1   **Number neurons in the nidopallium of young domestic chicks**

2   Dmitry Kobylkov[1], Uwe Mayer[1], Mirko Zanon[1], Giorgio Vallortigara[1*]

3   [1] Center for Mind/Brain Science, University of Trento, Rovereto, 38068, Italy.

4   * Corresponding author: Giorgio Vallortigara

5   P.zza Manifattura, 1, 38068 Rovereto, Italy; tel. 0464 808676

6   email: giorgio.vallortigara@unitn.it

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Abstract

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22   Numerical cognition is ubiquitous in the animal kingdom. Domestic chicks are a

23   widely used developmental model for studying numerical cognition. Soon after

24   hatching, chicks can perform sophisticated numerical tasks. Nevertheless, the neural

25   basis of their numerical abilities has remained unknown. Here, we describe for the

26   first time number neurons in the caudal nidopallium (functionally equivalent to the

27   mammalian prefrontal cortex) of young domestic chicks. Number neurons that we

28   found in young chicks showed remarkable similarities to those in the prefrontal

29   cortex and caudal nidopallium of adult animals. Thus, our results suggest that

30   numerosity perception based on the labeled-line code provided by number neurons

31   might be an inborn feature of the vertebrate brain.

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Significance

34   Numerosity, i.e. the number of items in a set, is a significant aspect in the perception

35   of the environment. Behavioural and in silico experiments suggest that number

36   sense belongs to a core knowledge system and can be present already at birth.

37   However, neurons sensitive to the number of visual items have been so far

38   described only in the brain of adult animals. Therefore, it remained unknown to what

39   extent their selectivity would depend on visual learning and experience. We found

40   number neurons in the caudal nidopallium (a higher associative area with functional

41   similarities to the mammalian prefrontal cortex) of very young, numerically naïve

42   domestic chicks. This result suggests that numerosity perception is possibly an

43   inborn feature of the vertebrate brain.

Introduction

Be it a number of conspecifics in a group (Balestrieri et al. 2019), a number of food items (Hunt et al. 2008), or a number of motifs in a song (Templeton et al. 2005), correct estimation of quantities is of vital importance for animals. Several behavioural studies have confirmed that numerical competence is not a prerogative of human beings, but is a widespread phenomenon in the animal kingdom (reviewed by Nieder 2019, Lorenzi et al. 2021). Mammals (Davis and Albert 1986, Ward and Smuts 2007, Beran et al. 2008), birds (Lyon 2003, Templeton et al. 2005, Rugani et al. 2009), reptilians (Gazzola et al. 2018), amphibians (Stancher et al. 2015), fishes (Potrich et al. 2015), and invertebrates (Bortot et al. 2021), although evolutionary distant, all can spontaneously assess quantities using an approximate number system (Brannon and Merritt 2011).

For the approximate number system, which is based on the Weber-Fechner law (Nieder 2016), the perception of cardinal numbers resembles the perception of continuous physical stimuli. As a consequence, discrimination of quantities is imprecise and depends on the numerical distance between stimuli. In other words, it is easier to tell apart 5 and 10 than 9 and 10. Moreover, discrimination of quantities becomes increasingly difficult with the numerical size. For a given numerical distance (e.g., 1) it is easier to discriminate between numbers with low magnitudes (1 vs. 2), than with high magnitudes (9 vs. 10).

Recent research has uncovered that the approximate number system relies on the activity of a specific neuronal population. Neurons that respond to abstract numerosity irrespective of objects' physical appearance (shape, colour, size) have been found in the forebrain of human and non-human primates (Nieder 2012, Kutter

68 et al. 2018) and in crows (Ditz and Nieder 2015). In mammals, numerical responses

69 were recorded in the parietal and the prefrontal cortices (PFC, Nieder 2012). In birds,

70 similar neurons have been described in the caudolateral nidopallium (NCL, Ditz and

71 Nieder 2015). The NCL is believed to be an analogue of the PFC in the avian brain

72 (Güntürkün et al. 2021) and is involved in a variety of cognitive processes, including

73 memory formation (Diekamp et al. 2002, Hahn et al. 2021), abstract rule learning

74 (Veit and Nieder 2013), and action planning (Veit et al. 2015).

75 Both monkeys and crows are among the most evolutionary advanced species of

76 their phylogenetic groups. They independently developed sophisticated intellectual

77 capacities (Nieder et al. 2020) and both possess enlarged forebrains (Olkowicz et

78 al., 2016). The neural representation of numerosities described in these species also

79 shares remarkable similarities (Nieder et al. 2002, Ditz and Nieder 2015,

80 Viswanathan and Nieder 2013, Wagener et al. 2018). In both species, the number

81 neurons tuned to a preferred numerosity show a gradual decrease in firing rate to

82 other numerosities (numerical distance effect). Their tuning curves are skewed

83 towards larger numerosities and become progressively broader (less selective) with

84 increasing numerosities (numerical size effect). However, it is unclear whether the

85 presence of similar number neurons in these two species emerges as a

86 consequence of their elaborate cognitive skills and enlarged forebrains. To

87 understand the evolution of the number sense we need to explore its neural

88 correlates in distant bird species with more ancestral traits.

89 Moreover, until now, number neurons have been described only in adult animals

90 (e.g. Nieder et al. 2002, Sawamura et al. 2002, Viswanathan and Nieder 2013, Ditz

91 and Nieder 2015, Wagener et al. 2018). At the same time, behavioural data from

92 human infants (Izard et al. 2009) and young domestic chicks (Rugani et al. 2008,

93 2009) indicate that some core numerical abilities might be an inborn or
94 spontaneously emerging (Kim et al. 2021, Nasr et al. 2019) property of the
95 vertebrate brain. Testing the presence of number neurons in young and untrained
96 organisms is crucial to verify this hypothesis.

97 In our study, we aimed to describe the neural correlates of the number sense in
98 domestic chicks (*Gallus gallus*), which belong to a sister group of modern Neoaves
99 (Prum et al. 2015). The domestic chick is a well-established developmental model for
100 studying numerical cognition. Soon after hatching these birds are already capable of
101 discriminating quantities (Rugani et al. 2008, 2013) and even performing basic
102 arithmetic operations (Rugani et al. 2009). It has also been shown that young chicks
103 represent numbers across the mental number line (Rugani et al. 2015), a cognitive
104 ability that had been previously attributed only to humans.

105 We hypothesised that neural processing of numerical information in young untrained
106 chicks might be similar to crows, despite them having been evolving independently
107 over the last ~ 70 million years (Prum et al. 2015). In a domestic chicken, the NCL is
108 morphologically different from that of corvids (von Eugen et al. 2020), but it is unclear
109 whether this reflects any functional difference. Therefore, we decided to search for
110 neural responses to numerical stimuli in the NCL of domestic chicks. For this
111 purpose we habituated young chicks to a computer monitor, where numerical stimuli
112 were presented (Fig. 1A). We explored neural responses to numerosities from 1 to 5.
113 To control for non-numerical parameters we presented three different categories of
114 stimuli:"radius-fixed", "area-fixed", and "perimeter-fixed" (Fig. 1B).

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Results

We recorded the activity of 471 units in the NCL of young domestic chicks and examined the mean firing rate of each unit during stimulus presentation (Fig. 2A-B). Among these units, 53 (11%) responded to numerosity irrespective of the stimulus type (henceforth "number neurons", see Nieder 2016). This was revealed by a two-way ANOVA with the factors "numerosity" (5 levels: 1-5) and "stimulus type" (3 levels: "radius-fixed", "area-fixed", "perimeter-fixed"). The unit was considered as a number neuron only if the main effect of the factor "numerosity" was highly significant ($p<0.01$), but not the effect of the "stimulus type" or the interaction between the two factors. The numerosity that elicited the strongest neural response was defined as the preferred numerosity for this number neuron (after Ditz and Nieder 2015). Five examples of number neurons tuned to different numerosities are shown in Fig. 2C-G. The corresponding statistics are summarised in Table 1. The responses of all 53 number neurons are summarised in Fig. 3A (for statistical results see Table S1 in the supplementary materials, for an example of trials with numerical responses see Video S1 in the supplementary materials).

