Data in Brief 33 (2020) 106405

Contents lists available at ScienceDirect

Data in Brief

journal homepage: www.elsevier.com/locate/dib

Data Article

A neuroimaging dataset of deductive reasoning in school-aged children

Marisa N. Lytle[a,b,*], Jérôme Prado[c], James R. Booth[a,**]

[a] Department of Psychology and Human Development, Vanderbilt University, Nashville, TN, USA
[b] Department of Psychology, The Pennsylvania State University, University Park, PA, USA
[c] Lyon Neuroscience Research Center, INSERM U1028 – CNRS UMR5292, University of Lyon, Bron, France

ARTICLE INFO

Article history:
Received 16 June 2020
Revised 17 August 2020
Accepted 8 October 2020
Available online 14 October 2020

Keywords:
fMRI
Deductive reasoning
Math
Children

ABSTRACT

Here we describe "Brain development of deductive reasoning" a pediatric neuroimaging dataset freely available on OpenNeuro.org. This dataset includes neuroimaging and standardized assessment data from 56 participants aged 8.47–15 years. Functional Magnetic Resonance Imaging (fMRI) data were collected while participants completed both set-inclusion and linear-order deductive reasoning tasks. A subset of participants (n=45) returned two years later for follow-up standardized assessment testing allowing for future research to investigate individual change in cognitive and academic skill. Previous research on this dataset has not examined the relation of skill and demographic measures to the neural basis of reasoning. Moreover, these studies have not examined the relation of the neural basis of reasoning to that of arithmetic or differences between children and adults in the neural basis of reasoning. Therefore, there are many opportunities to extend the research in the published reports on this data.

* Corresponding author Department of Psychology, The Pennsylvania State University, University Park, PA, USA. Department of Psychology and Human Development, Vanderbilt University, Nashville, TN, USA.
** Corresponding author.
E-mail addresses: m.n.lytle@psu.edu (M.N. Lytle), james.booth@vanderbilt.edu (J.R. Booth).
Social media: (M.N. Lytle), (J. Prado), (J.R. Booth)

https://doi.org/10.1016/j.dib.2020.106405

Specifications Table

Subject	Developmental Cognitive Neuroscience
Specific subject area	Neuroimaging of Deductive Reasoning in School-aged Children
Type of data	Tables Images
How data were acquired	3T Siemens Trio-Tim scanner, 16-channel head coil. E-prime software was used to display tasks and collect behavioral data.
Data format	Raw
Parameters for data collection	All participants were right-handed, native English speakers, having normal or corrected to normal vision and no history of psychological or neurological disorders, prematurity of less than 36 weeks, head injury causing overnight hospitalization, hearing loss, or contraindications for MRI.
Description of data collection	Participants (*n*=56) completed standardized measures of cognitive and academic ability, a practice MRI scan in a mock scanner, a structural MRI scan, and functional MRI scans while performing deductive reasoning tasks. In addition, a subset of children (*n*=45) returned two years later and completed follow-up standardized testing.
Data source location	Northwestern University Center for Advanced Magnetic Resonance Imaging (CAMRI), Chicago, IL
Data accessibility	Repository name: OpenNeuro Data identification number: 10.18112/openneuro.ds002886.v1.0.0 Direct URL to data: https://openneuro.org/datasets/ds002886/versions/1.0.0
Related research articles	R. Mathieu, J.R. Booth, J. Prado, Distributed Neural Representations of Logical Arguments in School-Age Children, Hum. Brain. Mapp. 36 (2015), 996-1009. https://doi.org/10.1002/hbm.22681.

Value of the Data

- Extensive skill and demographic measures allow for examination of how these variables are related to the neural basis of reasoning.
- Longitudinal assessment scores allow for prediction of individual change from behavioral or neuroimaging data.
- Matched participants with an external dataset allows for the comparison of the neural basis of reasoning and arithmetic.
- Parallel adult participants in an external dataset allows for examination of developmental differences.
- Compliance with Brain Imaging Data Structure (BIDS) specifications supports ease of future use.

1. Data Description

All raw data are freely available in the public neuroimaging dataset entitled "Brain Development of Deductive Reasoning" hosted on OpenNeuro.org [1]. The data are organized in accordance with the Brain Imaging Data Structure Specifications which allow for easy reuse of the data as well as utilization of tools that work with this standard [7]. The dataset includes raw and standardized scores from a battery of neuropsychological standardized assessments and questionnaires used to quantify cognitive and academic skill, structural Magnetic Resonance Imaging (MRI) images, functional MRI images collected while participants completed two deductive reasoning tasks, and behavioral data from those tasks. Table 1 in this article describes the number of subjects having completed each of the fMRI tasks by sex and Fig. 1 provides an illustration of the task design and timing.

