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OPEN Local/global visual processing impacts numerosity-magnitude conflict resolution

Léa Chrétien¹, Nicolas Poirel¹, André Knops¹ & Arnaud Viarouge¹✉

In non-symbolic numerical comparison tasks (Approximate Number System or ANS tasks) where participants determine which of two dot arrays is more numerous, judgments can be biased by irrelevant non-numerical dimensions of magnitude, such as dot size or the total occupied area. While inhibition may help overcome these conflicts, the mechanisms guiding attention toward relevant numerical information remain unclear. We hypothesized that modes of attentional processing - focusing on individual elements (local processing) versus the overall configuration (global processing) - may influence how participants resolve numerical conflicts. Fifty-four adults ($M_{age} = 32.07$ years, $SD = 11.38$) completed ANS trials preceded by prime items designed to activate either a local or global processing mode, or no prime in a control condition. Global priming did not significantly affect performance, while local priming modulated numerosity/magnitude conflicts across magnitude dimensions, notably reducing the impact of convex hull. These findings shed light on how perceptual modes impact adults' ability to extract numerical information in the face of visual conflict.

Keywords Numerical cognition, Global/local processing, Non-symbolic comparison, Numerical conflicts

Numerosity and non-numerical magnitude

In both everyday situations and formal learning experiences, we are constantly exposed to numbers in various forms, and our ability to reason and make decisions often depends on how we perceive and interpret this numerical information. In the numerical cognition literature, this ability is widely considered to be supported by the Approximate Number System (ANS), a non-verbal cognitive mechanism that enables individuals to perceive and estimate the number of objects in a set without relying on symbolic representations¹. ANS acuity is commonly assessed using non-symbolic numerical comparison tasks (hereafter referred to as “ANS tasks”), in which participants briefly view two arrays of dots and indicate which array contains more items^{2,3}. Performance in these tasks follows Weber's law, such that discriminability depends on the ratio between the quantities to be compared⁴. For instance, accuracy improves as the numerical distance between arrays increases.

While ANS precision is known to improve with age¹ and education⁵, performance on this task can nevertheless be affected by the visual features of the stimuli. In particular, non-numerical dimensions of magnitude such as dot size and convex hull (i.e., the smallest area enclosing all items in an array) are known to interfere with pure numerical judgments^{6,7}. These visual features can be either congruent or incongruent with numerosity. In congruent trials, the more numerous array also contains larger dots and/or occupies a larger area. In incongruent trials, by contrast, the more numerous array is composed of smaller dots or occupies a smaller area and may appear less numerous despite being numerically larger. These incongruent trials therefore create a conflict between numerical and non-numerical dimensions of magnitude, leading to congruency effects that often result in decreased accuracy and increased response times^{2,6,7,8,9,10,11}. These congruency effects suggest that participants do not rely exclusively on numerical information when performing this task, but are also influenced by irrelevant visual features. Thus, succeeding in the ANS task relies, at least in part, on the ability to process numerical information while ignoring potentially conflicting non-numerical dimensions of magnitude.

Several hypotheses have been raised to explain how individuals overcome the influence of such visual features in non-symbolic numerical comparison tasks. One proposed mechanism is “attention to number”^{12,13}, which encompasses both the ability to inhibit conflicting non-numerical dimensions of magnitude and the ability to focus on relevant numerical information. Supporting the inhibitory component, some studies^{14,15} showed that resolving numerosity/magnitude conflicts engages conflict-specific inhibitory processes using positive and negative priming paradigms. On the other hand, attention to number may also be driven by a spontaneous tendency to focus on numerosity, referred to as Spontaneous Focus on Number (SFON)¹⁶. While initially defined in the context of small, exact numbers in everyday situations, this competence may extend to larger,

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approximate quantities, as suggested by recent work using non-instructed tasks with large numerosities¹⁷. This broader construct, sometimes referred to as Spontaneous Focus on Numerical Magnitudes (SFOM), has been associated with reduced interference from conflicting visual features in ANS tasks^{18,19}. Taken together, these findings suggest that both inhibitory control and spontaneous attentional tendencies may play a key role in the resolution of numerosity/magnitude conflicts in ANS tasks.

Global-local visual processing as a candidate mechanism

While previous work has focused on what type of information is prioritized (i.e., numerosity versus non-numerical dimensions of magnitude), another question is how this information is processed at the perceptual level. Insight into this issue could come from research in visual attention, which has shown that individuals can process visual information at different hierarchical levels, typically referred to as global and local processing. These correspond to distinct attentional levels: on the one hand, global processing involves perceiving the overall structure or configuration of a stimulus, whereas on the other hand local processing focuses on its finer details or individual elements²⁰. In his seminal work, Navon²¹ introduced hierarchical figures in which a large letter (the global level) is made up of smaller letters (the local level). These stimuli can be congruent (e.g., a large H made of small Hs) or incongruent (e.g., a large L made of small Hs), enabling to examine attentional selection and interference between levels. A key feature of these stimuli is their structural independence: information at one level does not predict the content at the other, making them particularly useful for investigating level-specific processing. Navon's studies^{21,22} revealed what is now known as the global precedence effect, that can be characterized by two patterns in adults: faster and more accurate responses to global-level targets, and interference from the unattended level in incongruent trials, particularly when attention needs to be directed to local information^{21,22,23}. Navon²⁴ further clarified that this precedence reflects an earlier availability of global information under brief exposures, while also noting that its magnitude depends on perceptual factors such as visual angle and retinal position.