Most of the number neurons were tuned to the numerosity 1 (30%, N = 16) and 5 (32%, N = 17). However, we found neurons responsive to other numerosities as well (2: 11%, N = 6; 3: 9%, N = 5; 4: 17%, N = 9), covering the whole range of tested numerosities (Fig. 2B).

When grouped by their preferred numerosity, the tuning curves of number neurons were asymmetric and increasingly wider towards larger numerosities (Fig. 3B). To quantify this numerical magnitude effect, we plotted neural filter functions of single neurons on four different scales: a linear scale, a power function with an exponent of

141   0.5, a power function with an exponent of 0.33, and a logarithmic (log2) scale. The

142   neural filter functions became significantly more symmetric on a non-linear scale

143   (Friedman test: $X^2(3) = 10.653$; p = 0.014, Fig. 4A), with the linear scale significantly

144   different from the power 0.33 and logarithmic scales (Nemenyi test: p = 0.022 and p

145   = 0.028, respectively), but not from the power 0.5 scale (Nemenyi test: p = 0.176).

146   The sigma of the Gaussian fit increased with numerosity only when plotted on a

147   linear scale (Fig. 4B, slope of the linear fit = 0.17) but not with other non-linear scales

148   (Fig. 4B, power 0.5: slope = -0.003, power 0.33: slope = -0.01, log2: slope = -0.03).

149   To evaluate the probability of finding false positive numerical responses in our

150   dataset, we used the trial-shuffle method (1000 times for every recorded unit). After

151   each shuffling we selected false-positive number neurons by the same statistical

152   criteria described above. The proportion of real number neurons (11 %; 53 out of

153   471) was significantly higher than the proportion of false-positive units (0,95%; 4488

154   out of 471000) obtained by the analysis of randomly shuffled trials (proportion test:

155    $X^2(1) = 512,56$, p<0.001).

156   We further compared the tuning curves between the false positive number neurons

157   and the real number neurons. For this, for each numerical category we randomly

158   selected the same number of corresponding false-positive neurons as the actually

159   recorded number neurons in that category (Fig 2B). We compared the tuning curves

160   of the real and false-positive neurons (Fig 4C) computing a two-way ANOVA with the

161   factors "absolute numerical distance" (5 levels: 0-4) and "data type" (2 levels:

162   real/false positive). The response of real neurons decreased gradually with

163   numerical distance, meaning that closest numerosities were more likely to trigger the

164   number neurons. In contrast, the tuning curve of the false-positive neurons, which by

165   chance happened to have higher firing rates for a random numerical stimulus, was

166 markedly different from real number neurons (interaction for the factor "numerical

167 distance * data type": $F_{(1,526)} = 6.275$; $p = 0.01$).

168 We further described the selectivity of number neurons for unique numerosities by

169 performing a post hoc analysis and comparing the response between the most

170 preferred and other numerosities (Table 2). 9 out of 53 number neurons showed

171 statistically different firing rates between the most-preferred and closest

172 neighbouring numerosities. As expected from the numerical size effect, neurons

173 tuned to lower numerosities are generally more selective than neurons coding for

174 larger numerosities. 6 out of 16 neurons with the preferred numerosity 1 significantly

175 decreased their firing rate in response to the numerosity 2. At the same time, out of

176 17 neurons that preferentially responded to the numerosity 5, only 1 neuron showed

177 significantly lower response to the numerosity 4. The number neurons generally

178 better differentiated between numerosities with increasing numerical distance (GLM

179 for absolute numerical distance: $X^2(18) = 3.935$, $p = 0.047$; GLM for the log of the

180 numerical distance: $X^2(18) = 6.544$, $p = 0.011$). This effect was more prominent

181 when the numerical distance was calculated on the logarithmic scale: the GLM for

182 the log of the numerical distance had a better fit than the GLM for absolute numerical

183 distance ($\Delta BIC = 6.36$). For the summary of all post hoc results, see TableS2 in the

184 supplementary materials.

185

186 **Discussion**

187 We recorded number neurons in 8-12 day old chicks, the youngest animals in which

188 number neurons have been described so far. In the NCL of young domestic chicks,

189 11% of neurons showed a strong selective response to numerical stimuli, confirming

190   the role of this structure in avian numerical cognition. Moreover, our chicks were not

191   trained in any numerical discrimination task. Instead, they were simply paying

192   attention to the screen, where the numerical stimuli were presented (passive fixation,

193   Hussar and Pasternak 2009). Thus, our young chicks can be considered numerically

194   naïve (see Viswanathan and Nieder 2013).

195   This result is in line with previous studies on numerically naïve adult animals of

196   distant lineages: 14% of neurons in the prefrontal cortex (PFC) of adult monkeys

197   (Viswanathan and Nieder 2013) and 12% of neurons in the NCL of adult crows

198   (Wagener et al. 2018) have shown numerical response. It is important to note that in

199   any of these studies including our own, we cannot completely exclude a potential

200   unsupervised learning effect due to a repeated exposure to numerical stimuli.

201   Indeed, recent studies have found that in a deep neural network designed to analyse

202   images, a similar amount of number detectors can emerge spontaneously (Nasr et

203   al. 2019), even without pre-training (Kim et al. 2021). However, the hypothesis that

204   number neurons can spontaneously emerge in the biological visual system has not

205   been directly tested so far.

206   Our data, together with behavioural evidence from newly hatched domestic chicks

207   (Rugani et al. 2008, 2009) and newborn infants (Izard et al. 2009), suggest that

208   numerosity detection might be an inborn or spontaneously emerging feature of the

209   brain. Our results certainly should not be automatically extrapolated to other

210   newborn organisms, since the domestic chicken is a precocial species with a very

211   rapid development after hatching. Nevertheless, even in 2-weeks-old chicks, the

212   functional organization of the brain still remains immature and flexible (Zappia and

213   Rogers 1987). Thus, the presence of number neurons in young chicks, which were

214   not trained to discriminate any specific numerosity, supports the idea of an inborn

215   number sense. Moreover, since behavioural studies (Rugani et al. 2009, 2013) show

216   that newly hatched chicks perceive numerical information, we might expect to find

217   number neurons already at the first day after hatching.

218   The number neurons in domestic chicks showed very similar features to those

219   observed in primates and crows (Viswanathan and Nieder 2013, Ditz and Nieder

220   2015, 2016). First, the number neurons we observed were tuned to specific

221   numerosities, in accordance with the labelled-line code shown for the number

222   neurons in the NCL of crows (Ditz and Nieder 2015, 2016). Second, chicks' number

223   neurons showed a specific decay in response to non-preferred numerosities, which

224   was similar to number neurons in other species and could not have been obtained by

225   chance (see false-positive neurons in Fig. 4C). Third, we observed the numerical

226   magnitude effect: the tuning curves of number neurons became wider with increased

227   numerosity and more symmetrical when plotted on the non-linear scale (Fig. 3B).

228   Also the selectivity of the neural response to non-preferred numerosities increased

229   with the logarithm of the numerical distance, rather than with the absolute numerical

230   distance.

231   The overall low selectivity to specific numerosity at a single-cell level, as revealed by

232   the post hoc analysis (Table 2), appears to be similar to what was observed in other

233   species (Viswanathan and Nieder 2013; Ditz and Nieder 2015, 2016). How brains

234   can depict precise numerosities with such a noisy system may be explained by a

235   population rate code (Nieder 2016). Single cells respond to every trial in a

236   probabilistic way and only on average show increased firing rates to a given

237   numerosity. Smooth tuning curves only emerge after the neural filter functions of

238   many single cells tuned to the same numerosity are pooled together (Fig. 3B). For an

239   animal to immediately assess numerosity, independent responses of several number

240   neurons should be averaged simultaneously over a large population. Thus, at the

241   neural population level, stimulation by a specific numerosity would result in a distinct

242   activation pattern. This hypothesis can be tested only by implementing methods that

243   allow recording of single-cell activity over a large neural population.