This dataset has been used in part in one publication [2]. In addition, this dataset is accompanied by a larger dataset entitled "Brain Correlates of Math Development" which investigates arithmetic development in the same participants [3]. The arithmetic dataset is described

Table 1
Number of participants completing each task. Number of participants by sex having completed each experimental task.

		Number of participants		
		Female	Male	Total
Syllogistic reasoning	Run 1	30	21	51
	Run 2	29	21	50
Transitive reasoning	Run 1	28	17	45
	Run 2	29	21	50

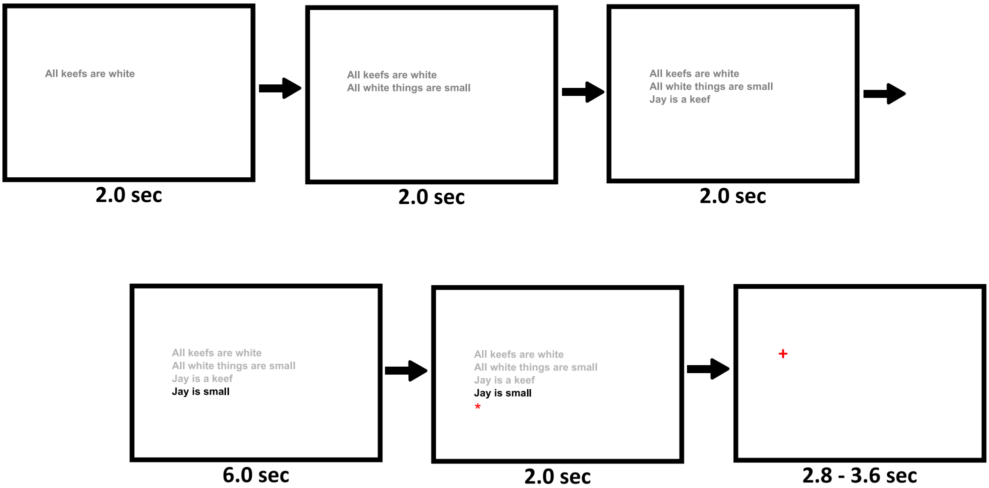

Fig. 1. Task design. Illustration of a single experimental trial in the syllogistic reasoning task.

in Suárez-Pellicioni et al., is freely available on OpenNeuro.org and includes longitudinal fMRI tasks of rhyming, numerosity, multiplication, and subtraction processing [4]. This dataset is also accompanied by an adult dataset on the same experimental tasks in the scanner, but with a reduced number of individual difference variables outside of the scanner [5,6]. The presently described dataset contains a new and unique contribution of deductive reasoning fMRI tasks that overlaps with the arithmetic dataset in standardized assessment scores and structural imaging data.

This dataset will allow for the examination of many additional research questions that have not yet been examined. First, participants completed an extensive standardized testing battery. This will allow others to examine the relation of skill measures to the neural basis of reasoning. Second, demographic data will allow researchers to compare variables such as socio-economic status to the neural basis of reasoning. Third, the overlap in subjects with the arithmetic dataset will allow for the examination of the connection between reasoning and arithmetic. Fourth, comparable adult data has been uploaded onto OpenNeuro, so studies can examine developmental differences.

2. Experimental Design, Materials and Methods

2.1. Participants

This dataset includes neuroimaging and standardized assessment data from 56 participants aged 8.47–15 years (mean age = 11.20, SD = 1.64, 32 female) at the first time point, session T1.

A subset of participants, aged 10.91–16.47 years (n=45, mean age = 13.47, SD = 1.59, 25 females) returned two years later for session T2 to complete follow up standardized testing. Participants completed additional neuroimaging tasks at both session T1 and T2 which are available in a previously published dataset [5]. All participants were recruited from the greater Chicago area through flyers, advertisements, and community events. Participants were screened and included only if they were right handed, native English speakers, had no uncorrected visual or hearing loss, and had no parent report of neurological disease, epilepsy, prematurity of less than 36 weeks, birth complications requiring admission to the neonatal intensive care, head injury requiring emergency medical evaluation, taking medication affecting the central nervous system, or contraindications for MRI.