Visual features in dot arrays

Interestingly, similar principles of hierarchical visual processing may also apply to the dot arrays used in the ANS task. Although these stimuli are not explicitly hierarchical, they include visual features that can be processed at different levels. According to DeWind and colleagues²⁵, such features can be described as intrinsic when they relate to individual elements of the array, and extrinsic when they reflect properties of the array as a whole. For instance, item size, which refers to the size of individual dots, is considered intrinsic and may be linked to more local-level processing. In contrast, the convex hull (or field area, as described by DeWind and colleagues²⁵) is considered an extrinsic property of the array and may be associated with more global processing. In the present study, we focused on one intrinsic feature (item size) and one extrinsic feature (convex hull), because manipulating these two dimensions allows us to create controlled conflicts with numerosity while the remaining visual features covary in systematic and predictable ways (see Appendix B). This provides a clear framework for examining whether global or local processing influences how adults resolve numerosity/magnitude conflicts. If dot arrays contain features whose perceptual salience varies depending on processing style, one may ask whether differences in global versus local visual processing could influence how individuals resolve conflicts between numerosity and non-numerical dimensions of magnitude. While this question has not yet been directly addressed in adults, developmental findings from both numerical and perceptual cognition offer converging clues that may inform such hypothesis. Several studies have shown that the influence of non-numerical dimensions of magnitude on numerical estimation changes with age. Young children exhibit strong congruency effects in ANS tasks, both when number conflicts with dot size or convex hull^{2,3,6,7,9,26}. However, as children grow older, interference from dot size tends to decrease, while the influence of the convex hull remains relatively stable into adulthood⁹. This pattern suggests that interference from local visual features becomes easier to overcome with development, whereas interference from more global features of dots arrays persists.

Interestingly, this pattern mirrors developmental changes observed in visual processing strategies. Vurpillot²⁷ showed that when comparing two visual scenes, young children often rely on limited sampling strategies, focusing on isolated elements rather than integrating the overall structure. Consistent with this, Poirel and colleagues²⁸ found that children under the age of six do not exhibit the global precedence effect typically observed in adults during Navon tasks. Instead, they showed a local processing bias, which gradually shifts during the early school years toward a global strategy typically observed in adults. This developmental trajectory aligns with findings in numerical cognition showing that children become increasingly able to ignore local visual features such as item size when performing ANS tasks⁹. Given that item size is typically considered a local feature of dot arrays²⁵, and that young children tend to favor local level processing²⁸, one may hypothesize that the developmental shift toward global processing contributes to more effective focus on numerosity in the presence of local visual distractors. Conversely, the predominantly local processing mode observed in young children may increase their sensitivity to such irrelevant features, resulting in greater interference in incongruent trials. These converging lines of evidence suggest that developmental improvements in numerical estimation may partly reflect an increasing ability to engage global visual processing mechanisms.

Yet, no study to date has directly examined whether global or local visual processing prevails during non-symbolic numerical processing in adults. To our knowledge, only one study has investigated this link more broadly. Pletzer and colleagues²⁹ assessed individual differences in visual processing style using two hierarchical figure tasks: the Navon task and the Kimchi–Palmer task. In the Navon task, participants detected targets at either a predefined or an unspecified hierarchical level. In the Kimchi–Palmer task, they judged which of two figures more closely resembled a target figure, with one matching in global configuration and the other in local features. A global advantage score was computed based on response time differences between global and local processing. In addition, participants completed a symbolic number comparison task involving two-digit

numbers. Some trials were unit-decade-compatible (e.g., 52 vs. 67), where the larger number had both the larger decade and unit digit. Others were unit-decade-incompatible (e.g., 57 vs. 62), because the larger number had the larger decade digit, but the smaller unit digit. The unit-decade-compatibility effect³⁰ refers to the tendency for responses to be slower and less accurate in incompatible trials, due to interference from irrelevant unit-digit information. Pletzer and colleagues²⁹ found a negative correlation between global advantage and unit-decade-compatibility effect, but only in female participants. This suggests that a stronger global processing style was associated with reduced interference from local numerical information, namely the unit digit, in symbolic number comparison. Although this evidence remains within the domain of symbolic processing, recent work using hierarchical Navon digits shows a similar interaction between visual processing mode and numerical processing. Prpic et al.³¹ reported that several numerical signatures (e.g., the size effect) vary depending on whether digits are processed at the global or local level. This further supports the idea that perceptual processing style can modulate how numerical information is extracted.

The present study

The present study investigates whether global versus local visual processing modulates performance in non-symbolic numerical comparison tasks. Building on the idea that dot arrays may engage hierarchical visual processing, we tested whether inducing a global or local processing mode of visual attention would influence participants' ability to focus on numerosity, in the presence of conflicting non-numerical dimensions of magnitude. To this end, we used a priming paradigm in which each trial began with a hierarchical stimulus designed to induce either a global or a local processing mode. This approach was chosen over a training-based manipulation, as prior work suggested that sustained training to induce global or local processing modes may require excessive trial counts (e.g., ~ 10,000 trials³²). Instead, priming paradigms have been shown to be effective to induce a certain visual processing mode: when a particular type of processing is activated on trial N , it can produce an attentional priming effect that persists into trial $N + 1$ ³³. The prime was immediately followed by a non-symbolic numerical comparison item involving either congruent or incongruent (either in item size or convex hull) dot arrays. We hypothesized that local priming would increase participants' reliance on local visual features of the arrays, such as item size, thereby amplifying interference in number/size incongruent trials. Conversely, global priming was expected to help participants focus more effectively on numerosity by reducing sensitivity to local features, and thus reduce interference in these trials. Finally, because convex hull is also a global visual feature, global priming could potentially increase interference in number/area incongruent trials, where numerosity conflicts with the overall spatial extent of the arrays.

Methods

Participants

We tested 54 adult participants (41 female; $M_{\text{age}} = 32.07$ years, $SD = 11.38$ years). An a priori power analysis conducted using G*Power³⁴ indicated that a minimum of 49 participants would be required to detect a medium effect size ($f = 0.25$) with $\alpha = 0.05$ and power = 0.80 for a 3 (Priming Condition: Neutral, Global, Local) \times 2 (Congruency: Congruent, Incongruent) \times 2 (Dimension: Item size, Convex hull) repeated-measures ANOVA. Because we used a Latin square design to counterbalance the order of the three priming conditions, we included 54 participants in the final sample to ensure equal assignment across the six possible condition orders. All participants were recruited through a national mailing list for research in cognitive science, provided written informed consent, and were compensated €10 for their participation. This study was approved by the Research Ethics Committee (CER) of Université Paris Cité (#00012020-79). All procedures were performed in accordance with the relevant guidelines and regulations, and with the Declaration of Helsinki.

Material and procedure

Participants completed all tasks in a single session lasting approximately 20 min, conducted individually in a quiet room at the laboratory. Each of them completed three non-symbolic numerical comparison tasks. All tasks were presented on a 13-inch laptop (resolution: 1620 \times 1080; refresh rate: 60 Hz) and programmed using PsychoPy³⁵.