244   Given these striking similarities between number neurons in the NCL of crows and

245   chicks, it seems a reasonable guess that they share the same evolutionary origin.

246   This, in turn, would mean that the neural mechanism of the number sense is not an

247   advanced evolutionary adaptation of a few highly intelligent species. Number

248   neurons in the NCL are likely an ancestral feature in avian species, since domestic

249   chicks belong to the sister group of modern Neoaves (Prum et al. 2015).

250   While it is very tempting to go one step further and discuss the idea of the common

251   evolutionary origin of number neurons for all vertebrates, this would be too

252   speculative. The NCL in birds and the prefrontal cortex in mammals do share similar

253   functions, but are not homologous structures (Güntürkün and Bugnyar 2016, Preuss

254   and Wise 2021). Birds independently developed cortical brain regions, including the

255   NCL, that enabled their high cognitive functions (Güntürkün et al. 2021) based on

256   similar to mammalian pallial architecture (Stacho et al. 2020). The same is likely true

257   also for the Dc (dorsal-central) region in the telencephalon of zebrafish, which has

258   been recently shown to process numerical information (Messina et al. 2021). The

259   possibility of a direct homology between the Dc and either the PFC or the NCL can

260   only be addressed at a macroscopic level. These three regions likely belong to larger

261   neocortex homologues in the respective species (Briscoe and Ragsdale 2019, but

262   see Puelles 2017). However, given the developmental and morphological differences

263   between these areas, new cortical subregions with similar functions must have

264   appeared multiple times during independent evolution of these structures.

265   Two hypotheses can be put forward on the evolution of number sense in vertebrates.

266   The first one is that number perception evolved independently several times in

267   different phylogenetic groups, although our data strongly suggest that number

268   neurons in the nidopallium are an ancestral trait of birds. This mechanism, however,

269   still can be an adaptation that evolved in parallel to mammalian number neurons. In

270   this case, the identical labelled-line coding scheme for numerosities adopted by birds

271   and mammals might be computationally advantageous and, therefore, evolved

272   independently in both groups (Ditz and Nieder 2015). The second hypothesis is that

273   numerosity processing can be based upon an ancient core neural circuit shared

274   among all vertebrates. In this case, we would expect to find numerosity responses in

275   other, evolutionary conserved brain regions homologically shared among vertebrates

276   (Lorenzi et al. 2021). Indeed, some indirect evidence suggests that at least a coarse

277   estimation of quantity, i.e. more vs. less, might be present already at the subcortical

278   level in humans (Collins et al. 2017) and in the midbrain of birds (Gusel'nikov et al.

279   1971) and zebrafish (Preuss et al. 2014).

280   These hypotheses are, however, not mutually exclusive. The putative ancestral

281   neural circuit might be dedicated to assess continuous physical parameters normally

282   associated with the numerosity, like total area of the stimulus. On the contrary,

283   higher order brain processing leading to estimation of cardinal numerosities at a

284   more abstract level may have developed several times, together with the

285   independent evolution of new cortex homologue brain areas in distant phylogenetic

286   groups (Striedter and Northcutt 2019).

287   Summing up, our study provides the first step in addressing a complex evolutionary

288   and developmental aspect of numerical cognition. By implementing a simplified

289   training procedure, we could, for the first time, demonstrate the existence of number

290 neurons in young numerically naïve domestic chicks. In the future, this method might

291 be easily adopted for studying the neural correlates of numerical cognition in other

292 brain regions, as well as in other species.

293

Materials and methods

Subjects

296 12 domestic chicks (*Gallus gallus domesticus*) of both sexes from the Aviagen

297 ROSS 308 strain were used. Fertilized eggs were obtained from a local commercial

298 hatchery (CRESCENTI Società Agricola S.r.l.–AllevamentoTrepola–cod.

299 Allevamento 127BS105/2). Eggs were incubated and hatched within incubators

300 (Marans P140TU-P210TU) at a temperature of 37.7 °C, with 60% humidity in a dark

301 room. After hatching in dark incubators, chicks were isolated and housed individually

302 in metal cages (28 cm wide $\times$ 32 cm high $\times$ 40 cm deep) with food and water

303 available *ad libitum*, at a constant room temperature of 30–32 °C and a constant

304 light–dark regime of 14 h light and 10 h dark. All experimental protocols were

305 approved by the research ethics committee of the University of Trento and by the

306 Italian Ministry of Health (permit number 745/2021-PR).

Experimental setup

308 The setup consisted of a rectangular shaped arena (28 X 40 X 32 cm; W X L X H)

309 with metal walls that were grounded. In the centre of one of the shorter walls there

310 was a circular opening (diameter 12 cm). A computer screen (AOC AGON

311 AG271QG4, 144Hz) used for stimuli presentation was positioned directly behind the

312 circular opening. Within the rectangular arena was a small wooden box 14 X 13 X 22

313   (W X L X H) cm whose frontal wall was made of a metal grid in. The box was placed

314   25 cm in front of the circular opening with the screen (Fig. 1A). During the

315   experiments chicks remained inside the box from where they could observe the

316   stimuli. Stimulus presentation was controlled by the PsychoPy toolbox (Pierce et al.

317   2019).

Habituation procedure

319   The habituation occurred between the 3rd and the 6th day after hatching. On the 3rd

320   day post hatching, chicks learned to peck on mealworms. During the day 4 after

321   hatching, chicks were, first, habituated to the experimental setup and then to the

322   number stimuli appearing on the screen. The birds received mealworms every time

323   after the stimulus appeared on the screen, which motivated them to pay attention to

324   the moment when any stimulus would appear. The stimuli were presented and

325   rewarded randomly, so that chicks would not associate any particular numerosity

326   with the reward. During the days 5 and 6 post hatching we gradually decreased the

327   reward rate, so that birds would still pay attention to the screen even without getting

328   a mealworm. This procedure allowed us to minimize rewarding during actual

329   recording sessions.

Surgery and recordings

331   On the 7th day after hatching chicks were fully anaesthetized using Isoflurane

332   inhalation (1.5 – 2.0% gas volume, Vetflurane, 1000mg/g, Virbac, Italy) and placed in

333   the stereotaxic apparatus with a bar fixed at the beaks' base and tilted 45° to ear

334   bars. Local anaesthesia (Emla cream, 2.5% lidocaine + 2.5% prilocaine,

335   AstraZeneka, S.p.A.) was applied to the ears and skull skin before and after the

336   surgery. Metal screws were placed into the skull for grounding and stabilisation of

the implant. A small craniotomy was made in the skull on the right hemisphere above the NCL (1.0 mm anterior to the bregma, 4.5 mm lateral to the midline). For extracellular recordings we used self-wired tetrodes made out of formvar-insulated Nichrome wires (17.78 μm diameter, A-M Systems, USA), which were gold-plated to reduce the impedance to 300 – 400 kOm (controlled by nanoZ, Plexon Inc., USA). Then, a commercially available Halo-5 microdrive (Neuralynx, USA) was assembled according to the producer instructions, where four single tetrodes were put into polymicro tubes (inner diameter 0.1 mm) and glued to the plastic shuttles. The microdrive was implanted and fixed first with quick adhesive silicone (Kwik-Sil, World Precision Instruments, USA) and then with dental cement (Henry Schein Krugg Srl, Italy). To increase the probability of finding number-responsive units, we did not glue the electrode tips within the tetrodes We, thus, considered each tetrode as a brush-like arrangement of four single electrodes. Since in this brush arrangement the positions of the electrode tips can vary, some of the electrodes may have recorded signals from the same neurons. Hence, for sorting and subsequent analyses we chose only the best electrode from each tetrode at every recording position to avoid double-counting of the same neurons.

After the surgery, the chicks were left to recover until the next day in their home cages. Between the 8th and the 12th day after hatching we recorded neural responses to numerical stimuli in the NCL of chicks. Before every recording session the microdrive was connected to the Plexon system (Plexon Inc., USA) via a QuickClip connector and an omnetics headstage (Neuralynx, USA). After every recording session the tetrodes were manually advanced by 60 – 100 μm.