2.2. Standardized assessments and questionnaires

Standardized assessments of cognitive and academic skill were administered during the first visit of session T1. These assessments included the Test of Mathematical Abilities 2nd Edition (TOMA-2) [8], the Automated Working Memory Assessment (AWMA-S) [9], the Comprehensive Math Abilities Test (CMAT) [10], the Comprehensive Test of Phonological Processing (CTOPP) [11], the KeyMath-3 [12], the Test of Word Reading Efficiency (TOWRE) [13], the Woodcock-Johnson Third Edition (WJ-III) [14], and the Weschler Abbreviated Scales of Intelligence (WASI) [15]. Guardians also completed the Attention Deficit and Hyperactivity Disorder (ADHD) Rating Scale-IV [16] and a questionnaire of developmental history. The developmental history questionnaire asked parents/guardians about their child's difficulties and diagnosed disorders, school environment, learning preferences, parental/family demographics, and parental/family medical history. A complete list of the questions on the developmental history questionnaire is located in the accompanying data dictionary in the phenotype directory of the dataset. A subset of participants returned two years later for session T2 and were administered all but the CTOPP and the developmental history questionnaire.

2.3. Practice imaging

Prior to the day of scanning all participants completed a practice MRI session in a mock scanner to become familiar with the scanning environment and the tasks. Participants were trained to remain still in the scanner using an infrared tracking device that would signal when participants moved their head more than 2 mm. Participants were introduced to the tasks outside the mock scanner via a presentation and then practiced the tasks inside the mock scanner. All practice tasks contained half as many trials as the in-scanner tasks, organized into one run, and did not contain any of the stimuli used in the in-scanner tasks.

2.4. Functional imaging tasks

Participants completed two deductive reasoning tasks while in the scanner called Syllogistic Reasoning and Transitive Reasoning. Tasks only differed in the type of reasoning problem that was solved. Each experimental trial contained one problem consisting of three premises and a conclusion. Half of the conclusions required the integration of all three premises and half required the integration of only two premises. In addition, some conclusions included a negation to make conclusions less predictable. This amounted to 36 problems organized into four groups; 18 true and affirmative problems (true_affirm), 6 false and affirmative problems (false_affirm), 6 true with negation problems (true_negate), and 6 false with negation problems (false_negate). Each category was further split into those requiring 2 premises to make the judgment and those requiring 3 premises to make the judgment for a total of eight conditions, premises required is denoted by a number preceding the validity in the condition name (i.e. 2_true_affirm). Premises and the conclusion were presented sequentially in 2 s intervals, with the next premise appearing below the last (i.e. first premise at 0 s, second at 2 s, third at 4 s, and conclusion at 6 s). Premises were presented in grey text while the conclusion was presented in black text to make it clear that a judgment had to be made. Each problem was also simultaneously presented auditorily through headphones. Once presented with the conclusion, participants were given 6 s to press one of two buttons to judge the validity of the conclusion given the premises. The trial continued as soon as participants provided a response or, after 6 s had passed, a red asterisk appeared below the conclusion for 2 s to indicate that no response had been made. At the end of each trial, a jittered red fixation cross was presented on the screen for 2.8–3.6 s. Fig. 1 illustrates an experimental trial in the Syllogistic Reasoning task. Each task also included 18 null trials to serve as a baseline correction. In these trials, a blue cross appeared on the screen for 2.8–3.6 s followed by a red cross for 2.8–3.6 s and participants were asked to press the button under their first finger when they saw a blue cross. Participants could respond as soon as they saw the blue cross and until it turned red. The trial would continue to the red cross as soon as the participant responded. Each task contained 54 trials total which were divided into two runs to allow for breaks and reduce participant fatigue. Each run ended with the presentation of a black fixation cross for 10 s.

Imaging and behavioral data are stored within each subject folder and titled sub-<sub_ID>_task-<task_name>_ bold.nii and sub-<sub_ID>_task-<task_name>_ events.tsv respectively, where sub-ID is the number assigned to the subject and task_name is the name of the functional task. Task names were shortened to syllogisms and transitive. Behavioral tab separated values files include trial onset, duration, type, accuracy, response time, premise text, conclusion text, and auditory stimulus file name.