We used a priming paradigm to induce either a global or a local visual processing mode before each numerical comparison trial. Participants completed three versions of the numerical comparison tasks: two priming tasks (the "global task" and the "local task") and one "neutral task". In each priming task, every trial consisted of a prime-probe sequence: a prime item (hierarchical figure designed to induce either a global or a local processing mode), followed by a probe item (a non-symbolic numerical comparison task). In the global task, prime items were designed to induce global attentional processing, whereas in the local task, they were intended to induce local attentional processing. The neutral task was a classical non symbolic comparison task, which involved the same probe items as in the priming tasks, but without any preceding prime items, serving as a baseline condition. The order of the three tasks (neutral, local and global) was counterbalanced across participants using a Latin square design (Table 1 in Appendix A).

Priming tasks

In both global and local priming tasks, each trial consisted of a sequence of two items: a prime item (a hierarchical figure) and a probe item (a pair of dot arrays).

Prime item In the prime item, participants were instructed to detect a predefined target (a tree) either at the global level (global task), or at the local level (local task), using a Go/No-Go response mode: they pressed the spacebar if the target was detected, and withheld any response otherwise.

The prime items were hierarchical figures composed of global black shapes made up of smaller local shapes (Fig. 1). To ensure that prime items induced a specific visual attentional mode without engaging conflict resolution mechanisms, each hierarchical figure was constructed so that only the attended level (global or local) contained a recognizable object, while the unattended level was composed of visually meaningless non-object shapes³⁷. This design avoided the potential interference effects associated with incongruent hierarchical stimuli, where the target appears at the unattended level^{21,22,39,40}. We created three distinct object shapes (a tree, a boat, and an umbrella) and three matched non-object shapes (labeled No.1, No.2, and No.3). Axial alignment of the elements was controlled to avoid any unintended spatial bias or visual guidance effects. All possible combinations between objects and non-objects were used, leading to 18 hierarchical figures in total. These 18 stimuli were pre-tested in a simple detection task to ensure that the detection of the target was feasible. This pre-test was conducted separately on a small group of individuals who did not take part in the main experiment. Its sole purpose was to verify that each hierarchical figure could be easily processed at the intended level (global or local) and that no unintended ambiguity occurred. No data from this pre-test were used in the main study.

In the global priming task, participants viewed the 9 figures where a global object was composed of local non-objects (each stimulus repeated 8 times). In the local priming task, the figures consisted of global non-objects made up of local objects (each repeated 8 times). All figures were centrally displayed within a white circle (8° of visual angle) on a gray background.

Probe item Following the prime item, participants were presented with the probe item, consisting of a numerical comparison between two dot arrays. They were asked to indicate which array contained more dots, by pressing “D” if more dots were present on the left array and “K” if more dots were present on the right array. This response mode (spacebar for Go/No-Go during the prime and lateralized D/K keypresses for the numerical comparison) was chosen to maintain simplicity and ergonomics, allowing participants to keep their hands comfortably positioned on the keyboard throughout the task.

Each stimulus of the probe items consisted of two arrays of black dots, displayed simultaneously to the left and right of a central fixation cross. The arrays were presented within white circles (8° of visual angle), positioned 5.3° to the left and right of screen center. Three numerical ratios were used to vary task difficulty: 0.67 (12 vs. 18 dots), 0.80 (20 vs. 25 dots), and 0.86 (18 vs. 21 dots). Dot array pairs were generated using NASCO’s Array Pair Generation tool⁴¹. Because our manipulations targeted item size and convex hull, total area and mean occupancy were set as the constant dimensions. We then specified the desired values for item size (in the number/item size manipulation) or convex hull (in the number/convex hull manipulation), and NASCO automatically computed the remaining values. To ensure comparable salience of the manipulated non-numerical dimension across numerical ratios, we matched the ratio of item size or convex hull to the numerical ratio following Salti et al.⁴². As these dimensions scale quadratically, we used the squared ratio when specifying target values (e.g. 2:3 ratio

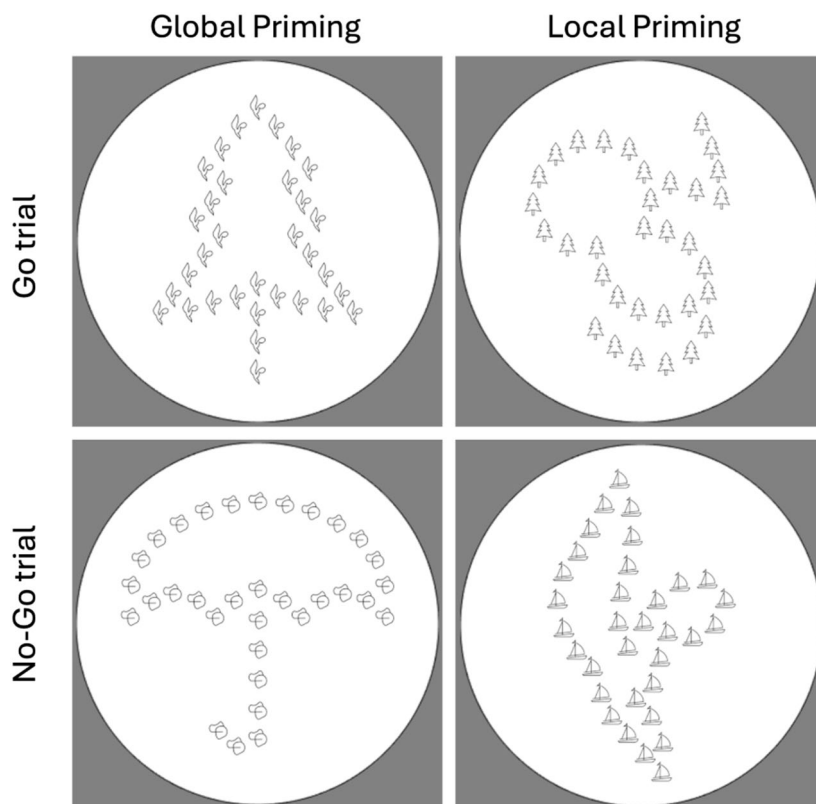


Fig. 1. Example of hierarchical stimuli used as prime items to induce global or local attentional processes.