Signals were pre-amplified with a 16-channel head-stage (20✕□, Plexon Model number: PX.HST/16V-G20-LN) subsequently amplified 1000□✕□, digitalised and

362   filtered (300 Hz high-pass filter, 3 kHz low-pass filter and 50 Hz noise removal).

363   Common average referencing (CAR) method (the averaged signal across channels)

364   of the PlexControl system was used for referencing. Spikes were detected with the

365   PlexControl software with an automatic 4-sigma threshold from the average noise

366   level. Subsequently, spike sorting was performed manually in the Plexon Offline

367   Sorter (see Figure S1 in supplementary information for examples of the raw signal

368   and spike sorting).

369   **Stimuli**

370   As numerical stimuli we used red dots outlined with a thin black line that appeared in

371   the centre of the screen in a white background circle 6 cm in diameter. The size of

372   stimuli ranged from 0.25 cm to 1.4 cm (0.6 – 3.2°, Schmid and Wildsoet 1998). We

373   explored neural responses to numerosities from 1 to 5. To control for visual

374   parameters that might interfere with numerosity perception, during every recording

375   session we presented three different types of stimuli (Fig. 1B). "Radius-fixed" type of

376   stimuli consisted of dots with a fixed radius, meaning that area and perimeter

377   increase with numerosity. "Area-fixed" stimuli have constant total area over all

378   numerosities, while the total perimeter of the dots increases with numerosity.

379   "Perimeter-fixed" stimuli have constant total perimeter over all numerosities, while

380   total area of these stimuli decreases with numerosity. To further control that neurons

381   do not respond to other visual parameters except for quantity, the inter-distance

382   interval between dots varied randomly. Moreover, for every day of recording we

383   created a new batch of stimuli consisting of 30 unique images for each

384   numerosity/stimulus type combination. Numerosity stimuli were created using

385   GeNEsIS software (Zanon et al. 2021).

16

386   During recording sessions we randomly presented stimuli for 500 ms with 2000 ms

387   of inter-stimulus interval. Experiments were video-recorded using CineLAB system

388   (Plexon Inc., USA). To enhance the motivation of birds to pay attention to the screen,

389   random trials were occasionally rewarded. These trials were subsequently discarded

390   from the analysis.

391   **Histological analysis**

392   After the last neural recording birds were overdosed with the ketamine/xylazine

393   solution (1:1 ketamine 10 mg/ml □+□xylazine 2 mg/ml). Electrolytic lesions were

394   made at the recording sites by applying a high-voltage current to the tetrodes for 10-

395   15 seconds. Then, the birds were perfused intracardially with the phosphate buffer

396   (PBS; 0.1 mol, pH□=□7.4, 0.9% sodium chloride, 5 °C) followed by 4%

397   paraformaldehyde (PFA). Brains were incubated for at least two days in PFA and

398   further two days in 30% sucrose solution in PFA. Coronal 60 µm brain sections were

399   cut at□-20 °C using a cryostat (Leica CM1850 UV), mounted on glass slides, stained

400   with the Giemsa dye (MG500, Sigma-Aldrich, St. Louis, USA), and cover slipped with

401   Eukitt (FLUKA). Brain sections were examined under the stereomicroscope (Stemi

402   508, Carl Zeiss, Oberkochen, Germany) to estimate the anatomical position of

403   recording sites.

404   **Data analysis**

405   Based on the analysis of video-recordings, we selected only those trials, when birds

406   were not rewarded. Since in birds there is an almost complete decussation of the

407   optic fibres we recorded from the right hemisphere and we selected only trials, when

408   birds looked at the stimulus with both eyes or with the contralateral (left) eye. For

409   each recorded unit, we excluded trials with a firing rate of less than 1 Hz. For the

410   final analysis we considered only those units that were recorded for at least 7 trials

411   for each numerosity and stimulus type (on average 23 trials per numerosity/stimulus

412   type).

413   The neural activity of recorded units was analysed as the mean firing rate over 500

414   ms of stimulus presentation. To find numerosity-responsive neurons we performed

415   two-way ANOVA with the numerosity (1 to 5) and the stimulus type ("radius-fixed",

416   "area-fixed", "perimeter-fixed") as factors. We considered the recorded neuron as

417   numerosity-responsive if only the effect of the "numerosity" factor was highly

418   significant ($p < 0.01$), but not of the stimulus type or the interaction between the two

419   factors. The numerosity that elicited the strongest neural response was defined as a

420   preferred numerosity for this neuron.

421   For every number neuron we performed a post hoc analysis (Tukey's test) to

422   compare the neural response between the most preferred and other numerosities.

423   To test for the numerical distance effect we applied a GLM for binomial data with the

424   logit-link function. In the model, the proportion of neurons that significantly

425   differentiate between given numerosities was taken as the response variable, and

426   either the absolute numerical distance or the logarithm of the numerical distance was

427   taken as a factor. We then compared the goodness-of-fit of these two models based

428   on the difference in the Bayesian Information Criterion (ΔBIC), where the lower is the

429   BIC value, the better is the model's fit.

430   To validate the stability of our recordings we performed a cross-validation analysis.

431   For each numerosity-responsive unit we calculated the preferred numerosity for the

432   first and the second half of all trials separately. If the neural response to number

433   stimuli was stable across the recording, we expected the Pearson's correlation

18

434   between the first and the second half of the trials to be close to 1 for the whole

435   population of number neurons. The cross-validation analysis showed a strong

436   correlation of 0.82 (p<0.001) between the preferred numerosity in the first and the

437   second half of the trials, confirming the stability of our recordings.

438   For every number neuron we normalised neural activity by setting the firing rate in

439   response to the preferred numerosity at 100% and to the least preferred numerosity

440   at 0%. The resulting neural filter functions were averaged by group based on the

441   preferred numerosity, thus, creating numerosity tuning curves for e.g. neurons

442   preferring numerosity 1, numerosity 2, etc.

443   To evaluate the chance level of finding false-positive numerical responses in our

444   dataset, for every recorded neuron we shuffled all the trials for 1000 times and

445   performed an ANOVA each time to select false-positive number neurons. We

446   compared the proportion of false-positive and real number neurons with the

447   proportion test. We further compared the tuning curves between the false-positive

448   number neurons and the real number neurons. For this, we randomly sampled from

449   the false-positive neurons the same number of neurons as the one of actually

450   recorded number neurons. We compared the tuning curves of real and false-positive

451   neurons performing a two-factor ANOVA with the interaction of "numerical distance"

452   and "data type" (real/false positive).

453   According to the Weber-Fechner law, the perception of sensory stimuli (including

454   quantities) is proportional to a logarithmic (Fechner 1860) or power scale (Stevens

455   1961) of stimulus magnitude. Therefore, when plotted on a linear scale, one might

456   expect tuning curves to become increasingly asymmetric and wide with increasing

457   numerosity. These properties are usually referred to as a numerical distance effect

458 and a numerical magnitude effect respectively. To evaluate the symmetry and the

459 width of the neural filter functions we fitted the Gaussian function to the curves

460 (MatLab Curve Fitting Toolbox) plotted on four different scales: linear, a power

461 function with an exponent of 0.5, a power function with an exponent of 0.33, and a

462 logarithmic (log2) scale (Ditz and Nieder 2016). The symmetry of the Gaussian fit

463 was estimated based on R-squared (r^2) values, i.e. the higher is r^2 the better and

464 more symmetric is the fit. The width of the Gaussian fit was reflected by its sigma

465 (σ). The four scaling methods were compared based on the r^2 values by the

466 Friedman's test for non-parametric data with repeated measures with the post-hoc

467 pairwise comparison with the Nemenyi test. The relationship between the numerosity

468 and the sigma of the Gaussian was tested by an ANOVA for different scaling

469 methods separately.

470 All statistical analyses and visualization of the data was performed in R (R Core

471 Team 2020) with packages "tidyverse", "ggplot2", and "PMCMRplus" and in MATLAB

472 using custom-made scripts and the Curve Fitting Toolbox.