2.4.1. Syllogistic reasoning

In the syllogistic reasoning task, participants were presented with set-inclusion problems. In this task, the premises described a series of relationships among three classes. In each problem, the first class was a monosyllabic pseudoword, and the second and third classes were one of sixteen adjectives: tall, short, big, small, old, young, fast, slow, brown, red, black, blue, green, white, or pink. The first premise stated that the first class was included in the second class and the second premise stated that the second class was included in the third class. The third premise of each problem characterized an imaginary character as belonging to one of the classes. An example of a valid and affirmative problem necessitating the integration of two premises was: (1) All blons are pink, (2) All pink things are young, (3) Ken is a blon, (C) Ken is pink.

2.4.2. Transitive reasoning

In the transitive reasoning task, participants were presented with linear order problems. In this task, the premises described a linear ordering of 4 imaginary characters. Each character had a single syllable name and one of eight comparative adjectives was used throughout: slower, faster, shorter, taller, younger, older, smaller, or bigger. An example of a valid and affirmative problem necessitating the integration of two premises was: (1) Wes is older than Pam, (2) Pam is older than Tim, (3) Tim is older than Wes, (C) Wes is older than Tim.

2.4.3. Additional tasks

Some participants completed additional fMRI tasks as part of a larger dataset [5]. These data are publicly available on OpenNeuro.org in the data repository, “Brain Correlates of Math Development” and are described in Suárez-Pellicioni et al. [6]. Participant labels are consistent across these datasets to allow for combined analyses.

2.6. MRI acquisition protocol

Magnetic Resonance Images were acquired at Northwestern University Center for Advanced Magnetic Resonance Imaging (CAMRI) using a 16-channel head coil in a 3T Siemens Trio-Tim scanner running Siemens Syngo software version MR B17. Participants were provided a right-handed button box to respond to the tasks during the scans. All tasks were presented on a screen behind the scanner in a counterbalanced order, and were viewed through a mirror attached to the head coil. During MPRAGE data acquisition, participants viewed a movie.

T1-weighted MPRAGE images were acquired with the following parameters: TR = 2300 ms, TE = 3.36 ms, matrix size = 256 $\times$ 256, bandwith = 240 Hz/Px, slice thickness = 1 mm, number of slices = 160, voxel size = 1 mm isotropic, flip angle = 9°.

Blood oxygen level dependent signal (BOLD) was acquired using a T2-weighted susceptibility weighted single-shot echo planar imaging (EPI) with the following parameters: TR = 2000 ms, TE = 20 ms, matrix size = 128 $\times$ 120, bandwidth = 1302 Hz/Px, slice thickness = 3 mm (0.48 mm gap), number of slices = 32, voxel size = 1.7 $\times$ 1.7 $\times$ 3.0 mm, flip angle = 80°, GRAPPA acceleration factor = 2. Slices were acquired interleaved from bottom to top with even slices acquired first. Tasks were subject paced resulting in a variable amount of volumes being collected for each run.

2.7. Quality control

Neuroimaging data followed a predefined series of steps to organize the data in accordance with the Brain Imaging Data structure, assess data quality, and remove identifying information. First, all data were converted from Dicom to nifti format with MRI Convert version 2.0 and necessary imaging parameters were extracted from the dicom header. These parameters are consistent across all subjects and are stored in a data dictionary file at the root level of the dataset for each task. All nifti images were then reoriented to the anterior commissure and facial features were removed from structural images. Facial features were removed by first running the FreeSurfer tool mri_deface on the images [17]. If, upon visual inspection, the face was not removed, images were then defaced manually by aligning the raw image to a template image using mri_robust_register and then using the inversion of the resulting transformation matrix to transform a facemask to the raw image space which was then multiplied by the raw image [18]. All structural images were reviewed to ensure no facial features remained.

On occasion, participants completed tasks on separate dates or completed structural scans in a different session. Shifted acquisition dates are included in the participants data table at the root level of the dataset. Dates were shifted from −365 to 0 days within a subject and were then shifted back 200 years to make the date shifting transparent.

In addition, due to high movement associated with collecting data from pediatric populations all functional images were reviewed for movement using the ArtRepair toolbox [19]. Any runs containing greater than 25% of all volumes with movement greater than 1.5 mm of volume to volume translation were removed from the dataset.

