



Parallel and serial processes in number-to-quantity conversion

Dror Dotan, Stanislas Dehaene

► To cite this version:

Dror Dotan, Stanislas Dehaene. Parallel and serial processes in number-to-quantity conversion. *Cognition*, 2020, 204, pp.104387 -. 10.1016/j.cognition.2020.104387 . hal-03492432

HAL Id: hal-03492432

<https://hal.science/hal-03492432>

Submitted on 18 Jul 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

Parallel and serial processes in number-to-quantity conversion

Dror Dotan^{1,2} and Stanislas Dehaene^{2,3,4}

¹ Mathematical Thinking Lab, School of Education and School of Neuroscience, Tel Aviv University, Tel Aviv 69978, Israel

² Cognitive Neuroimaging Unit, CEA DRF/I2BM, INSERM, Université Paris-Sud, Université Paris-Saclay, NeuroSpin center, 91191 Gif/Yvette, France

³ Collège de France, 11 Place Marcelin Berthelot, 75005 Paris, France

⁴ University Paris-Sud, Cognitive Neuroimaging Unit, F-91191 Gif/Yvette, France

Running page heading: Number-to-quantity conversion

Address correspondence to:

Dror Dotan

Mathematical Thinking Lab, School of Education, Tel Aviv University,
Tel Aviv 69978, Israel

Phone/Fax: +972-3-6298697

e-mail: dotandro@mail.tau.ac.il

Table 1. Individuals from Lumentxa and their assigned minimum number of elements (MNE).

| Individual ^a | NME | Estimated age-at-death ^b | Determined sex |
|----------------------------|------------|-------------------------------------|----------------|
| Individual 1 | 11 | 3-5 | - |
| Individual 2 ^{*a} | 2* | 3-5 | - |
| Individual 1-2 | 5 | - | - |
| Individual 3 ^a | 6 | 18-21 | - |
| Individual 4 ^a | 24 | 25-40 | F |
| Individual 5 ^a | 110 | 40-55, >55 | M |
| Individual 6 | 9 | - | - |
| Individual 7 | 3 | 8-16 | - |
| Indeterminate | 38 + 5* | - | - |
| Total | 213 | | |

^aSpecimens not stored at the Arkeologi Museoa (Bilbao, Bizkaia) but listed in Aranzadi (1929).

^a The number of these individuals have changed from previous studies (García-Sagastibelza et al., 2018, 2019).

^b See Table 3.

Table 2. Anatomical representation of the individuals identified in the site of Lumentxa.

| Anatomical region | Individual 1 | Individual 2 | Individual 1-2 | Individual 3 | Individual 4 | Individual 5 | Individual 6 | Individual 7 | Indeterminate | Total |
|--------------------------------------------------|--------------|--------------|-----------------------|--------------|--------------|--------------|--------------|--------------|---------------|-------|
| Neurocraneum | 4 | | 1 (6 small fragments) | | | | | | 14 | 20 |
| Maxillae | 2 | 1* | | | | 1 | | | | 3 |
| Mandibles | 1 | 1* | | 1 | 1 | 1 | | | | 5 |
| Isolated teeth | 4 | | | 4 | | 12 | | | 6 + 1* | 27 |
| Hyoid bone | | | | | | 1 | | | 1 | 2 |
| Cervical vertebrae | | | | | 2 | 6 | 1 | | 1 | 10 |
| Thoracic vertebrae | | | | | 7 | 9 | 4 | | | 20 |
| Lumbar vertebrae | | | | | 3 | 5 | 3 | | | 11 |
| Sacrum | | | | | | 1 | | | | 1 |
| Coccyx | | | | | | 1 | | | | 1 |
| Indeterminate vertebrae | | | | | | | | | 1 + 1* | 2 |
| Ribs | | | 1 | | 2 | 17 | | | 7 | 27 |
| Scapulae | | | | | 1 | 2 | | | 2 | 5 |
| Clavicles | | | | | | 2 | | | 1 + 1* | 4 |
| Humerii | | | 1 | | 1 | 1 | | 2 | 2 | 7 |
| Radius | | | | 1 | | 1 | | | | 2 |
| Ulnae | | | | | 1 | 1 | | | | 2 |
| Carpal bones | | | | | | 7 | | | | 7 |
| Metacarpals | | | | | | 6 | | | | 6 |
| Hand phalanges (proximal/intermediate/distal) | | | | | | 9/3/7 | | | 0/2/0 + 1* | 22 |
| Pubis | | | 2 | | | | | | | 2 |
| Femora | | | | | 1 | 1 | | 1 | 1* | 4 |
| Fibulae | | | | | 2 | 2 | 1 | | | 5 |
| Tarsal bones | | | | | | 8 | | | | 8 |
| Metatarsals | | | | | 1 | 3 | | | 1 | 5 |
| Foot phalanges (proximal/intermediate/distal) | | | | | 1/1 | 2/1/0 | | | | 5 |
| Total | 11 | 2* | 5 | 6 | 24 | 110 | 9 | 3 | 43 | 213 |