473

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Author contributions

D.K, U.M. and G.V. designed the experiment. D.K. and U.M. established the procedure for behavioural training and electrophysiology in freely moving chicks. D.K. performed the experiment and analysed the data. M.Z. developed the numerical stimuli and contributed to apart of the data analysis. D.K. wrote the original draft of the manuscript and implemented the comments of all authors. U.M. and G.V. revised and edited the manuscript.

Availability of data and material: A summary table including the mean firing rates for all numerosity-responsive neurons for all trials is included as a supplementary data file. Any additional data that support the findings of this study are available from the corresponding author upon reasonable request.

Code availability: The custom codes that were used for data analysis are available from the corresponding author upon reasonable request.

Competing financial interests: The authors declare no competing financial interests.

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677 **Figures**

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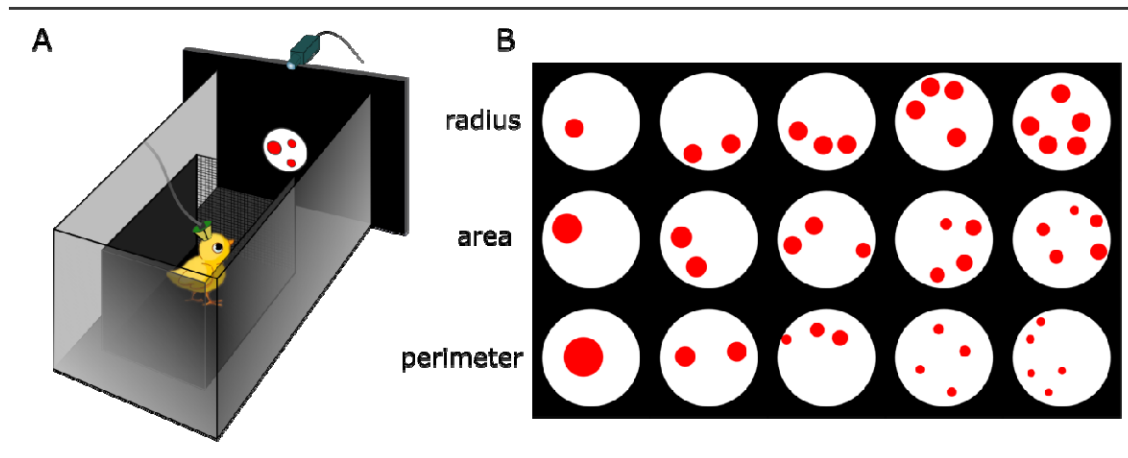
679 Figure 1. Experimental design. (A) Schematic drawing of the experimental setup.

680 Young chicks were placed in a small wooden box in front of the screen, where

681 numerical stimuli appeared. They were trained to pay attention to the stimuli without

682 any further discrimination between different numerosities. (B) Examples of different

683 types of numerosity stimuli that we presented by every neural recording: "radius-

684 fixed", "area-fixed", and "perimeter-fixed".

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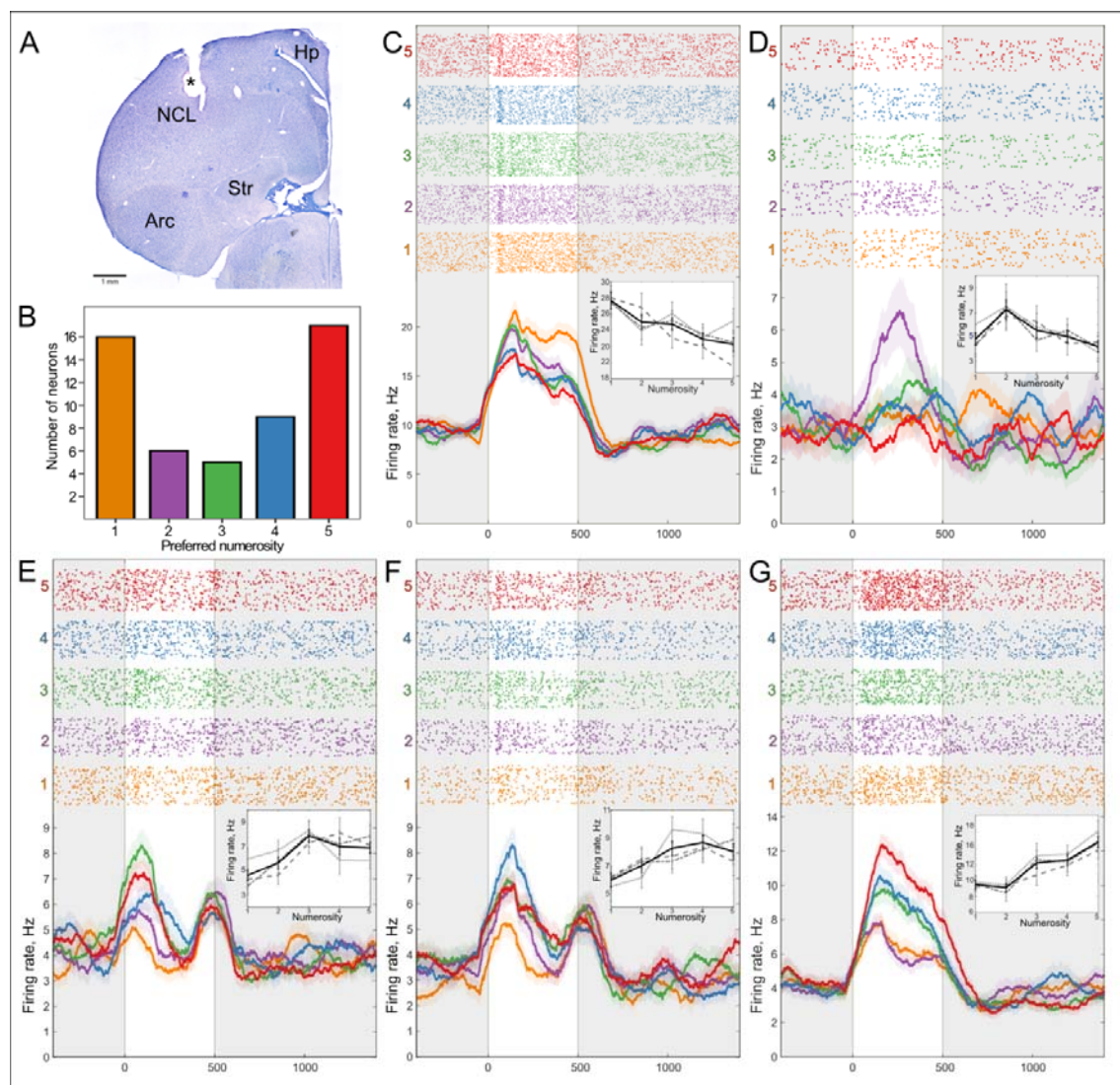
Figure 2. Neurons in the NCL of chicks responding to numerosity. (A) An exemplary coronal section of the chicken forebrain showing the recording site in the NCL (electrolytic lesion is marked by an asterisk). Arc: arcopallium, Hp: hippocampus, NCL: caudolateral nidopallium, Str: striatum. (B) Distribution of neurons that preferred each numerosity stimulus. Examples of neurons that were tuned to numerosity 1 (C), 2 (D), 3 (E), 4 (F), or 5 (G). Top: raster plots representing neural activity, where each line corresponds to one trial and each dot corresponds to a spike. Trials are grouped by numerosity. The 500-ms duration of the stimulus is marked by a transparent window. Bottom: averaged spike density functions

696   (smoothed by a 100 ms Gaussian kernel; SEM is plotted as a shaded area along the

697   lines). Insert: average firing rate in response to numerosities of each stimulus type.

698   Grey dotted line corresponds to "radius-fixed", dashed line – to "perimeter-fixed", dot-

699   dashed line – to "area-fixed" stimuli, and black solid line – to an average. Error bars

700   correspond to SEM.