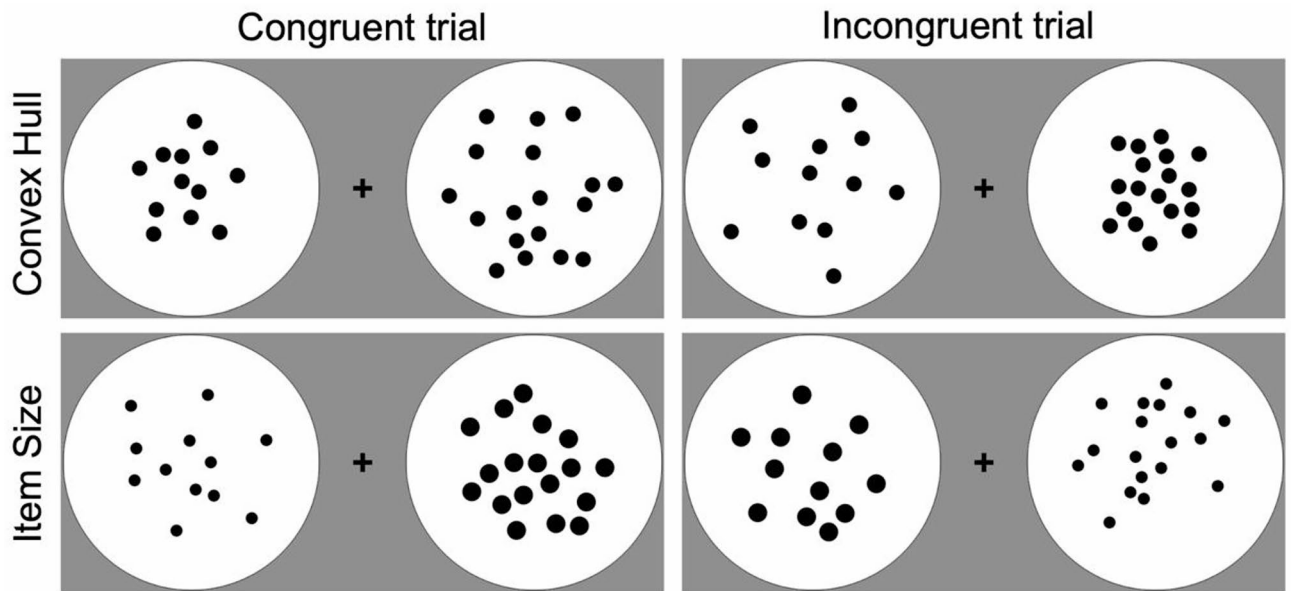


Fig. 2. Example of stimuli in the probe numerical comparison.

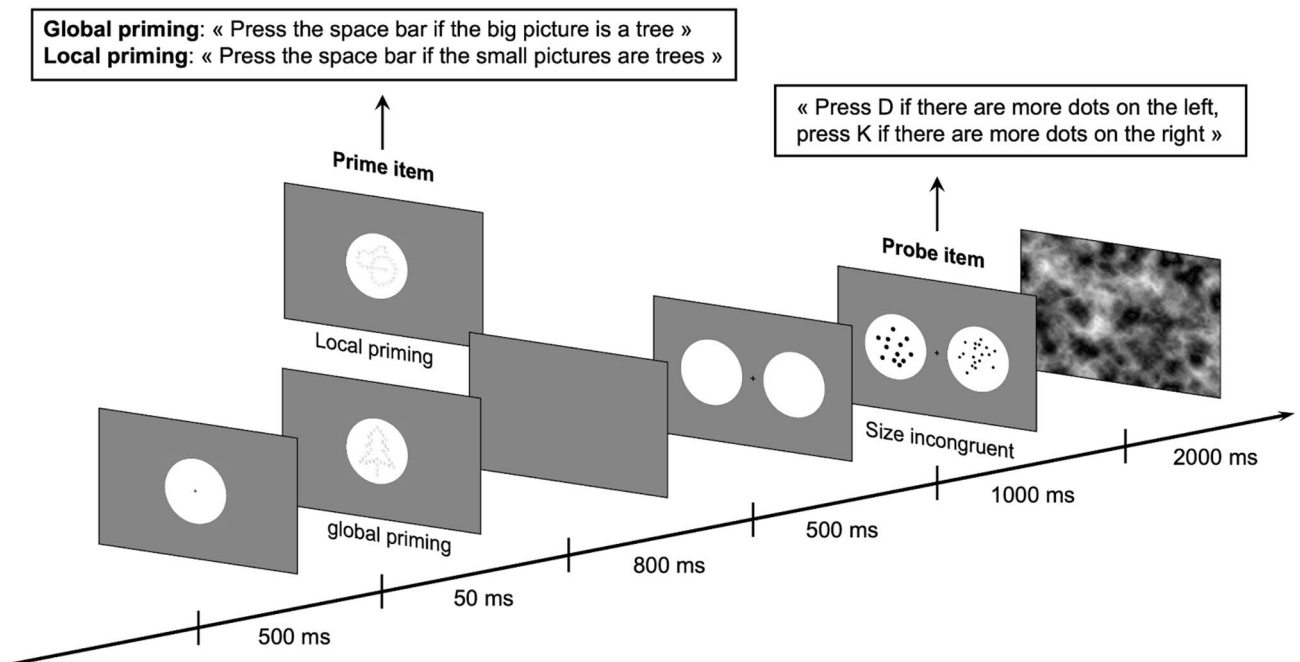


Fig. 3. Example of the sequence of events in one trial of the priming paradigm adapted to the non-symbolic comparison task.

for numerosity, 4:9 target ratio). NASCO occasionally adjusted these values slightly to generate valid arrays within the stimulus constraints.

In each pair, numerosity was either congruent or incongruent with the manipulated dimension (item size or convex hull) while the other dimension was held constant. For example, in incongruent number/item size trials, both arrays had the same convex hull area. For the number/item size manipulation, convex hull was fixed at 90 000 px; for the number/convex hull manipulation, item size was fixed at 1 018 px (both corresponding to the mean values across all stimuli, see Fig. 2). The exact item size and convex hull values used for each numerosity pair are provided in Supplementary Table S1 to ensure full reproducibility.

