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Data Article

A neuroimaging dataset on working memory and reward processing in children with and without ADHD

Marisa N. Lytle[a,*], Rubi Hammer[b], James R. Booth[a,*]

[a] *Department of Psychology and Human Development, Vanderbilt University, Nashville, TN*
[b] *Ping Identity, Tel Aviv, Israel*

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ABSTRACT

This article describes the public neuroimaging dataset entitled "Working Memory and Reward in Children with and without Attention Deficit Hyperactivity Disorder (ADHD)" available on OpenNeuro.org. This dataset uses functional magnetic resonance imaging (fMRI) while participants complete 8 n-back tasks designed to explore working memory, monetary reward, and feedback processing in typically developing children and children diagnosed with ADHD. In addition, this dataset includes longitudinal scores from a battery of standardized measures of cognitive ability, ADHD symptoms, and reading skill. Neuroimaging and standardized testing data were collected from 79 children, aged 8.6–12.0, of which 35 had a formal diagnosis of ADHD at session T1. 48 children returned two years later to complete standardized testing at session T2. Although some work has been published on the spatial working memory task, future research could investigate the verbal working memory and longitudinal data which are unexplored. In addition, this dataset is accompanied by an adult dataset, including 24 participants completing the same tasks entitled, "Working Memory and Reward in Adults" and available on OpenNeuro.org.

* Corresponding authors.
E-mail addresses: marisa.n.lytle@vanderbilt.edu (M.N. Lytle), james.booth@vanderbilt.edu (J.R. Booth).

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Specifications Table

Subject	Developmental Cognitive Neuroscience
Specific subject area	Neuroimaging of Working Memory
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	Participants were required to be right-handed, native English speakers, have normal or corrected to normal vision and have no history of neurological or psychological disorder, prematurity of less than 36 weeks, head injury causing overnight hospitalization, hearing loss, or contraindications for MRI. Participants could not be taking medication affecting the central nervous system other than ADHD medication, and all participants with ADHD were required to be male.
Description of data collection	79 children (35 with ADHD diagnosis) and 24 adults, completed fMRI scans while performing spatial and verbal working memory tasks. In addition, all children completed a battery of standardized tests and questionnaires and a subset of children ($n = 48$) were followed longitudinally and completed standardized tests again two years later.
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.ds002424.v1.1.1; 10.18112/openneuro.ds002687.v1.1.0 Direct URL to data: https://openneuro.org/datasets/ds002424/versions/1.1.1 https://openneuro.org/datasets/ds002687/versions/1.1.0

1. Value of the data

- Large sample of pediatric neuroimaging data in typical children and those with ADHD
- Longitudinal behavioral data allows for prediction of change in cognitive function
- Multi-factor task design allows neural mechanisms to be teased apart in order to explore unique contributions of reward and feedback
- Verbal working memory tasks and longitudinal standardized testing data have yet to be published
- Compliance with Brain Imaging Data Structure (BIDS) specifications supports ease of future use

2. Data

All raw developmental data are available to the public on OpenNeuro.org in the dataset entitled "Working Memory and Reward in Children with and without Attention Deficit Hyperactivity Disorder (ADHD)" [1] and are organized according to the Brain Imaging Data Structure (BIDS) version 1.3.0 [6]. The dataset is comprised of MPRAGE structural images, fMRI images acquired while participants completed eight different working memory tasks that varied in domain (i.e. spatial, verbal), reward amount (i.e. large, small) and feedback (i.e. immediate, delayed), scores from standardized tests of cognitive ability, and responses to questionnaires and interviews measuring ADHD symptomatology and participant demographics. This article includes tables and figures describing the characteristics of the participants and tasks. Table 1 lists the standardized assessments and questionnaires collected at each time point, Table 2 lists the number of participants completing each task by diagnosis, and Fig. 1 illustrates the multi-factor task design. Accompanying raw adult neuroimaging data are available on OpenNeuro.org in the dataset