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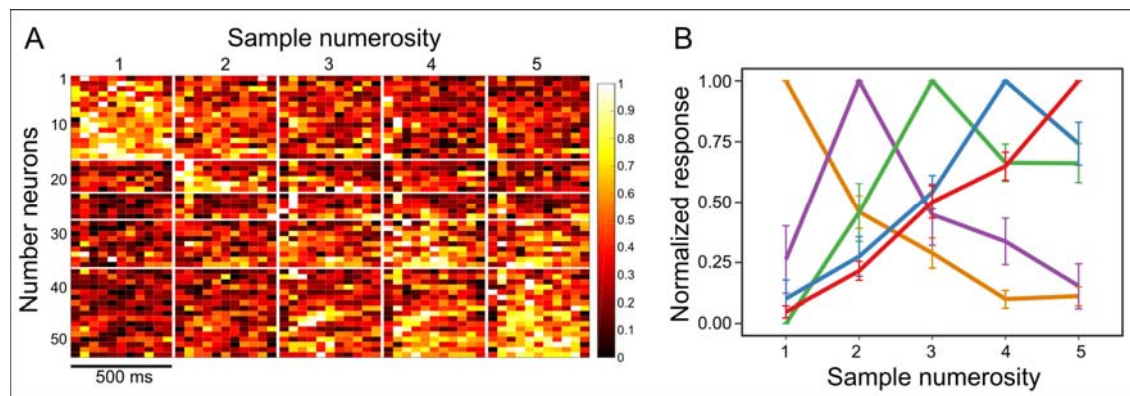
Figure 3. (A) Neural response of all recorded number neurons to numerosity stimuli. Heatmap values represent the mean firing rate during the stimulus presentation (binned by 50-ms), normalised [0, 1] for the corresponding neuron in each row. Values are further grouped by the numerosity stimuli from 1 to 5 (vertical white lines), and by the numerical preference of recorded neurons (horizontal white lines) from neurons that preferred numerosity 1 (top) to neurons that preferred numerosity 5 (bottom). (B) Average tuning curves of numerosity selective neurons. The neural activity of neurons is first normalised [0 = response to the least-preferred numerosity, 1 = response to the most-preferred numerosity] and then grouped by their most preferred numerosity. Error bars correspond to SEM.

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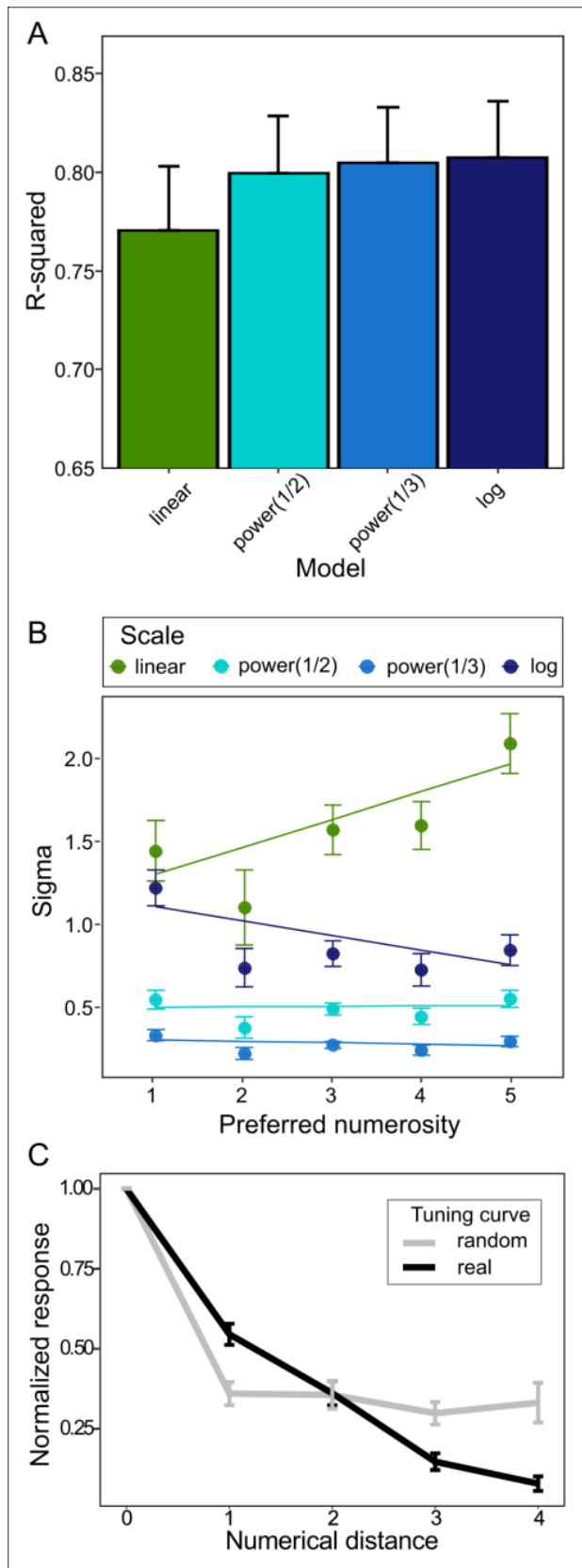
725   Figure 4. (A-B) Comparison of different scaling schemes for the tuning curves. (A) R-

726   squared, a measure of goodness-of-fit reflects symmetry of the tuning curves plotted

727   on the four different scales. The tuning curves of number neurons become more

728   symmetric when plotted on the non-linear scale. (B) Sigma of the Gaussian fit for

729   neurons preferring different numerosities. When plotted on the linear scale, the

730   tuning curves become wider with increased numerosity. Error bars correspond to

731   SEM. (C) Averaged normalised activity of all numerosity selective neurons compared

732   to the random tuning curve (see Materials and methods section for details). The

733   neural activity was normalised [0 = response to the least-preferred numerosity, 1 =

734   response to the most-preferred numerosity] and then plotted as a function of

735   absolute numerical distance from the most preferred numerosity. Neural response of

736   numerosity selective neurons (black line) gradually decreased with the numerical

737   distance. The slope of this tuning curve is notably different from the random tuning

738   curve (grey line) of false-positive neurons obtained by random shuffling of trials.

739   Error bars correspond to SEM.

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747 **Tables**

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Preferred numerosity	ANOVA (Firing rate ~ Stimulus type * Numerosity)		
	Numerosity	**Stimulus type**	**Interaction**
num1	$F(4,251)=5.7273$, $p < 0.001$	$F(2,251)=0.9275$, $p = 0.396$	$F(8,251)=1.2411$, $p = 0.273$
num2	$F(4,253)=3.5881$, $p = 0.007$	$F(2,253)=0.2355$, $p = 0.79$	$F(8,253)=0.454$, $p = 0.887$
num3	$F(4,496)=5.8789$, $p < 0.001$	$F(2,496)=0.1179$, $p = 0.889$	$F(8,496)=1.4538$, $p = 0.173$
num4	$F(4,308)=4.2385$, $p = 0.002$	$F(2,308)=0.1141$, $p = 0.892$	$F(8,308)=0.9124$, $p = 0.506$
num5	$F(4,355)=13.4938$, $p < 0.001$	$F(2,355)=1.832$, $p = 0.162$	$F(8,355)=0.3219$, $p = 0.958$

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750 Table 1. Results of the two-way ANOVA for five example number neurons shown in

751 the Figure 2 (C-G). Preferred numerosity: numerosity eliciting the strongest

752 response. ANOVA results (F-statistics and p-value) for the factor "stimulus type"

753 ("radius-fixed", "area-fixed", "perimeter-fixed"), "numerosity" (numerosity 1 to 5), or

754 interaction between them.

755

Summary		Number of neurons				
Sum	**Group**	**num1**	**num2**	**num3**	**num4**	**num5**
16	num1		6	9	12	14
6	num2	4		2	1	3
5	num3	5	1		0	0
9	num4	6	2	1		1
17	num5	15	12	6	1	

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757 Table 2. The summary of the post hoc analysis. For each group based on their

758 preferred numerosity we calculated the number of neurons that showed significant

759 difference between the most-preferred and the given numerosity.