Dot array stimuli were counterbalanced across four factors: congruency (congruent vs. incongruent), non-numerical dimension manipulated (Item size vs. Convex hull), numerical ratio (0.67, 0.80, or 0.86), and the side

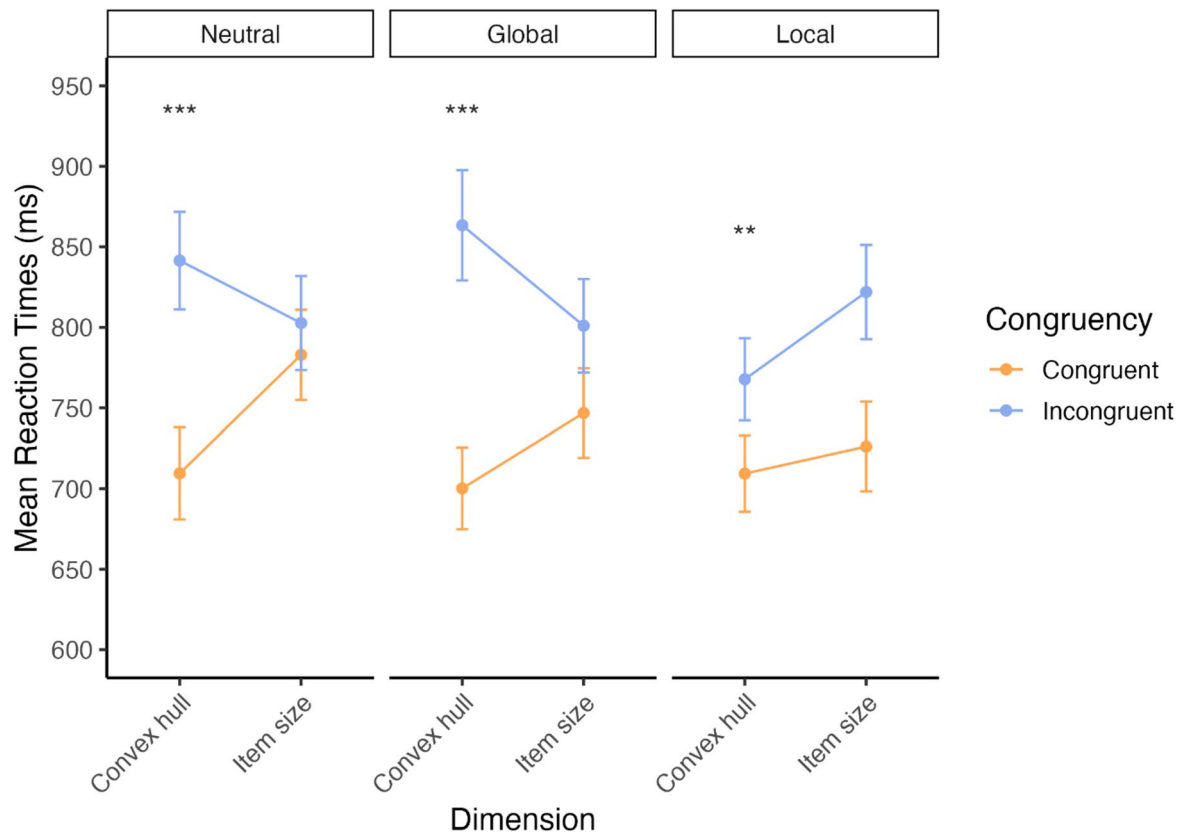


Fig. 4. Mean RTs scores for congruent and incongruent trials in the item size and convex hull dimensions, depending on the priming condition (neutral, global or local). Note. Error bars represent standard error of the mean (SEM). Significance levels for post-hocs between congruent and incongruent trials in each condition are shown: ** $p_{adj} < 0.01$, *** $p_{adj} < 0.001$.

of the correct response (left vs. right). Each combination appeared in three versions, resulting in a total of 72 dot array pairs.

Trial structure Each trial followed a fixed temporal sequence: a fixation cross was first displayed at the center of the screen for 500 ms, followed by the prime item, which appeared for 50 ms. The 50 ms duration was chosen because it corresponds to three refresh cycles on a 60 Hz monitor ($3 / 60 = 50$ ms), ensuring frame-accurate presentation. This was immediately followed by a gray screen for 800 ms, allowing time for a Go/No-Go response. A second fixation cross was then presented for 500 ms, followed by the probe item, displayed for up to 1000 ms or until the participant responded. If no response was made within this interval, the probe was replaced by a gray screen that remained until a response was given. Finally, a visual mask appeared for 2000 ms to prevent potential carry-over effects from the probe item to the next prime item³⁶. Presentation times were chosen based on prior studies using similar priming paradigms in the global/local visual processing and numerical cognition domains^{14,37} (Fig. 3).

Thus, in each of the two priming tasks, participants completed three blocks of 24 trials each (72 trials in total in each task, 144 trials in total). To ensure full counterbalancing, each dot array stimulus was paired with three different hierarchical figures, such that all object and non-object shapes appeared equally across trials, and each type of probe stimulus was associated with the same number of target-present and target-absent primes (Table 3 in Appendix B). Each of the tasks was preceded by a short training phase consisting of eight trials, during which participants received feedback based on their accuracy. Specifically, negative feedback was presented in cases of incorrect detection of the prime stimulus or incorrect responses during the numerical comparison probe. No feedback was provided during the test phase. In total, these two priming tasks lasted approximately 15 min.

Neutral task

The neutral task was a classic ANS task and was structurally identical to the probe phase of the priming tasks, except that no prime item was presented. Participants indicated which array contained more dots by pressing “D” to choose the left array and “K” to choose the right array. Each trial began with a fixation cross (500 ms), followed directly by a pair of dot arrays displayed for up to 1000 ms or until the participant responded. If no response was given within this interval, a gray screen was displayed and remained visible until a response was given, followed by a 2000 ms visual mask, consistent with the priming tasks.

As in the priming tasks, the neutral task consisted of three blocks of 24 trials (72 trials total), preceded by a brief training phase of eight trials with feedback provided on accuracy. No feedback was provided during the test phase. The same set of 72 counterbalanced pairs of dots arrays was used, varying in congruency (congruent vs. incongruent), manipulated non-numerical dimension (Item size vs. Convex hull), numerical ratio (0.67, 0.80, 0.86), and side of the correct response (left vs. right).