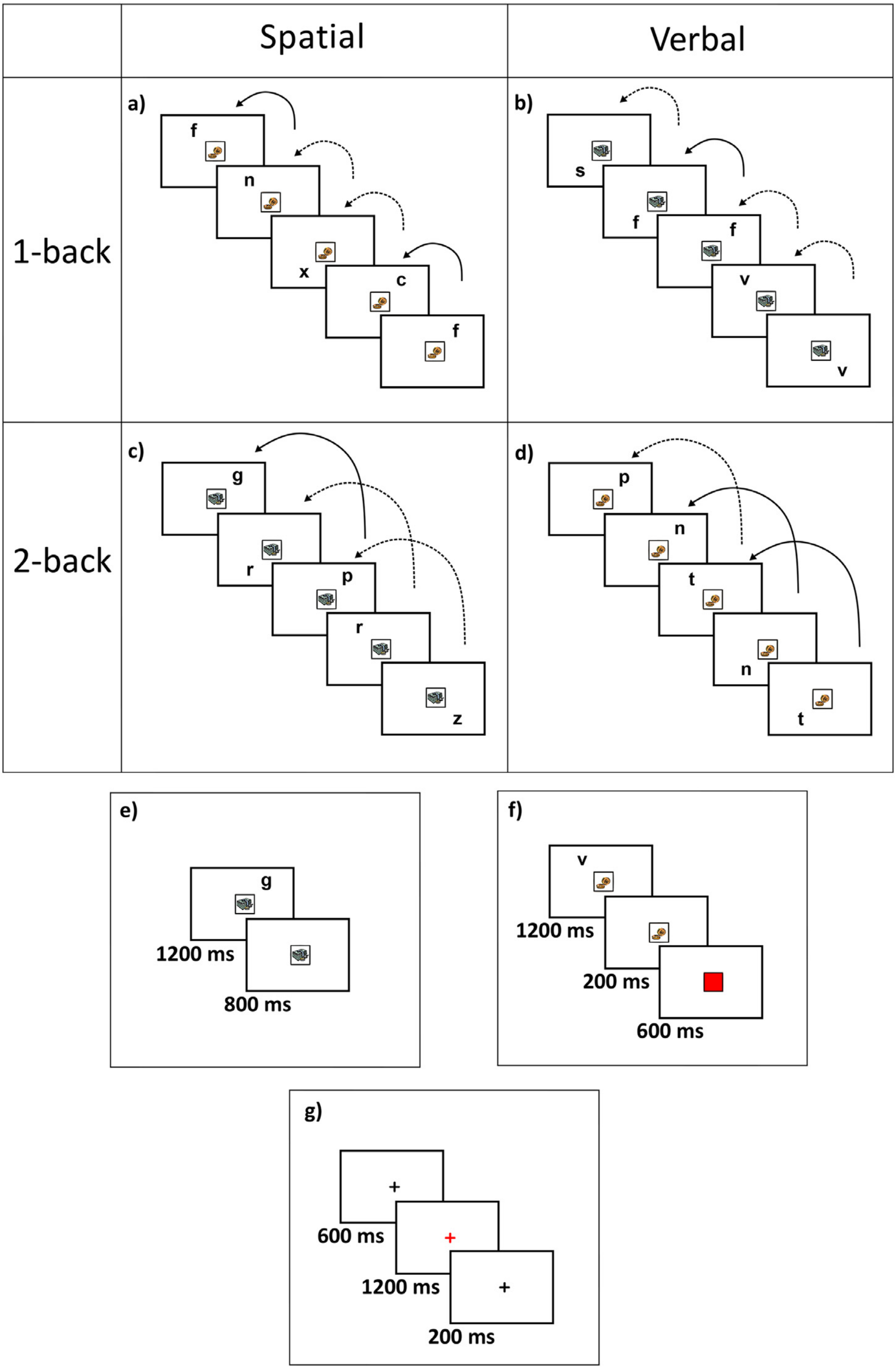

Fig. 1. Task Design. Illustration of correct (solid arrow) and incorrect (dashed arrow) trials in the (a) spatial 1-back, (b) verbal 1-back, (c) spatial 2-back, and (d) verbal 2-back tasks. Trial timing for the (e) delayed feedback large reward, (f) immediate feedback small reward, and (g) red cross fixation control trials.