Ethics Statement

Informed consent was obtained from all participants and their guardians and all protocols were approved by the Institutional Review Board at Northwestern University. In addition, all identifiable information was removed from the dataset to protect participant privacy.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This collection and organization of this dataset was supported by the National Institute of Child Health and Human Development [grant number R03-HD069781] awarded to James R. Booth. We thank Rachna Mutreja, John Binzak, and Ece Demir-Lira for their help with data collection and disseminating parts of this research as well as the children and families for their participation.

References

[1] M.N. Lytle, J. Prado, J.R. Booth, Brain Development of Deductive Reasoning, OpenNeuro, v1.1.0, 2020. doi:10.18112/openneuro.ds002886.v1.0.0.
[2] R. Mathieu, J.R. Booth, J. Prado, Distributed neural representations of logical arguments in school-age children, Hum. Brain. Mapp. 36 (2015) 996–1009, doi:10.1002/hbm.22681.
[3] M. Suárez-Pellicioni, M.N. Lytle, J.R. Booth, Brain Correlates of Math Development, OpenNeuro, v1.3.0, 2020. doi:10.18112/openneuro.ds001486.v1.3.0.
[4] M. Suárez-Pellicioni, M.N. Lytle, J.R. Booth, A longitudinal neuroimaging dataset on arithmetic processing in 8- to 16-year old children, Sci. Data 6 (2019) 190040, doi:10.1038/sdata.2019.40.
[5] J. Prado, R. Mutreja, J.R. Booth, Fractioning the neural substrates of transitive reasoning: task-dependent contributions of spatial and verbal representations, Cereb. Cortex 23 (2013) 499–507, doi:10.1093/cercor/bhr389.
[6] M.N. Lytle, J. Prado, J.R. Booth, Brain Correlates of Deductive Reasoning in Adults, OpenNeuro, v1.1.0, 2020. doi:10.18112/openneuro.ds003076.v1.0.0.
[7] K.J. Gorgolewski, T. Auer, V.D. Calhoun, R.C. Craddock, S. Das, E.P. Duff, G. Flandin, S.S. Ghosh, T. Glatard, Y.O. Halchenko, D.A. Handwerker, M. Hanke, D. Keator, X. Li, Z. Michael, C. Maumet, B.N. Nichols, T.E. Nichols, J. Pellman, J.B. Poline, A. Rokem, G. Schaefer, V. Sochat, W. Triplett, J.A. Turner, G. Varoquaux, R.A. Poldrack, The brain imaging data structure, a format for organizing and describing outputs of neuroimaging experiments, Sci. Data 3 (2016) 1–9, doi:10.1038/sdata.2016.44.
[8] V. Brown, E. McEntire, M.E. Cronin, Test of Mathematical Abilities, 2nd ed., Pro-ed, 1994.
[9] T.P. Alloway, Automated Working Memory Assessment Manual, Harcourt, 2007.
[10] W.P. Hresko, 2003 CMAT: Comprehensive Mathematical Abilities Test, Pro-ed, 2003.
[11] R.M. Bruno, S.C. Walker, Comprehensive test of phonological processing (CTOPP), Diagnostique 24 (1999) 69–82.
[12] A.J. Connolly, KeyMath-3 Diagnostic Assessment: Manual Forms A and B, Pearson, 2007.
[13] J.K. Torgesen, C.A. Rashotte, R.K. Wagner, TOWRE: Test of Word Reading Efficiency, Psychological Corporation, 1999.
[14] R.W. Woodcock, K.S. McGrew, N. Mather, F. Schrank, Woodcock-Johnson III, Riverside Publishing, 2001.
[15] D. Wechsler, Wechsler Abbreviated Scale of Intelligence, Harcourt Assessment, 1999.
[16] G.J. DuPaul, T.J. Power, A.D. Anastopoulos, R. Reid, ADHD Rating Scale—IV: Checklists, Norms, and Clinical Interpretation, Guilford Press, 1998.
[17] A. Bischoff-Grethe, B. Ozyurt, E. Busa, B.T. Quinn, A technique for the deidentification of structural brain MR images, Hum. Brain Mapp. 28 (2007) 9, doi:10.1002/hbm.20312.
[18] M. Reuter, H.D. Rosas, B. Fischl, Highly accurate inverse consistent registration: a robust approach, NeuroImage 53 (2010) 1181–1196, doi:10.1016/j.neuroimage.2010.07.020.
[19] P.K. Mazaika, S. Whitfield-Gabrieli, A.L. Reiss, Artifact repair of fMRI data from high motion clinical subjects, NeuroImage 36 (2007) S142.