Results

We first removed outlier trials based on response times (RTs) in the numerical comparison probe. Specifically, trials with RTs faster than 200 ms or slower than 2.5 standard deviations (SDs) above the participant's mean RT were excluded. This procedure led to the removal of 1.97% of the total trials across all participants. We also examined whether any individual participants' mean performance deviated substantially from the group. No participant had a mean accuracy below 2.5 SDs from the sample mean, nor a mean RT outside ± 2.5 SDs from the sample mean. Importantly, performance in the prime detection task was very high ($M = 94.21\%$, $SD = 0.11$). In line with our exclusion criterion, two participants whose prime detection accuracy fell below 70% were removed from the analyses. All analyses reported below were therefore conducted on the remaining 52 participants. Note that performance in the prime detection task was not used as an outcome variable but only as an inclusion criterion. All subsequent analyses are conducted on responses in the probe numerical comparison task only.

Data analyses

We assessed the assumptions of repeated-measures ANOVA. Normality of residuals was evaluated via visual inspection (Q-Q plots). Sphericity was tested with Mauchly's test, and Greenhouse-Geisser corrections were applied whenever it was violated. As is typical for within-subject behavioural data, residual deviations from normality were mild, and ANOVAs are robust to such violations.

RTs were analyzed in their raw form after removing outliers. Analyses using log-transformed RTs yielded the same pattern of effects. As is common in adult ANS tasks, accuracy showed ceiling effects in some conditions. An arcsine-square-root transformation was explored but did not alter the conclusions. Therefore, results are reported on untransformed data for clarity.

Accuracy

We first conducted a 3 (Priming Task: Neutral, Global, Local) \times 2 (Congruency: Congruent, Incongruent) \times 2 (Dimension: Item size, Convex hull) repeated-measures ANOVA on probe accuracy, i.e. participants' mean accuracy in the numerical comparison task. Because the main goal of the priming paradigm was to induce a processing mode (global or local), we only included trials with correct prime detection. Together with the RT-based outlier exclusion, this led to the removal of 4.61% of all trials in total for the accuracy analyses. The dependent variable in this section is probe accuracy. Mauchly's test indicated that sphericity was violated for factors involving the Priming Task variable, therefore, Greenhouse-Geisser corrections were applied to these effects. There was no main effect of the Priming Task, $F(1.97, 100.54) = 0.25$, $p = .775$, $\eta^2_p = .005$, indicating that overall accuracy did not differ between the neutral, global, and local tasks. There was a significant main effect of Congruency, $F(1, 51) = 64.83$, $p < .001$, $\eta^2_p = .560$, with higher accuracy in congruent trials ($M = 0.87$, $SD = 0.18$) compared to incongruent trials ($M = 0.73$, $SD = 0.21$). No significant main effect of Dimension was observed, $F(1, 51) = 0.91$, $p = .345$, $\eta^2_p = .017$. The analysis revealed a significant Congruency \times Dimension interaction, $F(1, 51) = 43.64$, $p < .001$, $\eta^2_p = .461$. Post-hoc comparisons with Holm-Bonferroni correction (p_{adj}) revealed that, only for the Convex hull dimension, congruent trials ($M = 0.96$, $SD = 0.07$) were performed better than the incongruent trials ($M = 0.65$, $SD = 0.22$), $t(51) = 10.71$, $p_{adj} < 0.001$. In contrast, no significant difference was found between congruent ($M = 0.77$, $SD = 0.21$) and incongruent ($M = 0.82$, $SD = 0.16$) trials for the Item size dimension, $p_{adj} = 0.2$. Finally, neither the Priming \times Congruency interaction, $F(1.75, 89.37) = 0.61$, $p = .524$, $\eta^2_p = .012$, nor the Priming \times Dimension interaction, $F(1.94, 99.00) = 2.46$, $p = .092$, $\eta^2_p = .046$, reached significance. The three-way interaction among Priming, Congruency, and Dimension was also non-significant, $F(1.94, 98.88) = 0.94$, $p = .390$, $\eta^2_p = .018$.

Reaction times

We next analyzed reaction times (RTs) for correct probe responses, considering only trials where both the prime target was correctly detected and the probe numerical comparison response was accurate, using the same $3 \times 2 \times 2$ repeated-measures ANOVA (Fig. 4). Together with the RT-based outlier exclusion, this led to the removal of 23.55% of all trials in total for the reaction time analyses. Mauchly's test indicated that sphericity was violated for factors involving the Priming Task variable. Therefore, Greenhouse-Geisser corrections were applied to these effects. We found no main effect of Priming Task, $F(1.83, 93.42) = 1.48$, $p = .233$, $\eta^2_p = 0.028$, indicating that overall reaction times did not significantly differ across the neutral, global, and local tasks. A significant main effect of Congruency was observed, $F(1, 51) = 90.06$, $p < .001$, $\eta^2_p = 0.64$, with faster responses in congruent trials ($M = 729.14$ ms, $SD = 194.63$ ms) than incongruent trials ($M = 816.37$ ms, $SD = 214.61$ ms). There was also a significant main effect of Dimension, $F(1, 51) = 8.60$, $p = .005$, $\eta^2_p = 0.144$, with faster responses for the Convex hull dimension ($M = 765.26$ ms, $SD = 211.91$ ms) than Item size ($M = 780.26$ ms, $SD = 206.72$ ms). The Priming Task \times Dimension interaction was significant, $F(1.89, 100.40) = 5.33$, $p = .007$, $\eta^2_p = 0.091$, as was the Dimension \times Congruency, $F(1, 51) = 6.05$, $p = .017$, $\eta^2_p = 0.106$, and the Priming Task \times Congruency interaction, $F(1.70, 86.90) = 3.45$, $p = .043$, $\eta^2_p = 0.063$. Critically, the analysis revealed a significant three-way Priming Task \times Congruency \times Dimension interaction, $F(1.40, 71.16) = 11.27$, $p < .001$, $\eta^2_p = 0.181$. To further examine this three-way interaction, we conducted Holm-Bonferroni post-hoc comparisons. First, for the Convex hull dimension, number/convex hull congruency effects were consistently observed in all three priming tasks: In the neutral task, RTs were significantly faster for congruent trials ($M = 709.46$ ms, $SD = 205.92$ ms) than incongruent trials