Table 1
Standardized assessment and questionnaire subtests. Subtests administered from each standardized assessment and questionnaire.

Measure	**Test**	**Subtest**	**Session T1**	**Session T2**
Achievement	Woodcock-Johnson III (WJ-III)	Letter-Word Identification	*	*
		Calculation	*	*
		Spelling	*	*
		Word Attack	*	*
Attention-deficit/hyperactivity disorder	ADHD Rating Scale-IV: Home Version	Hyperactivity and Impulsivity	*	*
		Inattention	*	*
		Total	*	*
	Kiddie Schedule for Affective Disorders and Schizophrenia – Present and Lifetime (K-SADS-PL)		*	*
	Conner's Continuous Performance Test II (CPT-II)		*	*
Behavioral Inhibition and Avoidance	Short Survey for Behavioral Avoidance System and Behavioral Inhibition System (BIS-BAS)	Behavioral Inhibition System	*	*
		Behavioral Avoidance Reward Responsiveness	*	*
		Behavioral Avoidance Drive	*	*
		Behavioral Avoidance Fun Seeking	*	*
Intelligence	Wechsler Abbreviated Scale of Intelligence (WASI)	Vocabulary	*	*
		Block design	*	*
		Similarities	*	*
		Matrix reasoning	*	*
Phonological Processing	Comprehensive Test of Phonological Processing (CTOPP)	Elision	*	
		Blending Words	*	
Reading	Test of Word Reading Efficiency (TOWRE)	Sight Word Efficiency	*	
		Phonemic Decoding Efficiency	*	
Working Memory	Automated Working Memory Assessment – Short Form (AWMA-S)	Verbal Short-Term Memory	*	*
		Verbal Working Memory	*	*
		Visuo-Spatial Short-Term Memory	*	*
		Visuo-Spatial Working Memory	*	*

entitled, "Working Memory and Reward in Adults" [2]. These datasets have been used, in part, in previous publications, but the verbal working memory tasks and longitudinal standardized testing data have yet to be explored [3-5].

Table 2
Number of participants by task and diagnosis. Number of participants having completed each fMRI task by diagnosis.

Task	Number of participants		
	TD	ADHD	Total
Verbal, Large Reward, Delayed Feedback (VLD)	43	30	73
Verbal, Large Reward, Immediate Feedback (VLI)	43	31	74
Verbal, Small Reward, Delayed Feedback (VSD)	43	27	70
Verbal, Small Reward, Immediate Feedback (VSI)	42	30	72
Spatial, Large Reward, Delayed Feedback (SLD)	35	27	62
Spatial, Large Reward, Immediate Feedback (SLI)	36	30	66
Spatial, Small Reward, Delayed Feedback (SSD)	36	28	64
Spatial, Small Reward, Immediate Feedback (SSI)	36	29	65

3. Experimental design, materials, and methods

3.1. Participants

The described developmental dataset contains data from 79 children at session T1 (mean age = 10.4, SD = 0.96, 14 female). A subset of the participants returned two years later to complete a follow-up standardized testing session ($n = 48$, mean age = 12.6, SD = 0.94). 35 participants at session T1 and 18 participants at session T2 had a diagnosis of Attention Deficit Hyperactivity Disorder (ADHD). All participants diagnosed with ADHD were male. Participants were recruited from the greater Chicago area through advertisements, flyers, letters to interested organizations serving individuals with ADHD, and brochures. All participants were right-handed, native English speakers, and had no history of prematurity less than 36 weeks, hearing loss, or contraindications for MRI reported by parents. In addition, all participants had no parent reported history of psychiatric illness or neurological disease and were not taking any medication affecting central nervous system processing, other than ADHD and associated medication. Participants taking stimulant medication for ADHD were instructed to not take the medication for the 24 h immediately prior to the study session. ADHD diagnosis was confirmed by guardian response to the ADHD rating scale – home version [7] and by interview evaluation using the Kiddie Schedule for Affective Disorders and Schizophrenia for School Aged Children: Present and Lifetime (K-SADS-PL) [8]. All participants were administered the supplemental screening for Disruptive Behavior and Oppositional Defiant Disorder and Conduct Disorder and additional supplemental modules were administered as needed. At session T1, interview results were reviewed by a licensed clinician specializing in ADHD to confirm diagnosis. Informed consent was obtained from all participants and their guardians and all protocols were approved by the Institutional Review Board at Northwestern University.