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Supplementary information
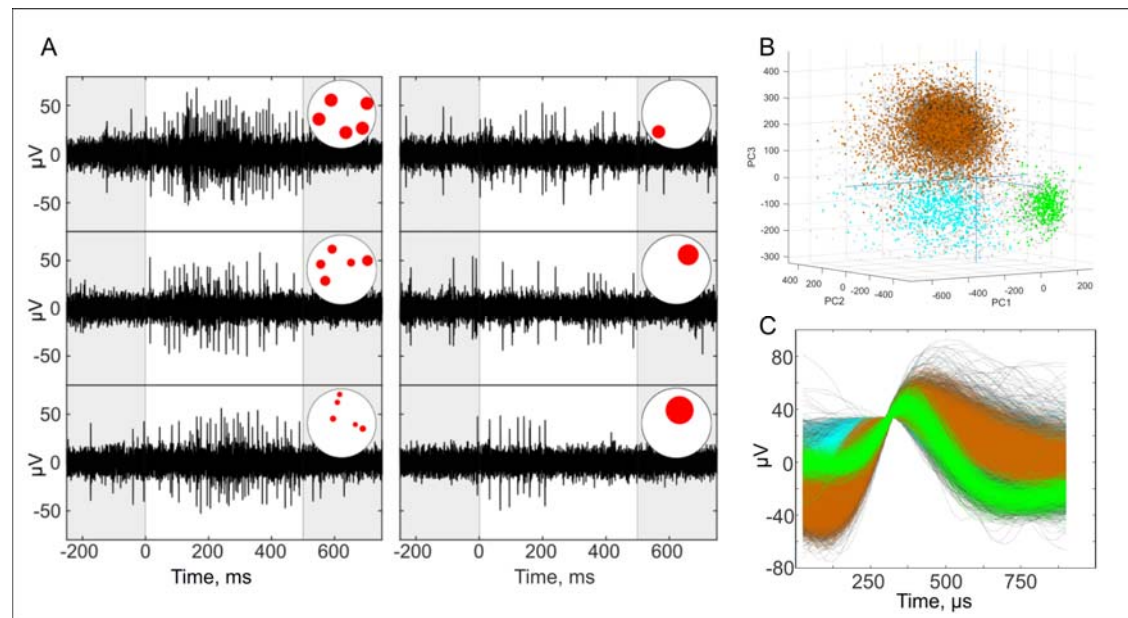
Figure S1. (A) Example of raw spike trains: electrical signal is shown after the high-pass filter was applied. Examples of single trials, representing neural response of the unit to numerosity 5 (left column), irrespective of the stimulus appearance (top: radius-fixed, middle: area-fixed, bottom: perimeter-fixed). Note the decreasing neural response to the numerosity 1 (right column). (B) The PCA clustering of the corresponding recording with waveforms of different units shown by different colours. The waveforms of the number-responsive unit are shown in orange, unsorted waveforms are shown in grey. (C) Spike waveforms of corresponding units isolated from the recording of one electrode.

Unit	Preferred numerosity	ANOVA (Firing rate ~ Stimulus type * Numerosity)		
		Numerosity	Stimulus type	Interaction
1	num1	$F(4,546)=4.0327$, p = 0.003	$F(2,546)=0.5228$, p = 0.593	$F(8,546)=1.4242$, p = 0.183
2	num1	$F(4,197)=3.5672$, p = 0.008	$F(2,197)=0.4656$, p = 0.628	$F(8,197)=0.8763$, p = 0.537
3	num1	$F(4,202)=4.0268$, p = 0.004	$F(2,202)=1.7732$, p = 0.172	$F(8,202)=1.1967$, p = 0.303
4	num1	$F(4,565)=4.2588$, p = 0.002	$F(2,565)=0.0012$, p = 0.999	$F(8,565)=0.7852$, p = 0.616
5	num1	$F(4,270)=5.3565$, p = 0	$F(2,270)=1.2038$, p = 0.302	$F(8,270)=0.9519$, p = 0.474
6	num1	$F(4,270)=5.4507$, p = 0	$F(2,270)=0.0475$, p = 0.954	$F(8,270)=0.7056$, p = 0.687
7	num1	$F(4,239)=3.7861$, p = 0.005	$F(2,239)=0.4114$, p = 0.663	$F(8,239)=1.6597$, p = 0.109
8	num1	$F(4,419)=4.9175$, p = 0.001	$F(2,419)=1.0111$, p = 0.365	$F(8,419)=1.0988$, p = 0.363
9	num1	$F(4,399)=7.4226$, p = 0	$F(2,399)=2.8675$, p = 0.058	$F(8,399)=2.1769$, p = 0.028
10	num1	$F(4,366)=4.2597$, p = 0.002	$F(2,366)=0.9588$, p = 0.384	$F(8,366)=1.4233$, p = 0.185
11	num1	$F(4,364)=6.4075$, p = 0	$F(2,364)=0.2249$, p = 0.799	$F(8,364)=1.2606$, p = 0.263
12	num1	$F(4,490)=3.9053$, p = 0.004	$F(2,490)=1.1902$, p = 0.305	$F(8,490)=0.6286$, p = 0.754
13	num1	$F(4,251)=5.7273$, p = 0	$F(2,251)=0.9275$, p = 0.396	$F(8,251)=1.2411$, p = 0.273
14	num1	$F(4,186)=3.5545$, p = 0.008	$F(2,186)=1.1998$, p = 0.304	$F(8,186)=0.6334$, p = 0.749
15	num1	$F(4,233)=4.4063$, p = 0.002	$F(2,233)=1.138$, p = 0.322	$F(8,233)=0.3761$, p = 0.933
16	num1	$F(4,316)=3.6533$, p = 0.006	$F(2,316)=1.4135$, p = 0.245	$F(8,316)=0.8235$, p = 0.582
17	num2	$F(4,177)=4.5348$, p = 0.002	$F(2,177)=0.2742$, p = 0.761	$F(8,177)=0.6772$, p = 0.711
18	num2	$F(4,176)=4.1623$, p = 0.003	$F(2,176)=0.8853$, p = 0.414	$F(8,176)=0.8814$, p = 0.533
19	num2	$F(4,147)=3.6633$, p = 0.007	$F(2,147)=0.929$, p = 0.397	$F(8,147)=0.5183$, p = 0.841
20	num2	$F(4,145)=3.7461$, p = 0.006	$F(2,145)=0.514$, p = 0.599	$F(8,145)=0.5375$, p = 0.827
21	num2	$F(4,298)=3.4934$, p = 0.008	$F(2,298)=0.7184$, p = 0.488	$F(8,298)=1.0979$, p = 0.364
22	num2	$F(4,253)=3.5881$, p = 0.007	$F(2,253)=0.2355$, p = 0.79	$F(8,253)=0.454$, p = 0.887
23	num3	$F(4,213)=3.4856$, p = 0.009	$F(2,213)=0.6473$, p = 0.524	$F(8,213)=0.5014$, p = 0.854
24	num3	$F(4,184)=3.6183$, p = 0.007	$F(2,184)=0.5629$, p = 0.571	$F(8,184)=0.6608$, p = 0.725
25	num3	$F(4,472)=5.1242$, p = 0	$F(2,472)=2.8061$, p = 0.062	$F(8,472)=0.809$, p = 0.595
26	num3	$F(4,410)=3.7563$, p = 0.005	$F(2,410)=4.5228$, p = 0.011	$F(8,410)=1.3146$, p = 0.233
27	num3	$F(4,496)=5.8789$, p = 0	$F(2,496)=0.1179$, p = 0.889	$F(8,496)=1.4538$, p = 0.173
28	num4	$F(4,176)=3.926$, p = 0.004	$F(2,176)=1.1196$, p = 0.329	$F(8,176)=0.6298$, p = 0.752
29	num4	$F(4,178)=3.9175$, p = 0.004	$F(2,178)=0.4244$, p = 0.655	$F(8,178)=0.6897$, p = 0.7
30	num4	$F(4,267)=4.5852$, p = 0.001	$F(2,267)=0.6043$, p = 0.547	$F(8,267)=0.8609$, p = 0.55
31	num4	$F(4,371)=3.6503$, p = 0.006	$F(2,371)=1.9928$, p = 0.138	$F(8,371)=0.5894$, p = 0.787
32	num4	$F(4,430)=3.4615$, p = 0.008	$F(2,430)=0.3739$, p = 0.688	$F(8,430)=0.513$, p = 0.847