($M = 841.45$ ms, $SD = 218.61$ ms), $t(51) = 6.61$, $p_{adj} < 0.001$. A similar pattern was found in the global priming task (congruent: $M = 700.152$ ms, $SD = 182.69$ ms; incongruent: $M = 863.37$ ms, $SD = 246.85$ ms), $t(51) = 6.61$, $p_{adj} < 0.001$. In the local priming task, the congruency effect also reached significance (congruent: $M = 709.35$ ms, $SD = 170.68$ ms; incongruent: $M = 767.75$ ms, $SD = 183.81$ ms), $t(51) = 4.32$, $p_{adj} = 0.003$. Comparisons between priming tasks revealed that RTs for the Number/Convex hull incongruent trials were significantly faster in the local priming task ($M = 767.752$ ms, $SD = 183.81$ ms) than in both the global priming task ($M = 863.37$ ms, $SD = 246.85$ ms), $t(51) = 3.70$, $p_{adj} = 0.023$, and the neutral task ($M = 841.61$ ms, $SD = 218.61$ ms), $t(51) = 3.53$, $p_{adj} = 0.036$. Second, for the Item size dimension in the local priming condition, RTs for congruent trials were faster ($M = 726.11$ ms, $SD = 200.5$ ms) than for incongruent trials ($M = 821.94$ ms, $SD = 211.03$ ms) but the difference did not reach significance, $t(51) = 3.37$, $p_{adj} = 0.054$. No significant congruency effect was observed in either the global or neutral tasks, $ps > 0.07$. No other between-tasks comparisons reached significance, $ps > 0.16$.

Discussion

This study investigated whether inducing local and global visual processing modulates the resolution of numerical conflicts in adults performing a non-symbolic numerical comparison task. To this end, we used a priming paradigm in which each numerical comparison trial was preceded by a hierarchical figure designed to activate either a global or a local processing mode. A third condition, without any prime, served as a neutral baseline.

As expected, and in line with previous findings in the literature^{2,6,7,9}, we observed clear overall congruency effects in the neutral ANS task, with participants performing less accurately and more slowly on trials where number conflicted with non-numerical dimensions of magnitude. These effects were most pronounced for the Convex hull dimension, whereas no clear interference emerged for the Item size dimension, a pattern consistent with previous findings showing reduced or absent number/size congruency effects in adults⁹. When considering performance across the three priming conditions, congruency effects were still found, confirming that participants consistently relied, to some extent, on irrelevant visual cues when comparing dots arrays. Additionally, the type of hierarchical priming modulated these effects, supporting our hypotheses that visual processing mode influences how numerical conflicts are resolved.

Effects of local and global priming

Local priming, specifically, seemed to affect this numerical conflict resolution, although its impact differed across magnitude dimensions. For the Item size dimension, we observed numerically larger differences between congruent and incongruent trials in the local condition than in the neutral and global conditions. However, pairwise comparisons in the local priming condition did not reach statistical significance. Moreover, post-hoc comparisons did not reveal significant differences between the local and neutral conditions when congruent and incongruent trials were examined separately. This suggests that local priming may have subtly increased the salience of intrinsic visual features such as dot size, but the present data do not allow firm conclusions regarding its specific effect on number/item size conflict. In contrast, for the Convex hull dimension, congruency effects seemed to be reduced under local priming compared to both the global priming and neutral conditions. This reduction appeared to be driven by faster reaction times on incongruent Convex hull trials, suggesting that local priming may have diminished participants' sensitivity to extrinsic visual features such as convex hull. As a result, participants may have been better able to ignore irrelevant global information when it conflicted with numerosity. This asymmetry between the Item size and Convex hull dimensions may reflect a distinction in how visual salience affects performance: in the Item size condition, increasing the salience of a weakly interfering dimension through local priming may lead to effects on both congruent and incongruent trials, whereas in the Convex hull condition, decreasing the salience of an initially strongly interfering dimension primarily improves performance on incongruent trials.

Contrary to our expectations, global priming had no significant impact on congruency effects compared to the neutral condition. One possible explanation is that in the number/convex hull trials of the neutral task, performance may have already approached ceiling-level response times for congruent trials and floor-level response times for incongruent trials. Given that the number/convex hull congruency effect was already substantial in the neutral task, this may have limited the potential for global priming to further enhance it. However, a more compelling explanation lies in the idea that global processing may already be the default mode in adults. Adults are already known to show a robust global precedence effect^{21,27}, suggesting that participants may have spontaneously engaged in global visual processing even in the neutral task. This may have limited the effectiveness of the priming manipulation in further enhancing global processing, explaining also why similar patterns of results were evidenced for global and neutral conditions.

Taken together, these findings suggest that visual attentional mode contributes to the way individuals resolve numerical conflicts. The fact that local priming modulated congruency effects differently depending on the type of conflict supports the idea that visual processing mode can selectively orient attention toward specific dimensions of magnitude, which in turn influences numerical judgments. Specifically, local visual processing appeared to reduce interference from global, extrinsic magnitude dimensions such as convex hull, while exerting a weak influence on intrinsic dimensions such as item size. Although our study did not directly assess Spontaneous Focus on Numerical Magnitudes (SFOM), our results may have implications for this construct. Our findings suggest that perceptual processing modes might be one mechanism influencing which types of magnitude information become salient and thus could contribute to interindividual or contextual variability in SFOM. More generally, our results also align with theoretical accounts emphasizing the importance of selective attention to numerical information in the face of competing non-numerical dimensions of magnitude^{12,13}. Global and local visual processing may act as an attentional filter that affects performance in non-symbolic

numerical comparison tasks. Future studies are needed to clarify how spontaneous attention tendencies, which vary for instance according to inter-individual particularities⁴³ interact during numerical comparison.

Limitations

Although the present study provides new insights into the role of global and local visual processing in numerical conflict resolution, several limitations should be acknowledged. First, our manipulation relied on a priming paradigm, which allowed us to capture only short-term effects. Future studies using sustained training or individual difference measures could provide complementary evidence regarding the stability of these effects.

