may compare ensemble perception tasks with recognisable and unrecognisable objects.

Conclusion

Our study not only replicated and extended the size congruency effects in coin estimation tasks, but also examined their limits across various visual cues. This comprehensive approach provides valuable insights into both the processing of monetary values and sensory integration in numerosity processing. Overall, our findings hold significant implications for designing accessible coin series. By understanding how individuals rely on visual cues like size for coin value estimation, we can create coins that enhance discrimination ability, not just for the visually impaired population, but even for unfamiliar (foreign) users. Future research could focus on numerical effects on monetary judgments in other modalities, such as the haptic modality or those associated to card transactions, which represent an important ecological use of money.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The material used and the dataset generated and analyzed as part of this study are available in the Open Science Framework (OSF) repository, https://osf.io/7chkj/.

Geolocation information

Our study was conducted in the research laboratories of University of Luxembourg (49.5045 ° N, 5.9472 ° E) and Technische Universität Dresden (51.0575 ° N, 13.7759 ° E).

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