*Human remains described by Aranzadi (1929) currently lost. Apart from a complete cranium and mandible (Figure 3). Aranzadi (1929) and Aranzadi and Barandiarán (1935) described that there was a human femoral head, a human molar, a subadult vertebra, a phalanx and a small clavicle.

Table 3. Age-at-death determination for individuals from Lumentxa based on the dentition.

| Individual | Label | Anatomical región | Side | Age group/cathegory | State of wear ^a | Age range ^a | Age range ^b | Age range ^c |
|------------|----------------|----------------------|-------|------------------------|-------------------------------|------------------------|------------------------|------------------------|
| 1 | L.14H.1 | maxilla | R | non-adult | - | - | 3-5 | 3.5-4.5 |
| | L.16H.160.1 | maxilla | L | | - | - | 3-5 | 3.5-4.5 |
| | L.28K.1198.rev | mandible | R + L | | - | - | 3-5 | 3.5-4.5 |
| 3 | L.14H.5 | mandible | R | young adult | B1 | 18-21 | >15 | 18-21 |
| 4 | L.14Z.455.2 | mandible | R | adult | F/G | 30-35/35-40 | >35 | 25-35 |
| 5 | L.11F.110 | maxilla | L | adult | H/>H | 40-50/>50 | >35 | 35-45 |
| | L.14Z.480.1 | mandible | R + L | | I/>I | 45-55/>55 | >35 | 35-45 |

^aBased on Lovejoy (1985).

^bBased on Buikstra and Ubelaker (1994).

^cBased on Brothwell (1981).

Table 4. C14 dates of the human remains of Lumentxa.

| Individual | Anatomical region | Label | Archaeological context | Laboratory number | C:N proportion | Radiocarbon age (BP) | Calendar calibrated results (95% probability)* | | Reference |
|--------------|-------------------|---------------------------------|---------------------------------|-------------------|----------------|----------------------|------------------------------------------------|-------------|---------------------------------------------------------------------------|
| | | | | | | | BCE age | BP age | |
| Individual 1 | Cranium fragment | L.22H.REV.46 ² | Trench cleaning (see main text) | Beta-493404 | 3.3 | 3,550 ± 30 | 2,009-1,772 | 3,958-3,721 | This study |
| Individual 4 | Fibula | L.28F.220.10.L7 ² | IIB | Beta-493405 | 3.2 | 4,780 ± 30 | 3,641-3,519 | 5,590-5,468 | This study |
| | Vertebra | L.32F.198.11.L5 ² | IIB | CNA 5113.1.1 | 3.0 | 4,810 ± 35 | 3,656-3,521 | 5,605-5,470 | This study |
| | Premolar | L.14Z.455.2 | | CNA | - | No collagen | | | |
| Individual 5 | Rib fragment | L.26F.240.5.L10 ² | IIC | Ua-12665 | - | 5,105 ± 80 | 4,147-3,700 | 6,096-5,649 | Arribas Pastor and Berganza Gochi, 2018; García-Sagastibelza et al., 2018 |
| Individual 6 | Vertebra | L.18G.208,5.184.L8 ² | IIB | CNA 5114.1.1 | - | 6,110 ± 35 | 5,208-4,943 | 7,157-6,892 | This study |
| | Fibula | L.10B.80 ¹ | III | OxA-18236 | 2.9 | 6,122 ± 38 | 5,209-4,959 | 7,158-6,908 | Arias Cabal, 2012b; Arias and Cubas, 2018 |

* Calibrated using Oxcal v.4.3 software (Bronk Ramsey, 1998; 2009) and Intcal13 calibration curve (Reimer et al. 2013).

¹Recovered during the first period of excavation (1926-1929).

² Recovered in the third period of excavation (1984-1993).