Second, a conceptual limitation concerns the fact that dot arrays inherently combine several correlated dimensions of magnitude. As shown in Appendix B (Tables 2 and 3), when one dimension was manipulated, other dimensions from the same group (intrinsic or extrinsic) varied in the same direction, whereas dimensions from the other group were either held constant or showed a consistent directional bias across congruent and incongruent trials. Although our design specifically targeted item size and convex hull, other intrinsic and extrinsic dimensions (such as total area, total perimeter, and mean occupancy) covaried in systematic ways due to the constraints of stimulus generation. These covariations were identical across priming conditions and therefore cannot account for the differential effects of global versus local priming. However, they imply that our findings likely reflect changes in the relative weighting of groups of visual features rather than effects attributable to a single feature in isolation. Future research could examine how global and local processing shape the integration of multiple co-occurring visual features during numerosity judgments.

Third, our sample consisted solely of adults, who are already known to exhibit a global processing bias^{21, 22, 28}. This may have limited the observable impact of global priming, as discussed above. A further limitation concerns the gender imbalance in our sample, which reflects the demographics of our recruitment platform. Although we did not have specific hypotheses about gender effects and the study was not powered to test them, previous work had reported gender-specific effects in related tasks²⁹. We therefore cannot draw conclusions regarding potential gender differences, and futures studies specifically designed to examine this question would be valuable.

Implications and directions for future research

These limitations point to promising directions for future research. Investigating how visual processing mode interacts with numerical conflict resolution in children, who tend to rely more on local features²⁸ and show stronger interference effects in ANS tasks⁹, could clarify how visual processing mode interacts with numerical conflict resolution across development. Furthermore, directly assessing spontaneous attention to numerical vs. non-numerical dimensions of magnitude, possibly in combination with eye-tracking measures, could help test the relation between the effects observed and spontaneous focusing tendencies.

Taken together, these findings show that modulating visual processing mode can selectively impact how adults resolve specific types of numerical conflicts. The present results also suggest that even when participants are presented with the same numerical task, their attentional state influences how they process numerical information. This provides new insights into how visuo-attentional mechanisms can influence core aspects of numerical cognition such as attention to number and opens new avenues for understanding numerical cognition across development.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Appendix A

See Table 1.

Order	Task		
1	Neutral	Global	Local
2	Local	Neutral	Global
3	Global	Local	Neutral
4	Neutral	Local	Global
5	Global	Neutral	Local
6	Local	Global	Neutral

Table 1. Latin square design for the order of the three tasks (neutral, global, local).

Appendix B

See Tables 2, 3 and 4.

Numerosity pair	Dimension	Small value	Large value
(12,18)	Item size	616	1521
(20,25)	Item size	804	1385/1521
(18,21)	Item size	908	1257

Numerosity pair	Dimension	Small value	Large value
(12,18)	Convex hull	54,990	123,750
(20,25)	Convex hull	70,000	109,375/109,380
(18,21)	Convex hull	75,995	103,446

Table 2. Exact item size and convex hull values (in px) used in NASCO for each numerosity pair. Values correspond to the closest solutions produced by NASCO, which applies minor automatic adjustments when generating valid dot arrays.

Numerical pair	Condition	Item size	Total area	Total perimeter	Convex hull	Mean occupancy
(12,18)	Item size cong.	2.47 (C)	3.7 (C)	2.36 (C)	1	1.5 (I)
	Item size incong.	2.47 (I)	1.66 (I)	1.05 (I)	1	1.5 (I)
	Convex hull cong.	1	1.5 (C)	1.5 (C)	2.25 (C)	1.5 (C)
	Convex hull incong.	1	1.5 (C)	1.5 (C)	2.25 (I)	3.38 (I)
(20,25)	Item size cong.	1.72 (C)	2.15 (C)	1.64 (C)	1	1.25 (I)
	Item size incong.	1.89 (I)	1.51 (I)	1.1 (I)	1	1.25 (I)
	Convex hull cong.	1	1.25 (C)	1.25 (C)	1.56 (C)	1.25 (C)
	Convex hull incong.	1	1.25 (C)	1.25 (C)	1.56 (I)	1.95 (I)
(18,21)	Item size cong.	1.38 (C)	1.62 (C)	1.37 (C)	1	1.17 (I)
	Item size incong.	1.38 (I)	1.19 (I)	1.17 (I)	1	1.17 (I)
	Convex hull cong.	1	1.17 (C)	1.17 (C)	1.36 (C)	1.17 (C)
	Convex hull incong.	1	1.17 (C)	1.17 (C)	1.36 (I)	1.59 (I)

Table 3. Ratios of non-numerical dimensions of magnitudes for each congruency condition and each numerical pair. Values represent ratios (larger/smaller) for each non-numerical dimension. (C) indicates that the dimension was congruent with numerosity, whereas (I) indicates that it was incongruent.

ANS probe			Hierarchical prime		
Ratios	Response side	Congruency	Prime 1	Prime 2	Prime 3
0.67	Left	Congruent	Tree - No1	Boat - No2	Umbrella - No3
0.67	Left	Incongruent	Tree - No2	Boat - No3	Umbrella - No1
0.67	Right	Congruent	Tree - No3	Boat - No1	Umbrella - No2
0.67	Right	Incongruent	Tree - No1	Boat - No2	Umbrella - No3
0.80	Left	Congruent	Tree - No2	Boat - No3	Umbrella - No1
0.80	Left	Incongruent	Tree - No3	Boat - No1	Umbrella - No2
0.80	Right	Congruent	Tree - No1	Boat - No2	Umbrella - No3
0.80	Right	Incongruent	Tree - No2	Boat - No3	Umbrella - No1
0.86	Left	Congruent	Tree - No3	Boat - No1	Umbrella - No2
0.86	Left	Incongruent	Tree - No1	Boat - No2	Umbrella - No3
0.86	Right	Congruent	Tree - No2	Boat - No3	Umbrella - No1
0.86	Right	Incongruent	Tree - No3	Boat - No1	Umbrella - No2

Table 4. Counterbalancement of the probe-prime pairs of stimuli.

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Conceptualization, L.C., A.V., N.P., and A.K.; Methodology, L.C., A.V., N.P., and A.K.; Formal Analysis, L.C., and A.V.; Investigation, L.C., and A.V.; Writing – Original Draft, L.C., and A.V.; Writing – Review and Editing, L.C., A.V., N.P., and A.K.; Visualization, L.C., and A.V.; Supervision, A.V.

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Additional information

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