The Development of Size Sequencing Skills: An Empirical and Computational Analysis

Maggie McGonigle-Chalmers & Iain Kusel

Monographs of the Society for Research in Child Development
Lynn S. Liben, Editor
INFORMATION FOR AUTHORS

The Monographs of the Society for Research in Child Development is a quarterly journal which publishes conceptually rich and empirically distinguished work in support of the SRCD mission—advancing developmental science and promoting its use to improve human lives. To be accepted for publication, manuscripts must be judged to serve one or more core goals of SRCD’s Strategic Plan, which include (1) the advancement of cutting-edge and integrative developmental science research; (2) the fostering of racial, cultural, economic, national, and contextual diversity in developmental science; and (3) the application of developmental science to policies and practices that improve human well-being.

As explained more fully in the document Editorial Statement [https://www.srcd.org/publications/monographs/monographs-editorial-statement], such goals may be achieved in varied ways. For example, a monograph might integrate results across waves of a longitudinal study; consolidate and interpret research literatures through meta-analyses; examine developmental phenomena across diverse and intersecting ethnic, geographic, economic, political, or historical contexts; describe and demonstrate new developmental tools for data acquisition, visualization, analysis, sharing, or replication; or report work contributing to conceptualizing, designing, implementing, and evaluating national and global programs and policies (e.g., related to parenting, education, or health).

The journal has an extensive reach via direct distribution to 5,000+ SRCD members and to readers via access provided through 12,000+ institutions worldwide. Beginning with the first issue under the Editorship of Lynn Liben (84.2, June 2019), this reach will be enhanced by a companion web- and media-based forum Monograph Matters (MM)—designed to expand Monographs’ contributions to scholarship, teaching, and outreach. MM may be reached via monographmatters.srcd.org. MM includes materials such as invited commentaries, video highlights of monograph content, video tutorials on methods, teaching resources, and discussions between authors and end-users (e.g., parents, teachers, and policymakers).

Each Monograph should be a cohesive contribution, written by an individual author or by a collaborative team. It should be engaging and accessible not only to other experts in the specialized topic of the Monograph but also to the general SRCD audience. Potential authors are strongly advised to begin by sending a brief description of the proposed Monograph directly to the Editor, liben@psu.edu. If the editor judges the idea to be suitable for the journal, she will invite and then comment on a more detailed prospectus. These initial steps are completely optional; all editorial decisions will be based on peer reviews of manuscripts as submitted. Complete manuscripts (text, tables, figures, references, etc.) should be about 150–200 double-spaced manuscript pages, and should be submitted electronically via http://mc.manuscriptcentral.com/mono. Details about manuscript preparation, submission, author assurances, and review are provided in the journal’s Submission Guidelines, https://www.srcd.org/Monographs-Submission-Guidelines.

Inquiries may be addressed to the Editor:

Lynn S. Liben
Department of Psychology
The Pennsylvania State University
University Park, PA 16802
liben@psu.edu
The Development of Size Sequencing Skills: An Empirical and Computational Analysis

Maggie McGonigle-Chalmers
University of Edinburgh

Iain Kusel
University of Edinburgh

Lynn S. Liben
Series Editor

Monographs of the Society for Research in Child Development
Vol. 84, No. 4, 2019, Serial No. 335
# The Development of Size Sequencing Skills: An Empirical and Computational Analysis

## Contents

Abstract: The Development of Size Sequencing Skills: An Empirical and Computational Analysis | 7

I. Discontinuity in Discrete Set Understanding: An Enduring Issue | 9

II. The Development of Sequential Size Understanding: Evidence for Developmental Discontinuity | 45

III. A Computational Model of The Emergence of Sequential Size Understanding | 76

IV. The Development of Ordinal Size Understanding and a Computational Model | 108

V. Sequential and Ordinal Size Understanding: A New Characterization | 151

Acknowledgments | 183

Notes | 184

References | 186

Authors | 201

Subject Index | 202
The Development of Size Sequencing Skills: An Empirical and Computational Analysis

Maggie McGonigle-Chalmers1 and Iain Kusel2

Abstract We explore a long-observed phenomenon in children’s cognitive development known as size seriation. It is not until children are around 7 years of age that they spontaneously use a strict ascending or descending order of magnitude to organize sets of objects differing in size. Incomplete and inaccurate ordering shown by younger children has been thought to be related to their incomplete grasp of the mathematical concept of a unit. Piaget first brought attention to children’s difficulties in solving ordering and size-matching tests, but his tasks and explanations have been progressively neglected due to major theoretical shifts in scholarship on developmental cognition. A cogent alternative to his account has never emerged, leaving size seriation and related abilities as an unexplained case of discontinuity in mental growth. In this monograph, we use a new training methodology, together with computational modeling of the data to offer a new explanation of size seriation development and the emergence of related skills.