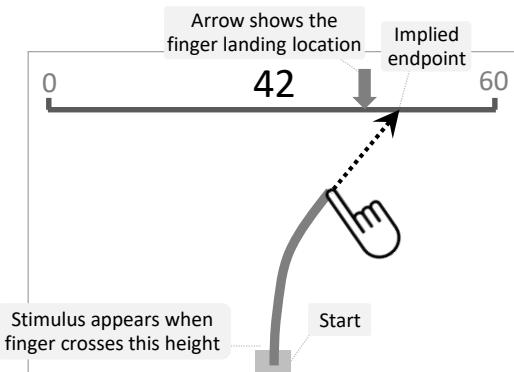
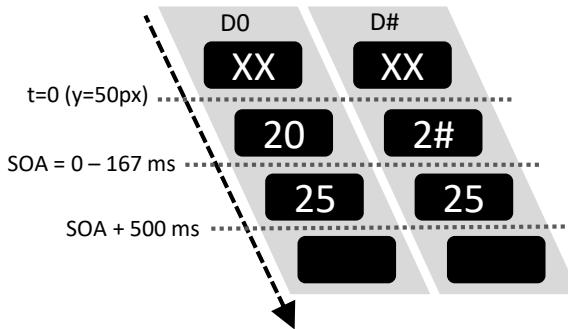
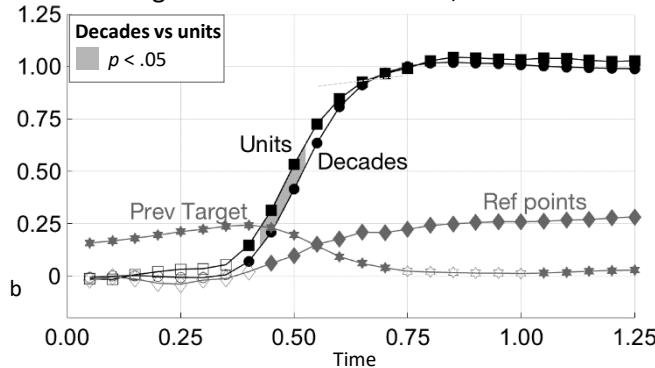


Figure 1

a Unit digit delayed
by a variable amount



b Regression results in SOA=0, D0 block



c Regression results in SOA=0, D# block

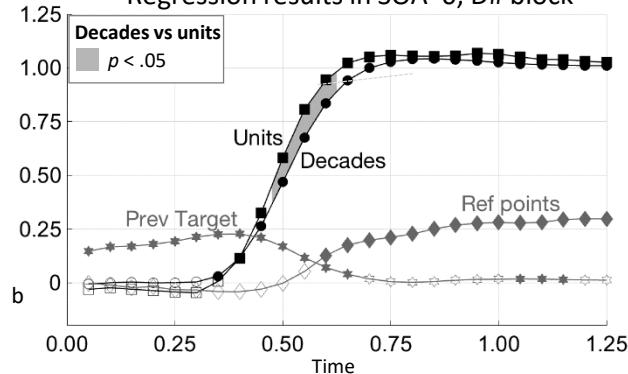


Figure 2.