33	num4	$F(4,420)=4.4972, p = 0.001$	$F(2,420)=1.1432, p = 0.32$	$F(8,420)=1.1135, p = 0.353$
34	num4	$F(4,459)=6.5488, p = 0$	$F(2,459)=2.8234, p = 0.06$	$F(8,459)=1.3186, p = 0.232$
35	num4	$F(4,333)=3.4399, p = 0.009$	$F(2,333)=3.3226, p = 0.037$	$F(8,333)=1.5331, p = 0.145$
36	num4	$F(4,308)=4.2385, p = 0.002$	$F(2,308)=0.1141, p = 0.892$	$F(8,308)=0.9124, p = 0.506$
37	num5	$F(4,323)=5.0184, p = 0.001$	$F(2,323)=1.9782, p = 0.14$	$F(8,323)=0.3722, p = 0.935$
38	num5	$F(4,188)=3.5707, p = 0.008$	$F(2,188)=1.1655, p = 0.314$	$F(8,188)=0.5456, p = 0.821$
39	num5	$F(4,307)=5.1489, p = 0$	$F(2,307)=0.0322, p = 0.968$	$F(8,307)=0.4935, p = 0.861$
40	num5	$F(4,260)=5.1953, p = 0$	$F(2,260)=0.945, p = 0.39$	$F(8,260)=0.682, p = 0.707$
41	num5	$F(4,234)=4.65, p = 0.001$	$F(2,234)=0.7971, p = 0.452$	$F(8,234)=0.8709, p = 0.542$
42	num5	$F(4,232)=3.7216, p = 0.006$	$F(2,232)=0.0802, p = 0.923$	$F(8,232)=1.3969, p = 0.199$
43	num5	$F(4,484)=3.6509, p = 0.006$	$F(2,484)=0.1205, p = 0.887$	$F(8,484)=0.7686, p = 0.631$
44	num5	$F(4,458)=12.8202, p = 0$	$F(2,458)=0.7574, p = 0.469$	$F(8,458)=0.4219, p = 0.908$
45	num5	$F(4,192)=4.4432, p = 0.002$	$F(2,192)=2.0198, p = 0.135$	$F(8,192)=1.8229, p = 0.075$
46	num5	$F(4,415)=3.8044, p = 0.005$	$F(2,415)=1.618, p = 0.2$	$F(8,415)=0.5316, p = 0.832$
47	num5	$F(4,685)=14.1207, p = 0$	$F(2,685)=1.9687, p = 0.141$	$F(8,685)=1.4958, p = 0.156$
48	num5	$F(4,371)=6.7422, p = 0$	$F(2,371)=0.6683, p = 0.513$	$F(8,371)=1.6257, p = 0.115$
49	num5	$F(4,359)=4.1619, p = 0.003$	$F(2,359)=0.1355, p = 0.873$	$F(8,359)=0.4252, p = 0.906$
50	num5	$F(4,355)=13.4938, p = 0$	$F(2,355)=1.832, p = 0.162$	$F(8,355)=0.3219, p = 0.958$
51	num5	$F(4,354)=6.4972, p = 0$	$F(2,354)=0.6433, p = 0.526$	$F(8,354)=0.9821, p = 0.45$
52	num5	$F(4,288)=3.3897, p = 0.01$	$F(2,288)=2.1069, p = 0.123$	$F(8,288)=1.2445, p = 0.273$
53	num5	$F(4,460)=5.4865, p = 0$	$F(2,460)=1.4027, p = 0.247$	$F(8,460)=0.7622, p = 0.636$

775

776 Table S1. Summary of the two-way ANOVA for every recorded unit. Unit: id of the

777 recorded unit. Preferred numerosity: numerosity stimulus that elicited the strongest

778 response in the corresponding unit. ANOVA results (F-statistics and p-value) are

779 summarized for the factor "Stimulus type" (radius-fixed, area-fixed, perimeter-fixed),

780 "Numerosity" (numerosity "one" to "five"), or interaction between them.

781

782

Unit	Preferred numerosity	Post hoc analysis, p-value				
		num1	num2	num3	num4	num5
1	num1		**0.016**	**0.022**	**0.019**	**0.007**
2	num1		0.081	**0.019**	**0.011**	**0.021**
3	num1		0.988	0.903	0.303	**0.003**
4	num1		0.974	0.315	**0.002**	0.209
5	num1		0.890	0.650	**0.000**	**0.027**
6	num1		0.176	0.063	**0.001**	**0.001**
7	num1		**0.035**	**0.048**	**0.006**	**0.020**
8	num1		**0.031**	**0.001**	**0.001**	**0.023**
9	num1		0.788	0.174	**0.000**	**0.000**
10	num1		0.465	**0.002**	**0.009**	0.169
11	num1		**0.033**	**0.000**	**0.000**	**0.001**
12	num1		**0.036**	**0.013**	0.090	**0.004**
13	num1		0.221	0.120	**0.001**	**0.000**
14	num1		0.147	0.142	0.061	**0.004**
15	num1		**0.031**	**0.002**	0.084	**0.004**
16	num1		0.304	**0.048**	**0.008**	**0.014**
17	num2	0.447		0.986	0.362	**0.001**
18	num2	**0.001**		**0.027**	**0.025**	0.206
19	num2	**0.023**		0.945	0.065	0.063
20	num2	**0.013**		**0.017**	0.826	0.608
21	num2	0.973		0.181	0.125	**0.011**
22	num2	**0.040**		0.312	0.075	**0.004**
23	num3	**0.005**	0.807		0.760	0.123
24	num3	**0.006**	0.094		0.504	0.899
25	num3	**0.001**	0.913		0.998	0.796
26	num3	**0.005**	0.059		0.370	0.857
27	num3	**0.000**	**0.024**		0.798	0.683
28	num4	**0.003**	0.282	0.120		**0.016**
29	num4	**0.020**	0.051	0.213		0.999
30	num4	0.710	**0.001**	**0.028**		0.103
31	num4	**0.007**	0.369	0.813		0.998
32	num4	0.059	0.059	0.936		0.999
33	num4	0.065	**0.007**	0.864		1.000
34	num4	**0.000**	0.092	0.419		0.968
35	num4	**0.004**	0.628	0.616		0.850
36	num4	**0.003**	0.194	0.981		0.928
37	num5	**0.002**	**0.002**	**0.007**	0.054	
38	num5	**0.022**	0.287	0.995	0.999	
39	num5	**0.000**	0.148	0.653	0.803	
40	num5	**0.000**	**0.026**	0.525	0.214	
41	num5	**0.001**	**0.021**	0.226	**0.012**	
42	num5	**0.008**	0.150	**0.010**	0.431	
43	num5	**0.004**	0.097	0.111	0.725	
44	num5	**0.000**	**0.000**	0.750	0.851	
45	num5	**0.015**	**0.032**	**0.001**	0.080	
46	num5	0.070	**0.002**	0.428	0.069	

47	num5	**0.000**	**0.000**	**0.016**	0.868
48	num5	**0.000**	**0.003**	0.251	0.901
49	num5	**0.003**	0.394	0.940	0.997
50	num5	**0.000**	**0.000**	**0.034**	0.078
51	num5	**0.000**	**0.009**	**0.014**	0.801
52	num5	0.074	**0.023**	0.988	0.798
53	num5	**0.006**	**0.004**	0.276	0.998

783

784   Table S2. The post hoc analysis of the two-way ANOVA based on the Tukey-Kramer

785   method summarising p-values for every pairwise comparison between the most-

786   preferred and other numerosities. Significant p-values <0.05 are highlighted in bold.

787