We describe a connected set of touchscreen tasks that measure the abilities of 5- and 7-year-old children to (a) learn a linear size sequence of five or seven items and (b) identify unique (unit) values within those same sets, such as second biggest and middle-sized. Older children required little or no training to succeed in the sequencing tasks, whereas younger children evinced trial-and-error performance. Marked age differences were found on ordinal identification tasks using matching-to-sample and other methods. Confirming Piaget’s findings, these tasks generated learning data with which to develop a computational model of the change.

Using variables to represent working and long-term memory (WM and LTM), the computational model represents the information processing of the

---

1Department of Psychology, University of Edinburgh. 2Department of Psychology, University of Edinburgh. Now affiliated with the Sword Group.

Corresponding author: Maggie McGonigle-Chalmers, School of Philosophy, Psychology and Language Sciences, The University of Edinburgh, 7 George Square, Edinburgh EH8 9JZ, UK, email: Maggie.McGonigle@ed.ac.uk


DOI: 10.1111/mono.12411

© 2019 Society for Research in Child Development
younger child in terms of a perception-action feedback loop, resulting in a heuristic for achieving a correct sequence. To explain why older children do not require training on the size task, it was hypothesized that an increase in WM to a certain threshold level provides the information-processing capacity to allow the participant to start to detect a minimum interval between each item in the selection. The probabilistic heuristic is thus thought to be replaced during a transitional stage by a serial algorithm that guarantees success. The minimum interval discovery has the effect of controlling search for the next item in a principled monotonic direction. Through a minor additional processing step, this algorithm permits relatively easy identification of ordinal values.

The model was tested by simulating the perceptual learning and action selection processes thought to be taking place during trial-and-error sequencing. Error distributions were generated across each item in the sequence and these were found to correspond to the error patterns shown by 5-year-olds. The algorithm that is thought to emerge from successful learning was also tested. It simulated high levels of success on seriation and also on ordinal identification tasks, as shown by 7-year-olds.

An unexpected finding from the empirical studies was that, unlike adults, the 7-year-old children showed marked difficulty when they had to compute ordinal size values in tasks that did not permit the use of the serial algorithm. For example, when required to learn a non-monotonic sequence where the ordinal values were in a fixed random order such as “second biggest, middle-sized, smallest, second smallest, biggest,” each item has to be found without reference to the “smallest difference” rule used by the algorithm. The difficulty evinced by 7-year-olds was consistent with the idea that the information in LTM is integrally tied to the search procedure itself as a search-and-stop based on a cumulative tally, as distinct from being accessed from a more permanent and atemporal store of stand-alone ordinal values in LTM. The implications of this possible constraint in understanding are discussed in terms of further developmental changes.

We conclude that the seriation behavior shown by children at around 7 years represents a qualitative shift in their understanding but not in the sense that Piaget first proposed. We see the emergent algorithm as an information-reducing device, representing a default strategy for how humans come to deal with potentially complex sets of relations. We argue this with regard to counting behaviors in children and also with regard to how linear monotonic devices for resolving certain logical tasks endure into adulthood.

Insofar as the monograph reprises any aspect of the Piagetian account, it is in his highlighting of an important cognitive discontinuity in logico-mathematical understanding at around the age of 7, and his quest for understanding the transactions with the physical world that lead to it.
The Development of Size Sequencing Skills: An Empirical and Computational Analysis

In this monograph, Maggie McGonigle-Chalmers and Iain Kusel report an investigation into a phenomenon called size seriation. At around the age of seven years, children suddenly become capable of systematically organizing objects in order of size. Using touchscreen tasks, they explore the differences between children of five and seven years when learning seriation tasks and when trying to identify size relations such as middle-sized. A computer model simulates the findings and shows how the act of size sequencing itself, together with an increase in memory capacity, creates a new solution for the older child that is not available to the younger child. Taken together, the findings and model reveal changes in mental functioning that explain spontaneous seriation and how the concept of a “unit” emerges during development.

Maggie McGonigle-Chalmers, MA, Ph.D.

is a retired Senior Lecturer (now Honorary Fellow) from the University of Edinburgh, Psychology Department with a research interest in Developmental Cognition and Autism Spectrum Disorders. In addition to publications arising from that work, she has authored a textbook entitled *Understanding Cognitive Development* (SAGE Publications, 2015).

Iain Kusel, MA, MSc, Ph.D.

is a software engineer with a research interest in developmental cognition and computational modelling. He received his Ph.D. from the Department of Engineering and Innovation, Faculty of Maths, Computing and Technology, The Open University. He was affiliated with the University of Edinburgh at the time this work was completed, and is now a software engineer at the Sword Group.

Front cover photo credit: Dan Weiss/Penn State/danw.smugmug.com