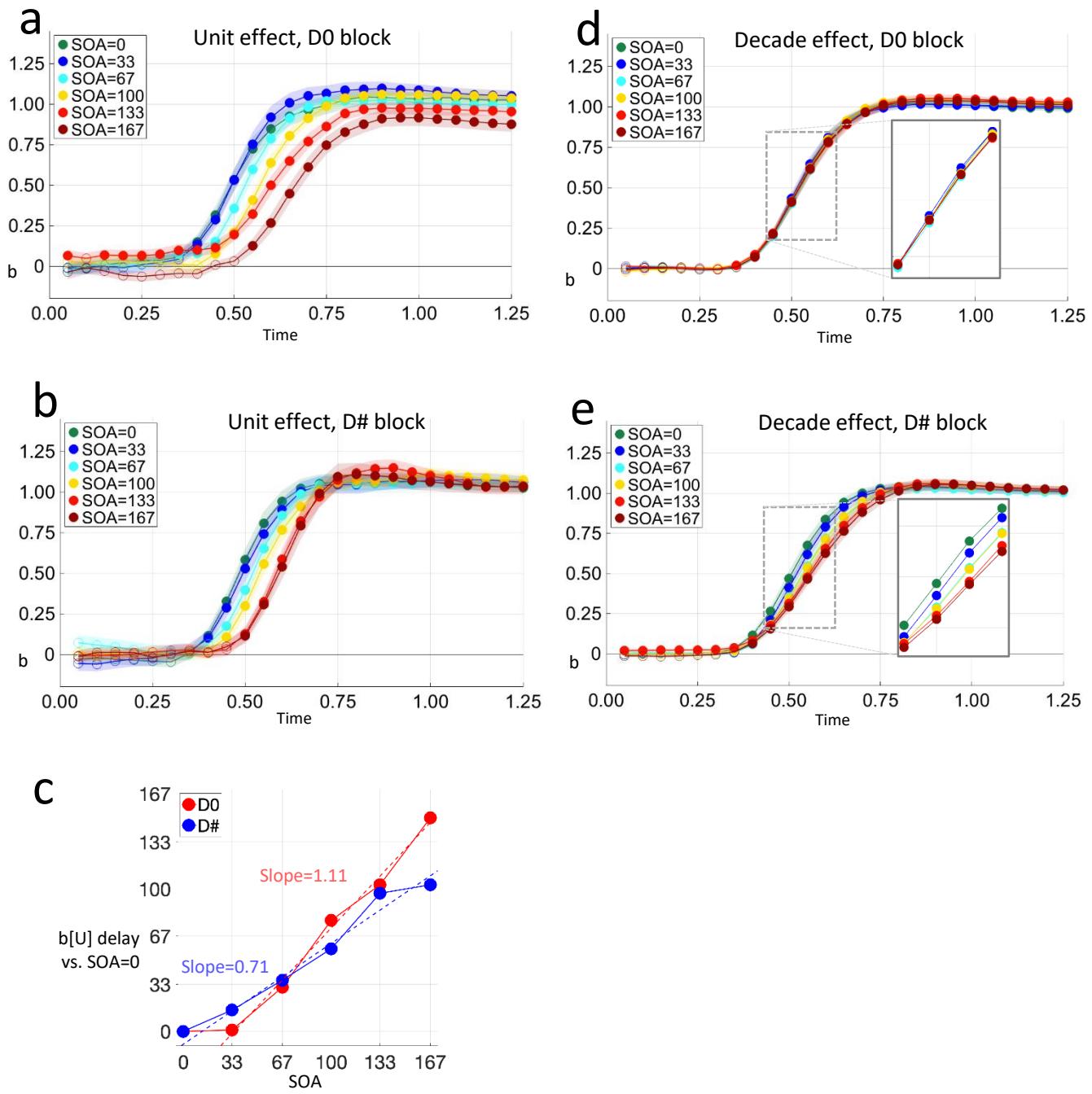
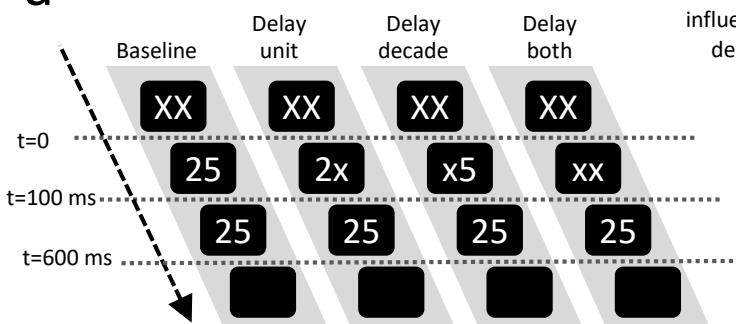