The accompanying adult neuroimaging dataset contains data from 24 adults (mean age = 26.2, SD = 2.57, 14 female). Participants completed the same eight in-scanner tasks described below that were utilized in the developmental dataset. Adult participants did not complete standardized assessments, questionnaires, or a practice scanning session, but their basic demographic information (e.g. age, sex, race) is available in the participants table at the root level of the dataset.

3.2. Standardized assessments and questionnaires

In the first visit of session T1, participants and their guardians completed nine different standardized measures and questionnaires of cognitive ability, achievement, and ADHD. Standardized psycho-educational measures included the Automated Working Memory Assessment – Short Form (AWMA-S) [9], the Comprehensive Test of Phonological Processing (CTOPP) [10], the Conner's Continuous Performance Test II (CPT-II) [11], the Test of Word Reading Efficiency (TOWRE) [12], the Wechsler Abbreviated Scale of Intelligence (WASI) [13], and the Woodcock-Johnson III Tests of Achievement (WJ-III) [14]. Questionnaire measures included the ADHD Rating Scale-IV: Home Version [7], the Short Survey for Behavioral Avoidance System and Behavioral Inhibition System (BIS-BAS) [15], and the Kiddie Schedule for Affective Disorders and Schizophrenia – Present and Lifetime (K-SADS-PL) [8]. At session T2, participants were invited to return to complete an additional standardized testing visit that included all tests completed at session T1 except for the CTOPP and the TOWRE. Table 1 describes the purpose of each test, and the subtests administered at each time point. Test order was counterbalanced to account for fatigue. Scores are separated by session and then assessment and are stored in tab separated values files in the phenotype directory at the root level of the dataset. When possible, data files contain both raw, age-normalized, and composite scores. All data files are accompanied by a data dictionary describing the test and the columns included in the data file.

In addition to the standardized measures and questionnaires, at session T1, guardians of participants also completed a developmental history questionnaire. The developmental history questionnaire asked parents/guardians about their child's difficulties and/or diagnosed disorders, school environment, learning preferences, parental/family demographics, and parental/family medical history. A complete list of the questions on the questionnaire is located in the accompanying data dictionary for the questionnaire in the phenotype directory of the dataset.

3.3. Practice imaging procedure

Participants completed an MRI practice session where they completed short versions of the MRI tasks in a mock scanner. In these sessions, participants were introduced to the scanner environment and sounds. Participants were trained to hold still using an infrared tracking device placed in front of a computer screen that provided feedback when detecting greater than 2 mm of movement. Participants were trained on the tasks outside of the mock scanner to ensure they understood the task, and then completed all practice tasks in the mock scanner. All practice tasks were half the total length of the in-scanner tasks in order to reduce fatigue associated with practicing the tasks both inside and outside the mock scanner.

3.4. Functional MRI tasks

Participants completed eight n-back working memory tasks in the scanner which varied in three factors: reward amount, feedback delay, and judgment type. In all tasks, participants were presented with a series of letters one at a time. These letters were located in one of four positions around a fixation box, in the top right corner, the top left corner, the bottom left corner, or the bottom right corner. All tasks were generated using E-prime software (Psychology Software Tools, Pittsburgh, PA).