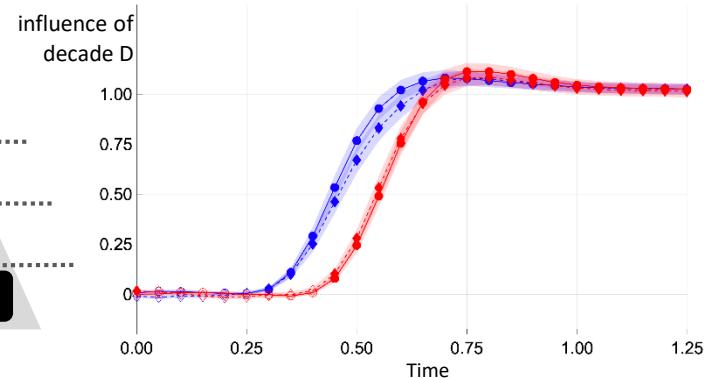
Figure 3

Comparison between conditions

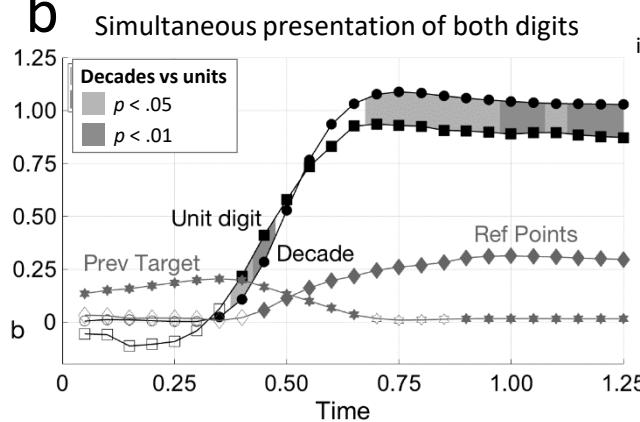
a



c



b



d

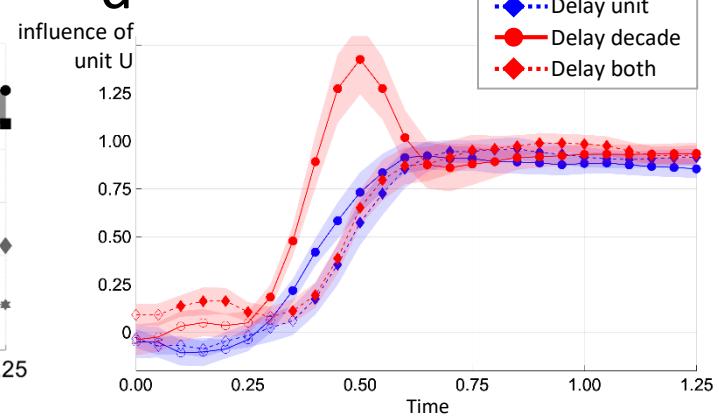


Figure 4.

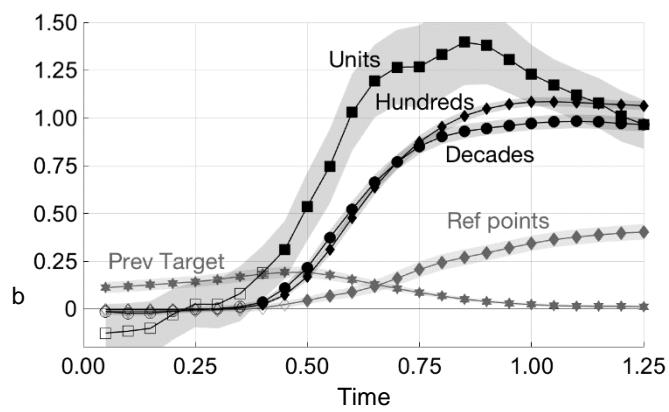
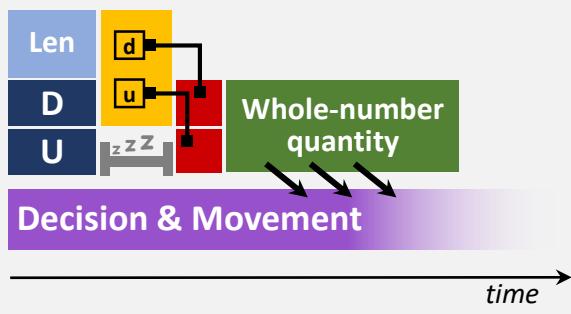


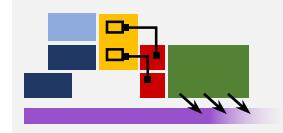
Figure 5

a Simultaneous presentation of all digits

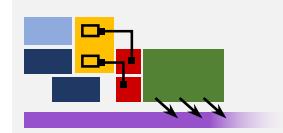


Visual identification of ■ digits ■ length
■ Syntactic frame creation
■ Idle time window
■ Quantify each digit according to decimal role
■ Whole-number quantity
■ Decision on target location, finger movement

b Decade delay



c Small unit delay



d Large unit delay

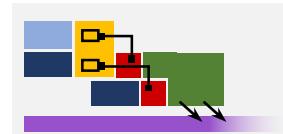


Figure 6