Depending on the task, participants were required to make judgments in two different domains. In the verbal working memory task (V), participants were asked to judge whether the letter that appears on the screen was the same letter as the one presented n letters back. In the spatial working memory task (S), participants were asked to judge whether the letter that appears on the screen was in the same position as the one presented n letters back. Participants made responses by selecting one of two buttons on a right-handed button box. All tasks contained 1-back, 2-back, and fixation conditions presented in a block design. Fig. 1(a-d) illustrates the task design by domain and n-back amount. Prior to the beginning of each block, the program would indicate which task instructions were to be followed (1-back, 2-back or fixation). Each n-back experimental block contained 48 trials and each fixation block contained 12 trials. The 1-back block required 47 responses and the 2-back block required 46 responses as participants did not respond until they had enough information to make the judgement. Each task was arranged as experimental block, fixation block, experimental block, fixation block. The order of experimental blocks, 1-back first vs 2-back first, was counter balanced across participants.

Tasks also varied in reward amount. Participants were told that they would make $.02 or $.25 for every correct answer for the small (S) and large (L) reward tasks respectively. At the end of the study all participants were compensated with the same amount regardless of performance and were debriefed about this deception. Participants were reminded of what reward amount was being offered by one of two images, presented continuously, in the center of the fixation square. In the small reward tasks, the image was two coins, and in the large reward tasks the image was a stack of paper bills. Reward images are provided in the stimuli/ directory at the root level of the dataset.

Tasks contained one of two feedback times, immediate (I) or delayed (D). In the immediate feedback tasks, following the presentation of each letter, the fixation square would turn green or red to indicate a correct or incorrect response. In the delayed feedback tasks, participants would continue to view a black fixation square. At the end of each experimental block, participants would be told their percentage of correct responses.

In all tasks, trial timing was as follows. Participants were presented with the letter in one of the four corners for 1200 ms followed by a 200 ms fixation period where the letter disappeared and only the fixation square remained. Participants then continued to see a fixation period for 600 ms, in immediate feedback tasks the color of the fixation square changed depending on response and in delayed feedback the fixation square remained black. Trial timing is illustrated in Fig. 1(e-f).

Following each experimental block, participants completed a fixation block containing 12 trials. During fixation trials, subjects were presented with a black fixation cross for 600 ms, then were presented with 1200 ms of either a black or red fixation cross, and finally 200 ms of a black fixation cross. Subjects were instructed to press the first finger whenever a black fixation-cross turned red which took place in 4 out of the 12 trials. Fixation trial timing is illustrated in Fig. 1(g).

Behavioral data are stored alongside imaging files and titled sub-<sub_ID>_task-<task_name>_ events.tsv and include trial onset, duration, type, accuracy, response time, letter, and letter position. Table 2 describes the number of participants having completed each functional neuroimaging task by diagnosis group.

3.5. 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, Siemens Syngo software version MR B17. Participants were positioned supine and were given a right-handed button box to respond to the tasks during the scans. All tasks were presented on a screen behind the scanner, and 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 × 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 × 120, bandwidth = 1302 Hz/Px, slice thickness = 3 mm (0.48 mm gap), number of slices = 32, voxel size = 1.7 × 1.7 × 3.0 mm, flip angle = 80°, GRAPPA acceleration factor = 2. Slices were acquired interleaved from bottom to top with even slices acquired first. 145 vol were acquired for each task and the first 6 were removed to allow for equilibration resulting in 139 vol per task.

3.6. Quality control

Neuroimaging data were converted from DICOM to NifTI format using MRIConvert version 2.0 and imaging parameters were extracted from the DICOM headers and stored in a data dictionary file at the root level of the dataset by imaging type and task. To protect participant privacy, facial features were scrubbed from all structural MPRAGE images using FreeSurfer mri_robust_register, using an inverse registration on a template defacing mask, and then multiplying the transformed mask by the raw image [16]. All images were inspected to ensure no facial features remained.

Due to participant fatigue or movement, scanning would occasionally take place over multiple dates. Shifted acquisition dates for each completed task are provided in the participants demographics table located at the root level of the dataset and titled participants.tsv. These dates were randomly shifted per participant −365 to 0 days and years were shifted prior to 1900 to indicate that dates were shifted.

All functional images were reoriented to the anterior commissure and were reviewed for movement using the ArtRepair toolbox [17]. Images containing 25% or more of the total number of volumes having volume-to-volume movement of greater than 2 mm were removed from the dataset.

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.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.dib.2020.105801.

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