Morphological and phonological processing in English monolingual, Chinese-English bilingual, and Spanish-English bilingual children: An fNIRS neuroimaging dataset

Authors
Xin Sun*, Kehui Zhang, Rebecca Marks, Zachary Karas, Rachel Eggleston, Nia Nickerson, Chi-Lin Yu, Neelima Wagley, Xiaosu Hu, Valeria Caruso, Tai-Li Chou, Teresa Satterfield, Twila Tardif, Ioulia Kovelman

Affiliations
1 Department of Psychology, University of Michigan Ann Arbor
2 Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology
3 Department of Psychology and Human Development, Vanderbilt University
4 Department of Psychology, National Taiwan University

Corresponding author’s email address and Twitter handle
Email address: sunxin@umich.edu
Twitter handle: @xinsun1007

Keywords
fNIRS, children, bilingualism, morphological awareness, phonological awareness, reading

Abstract
This article documents a functional Near-Infrared Spectroscopy (fNIRS) neuroimaging dataset deposited in Deep Blue Data. The dataset included neuroimaging and behavioral data from N = 343 children aged 5-10 with a diverse linguistic background, including children who are English monolingual, Chinese-English, and Spanish-English bilingual. Children completed phonological and morphological awareness tasks in each of their languages during fNIRS neuroimaging. They also completed a wide range of language and reading tasks. Parents filled in questionnaires to report children’s demographic information as well as their home language and literacy backgrounds. The dataset is valuable for researchers in the field of developmental cognitive neuroscience to further investigate questions such as the effects of bilingualism on children’s neural basis for literacy development.
### Specifications Table

| Subject                  | Developmental and Educational Neuroscience |
|--------------------------|--------------------------------------------|
| Specific subject area    | fNIRS neuroimaging of morphological and phonological awareness in English monolingual, Chinese-English, and Spanish-English bilingual children |
| Type of data             | Tables, Images, fNIRS hemodynamic data |
| How data were acquired   | TechEn Inc. CW6 fNIRS system with 690 and 830 nm wavelengths, 12 signals, 24 detectors, 46 channels. E-Prime software was used to display stimuli and collect data. |
| Data format              | fNIRS data with block stimuli marks are stored in .nirs files; Proficiency/demographic raw data are stored in excel sheets. |
| Parameters for data collection | All participants are children growing up in the US and attending English-only schools. The monolingual participants are all native speakers of English and only speak English. The bilingual participants have Spanish or Chinese exposure from home since birth. |
| Description of data collection | Participants (N = 343) completed a behavioral session and a neuroimaging session. The behavioral session assessed participants’ language and reading proficiency in each of their languages. The neuroimaging session asked participants to complete morphological and phonological awareness tasks in each of their languages during fNIRS scanning. |
| Data source location     | University of Michigan, Department of Psychology, Ann Arbor, MI. |
| Data accessibility       | Repository: Deep Blue Data Link to data Persistent Identifier: https://doi.org/10.7302/kxgf-ps11 |
| Related research article | 1. Sun, X., Zhang K., Marks, R., Nickerson, N., Eggleston, R., Yu, C.L., Chou., T., Tardif, T., & Kovelman, I. (2021). What’s in a word? Cross-linguistic influences on Spanish-English and Chinese-English bilingual children’s word reading development. *Child Development* 93(1), 84-100. [http://doi.org/10.1111/cdev.13666](http://doi.org/10.1111/cdev.13666) This article used data from the behavioral assessments of N = 283 participants from the current dataset. 2. Sun, X., Marks, R., Zhang, K., Yu, C.L., Eggleston, R., Nickerson, N., Chou, T.L., Hu, X.S., Tardif, T., Satterfield, T., & Kovelman, I. (In Press). Brain bases of English morphological processing: A comparison between Chinese-English, Spanish-English bilingual, and English monolingual children. *Developmental Science* Preprint available at: [https://osf.io/9zx2t/](https://osf.io/9zx2t/) 3. Marks, R. A., Eggleston, R., Sun, X., Yu, C. L., Zhang, K., Nickerson, N., Hu, X., & Kovelman, I. (2021). The neurobiological basis of morphological processing for typical and impaired readers. *Annals of Dyslexia* [https://doi.org/10.1007/s11881-021-00239-9](https://doi.org/10.1007/s11881-021-00239-9) |
Value of the Data (400 characters per point)

- Bilingualism research will benefit from this developmental dataset of young Spanish-English and Chinese-English bilinguals, allowing for inquiries into the effects of age of acquisition, experience, proficiency, and cross-linguistic transfer in children’s emerging neural architectures for language and literacy development.
- The dataset will equip researchers in the fields of developmental, educational, and cognitive neuroscience to address questions about children’s neuro-cognitive profiles for language and literacy development across three typologically-distinct languages.
- The dataset is extensive and allows for investigations into (but not limited to) meaningful research topics: the neural basis of phonological and morphological skills, behavioral indicators associated with the developing language brain networks, and the neural and behavioral profiles of children from diverse backgrounds such as those with bilingual experiences, dyslexia or reading disabilities.

1. Data Description

All data (raw neuroimaging data, neuroimaging task accuracy and reaction time, behavioral assessment raw and standard scores, and demographics) are available in the DeepBlue repository under the name “Morphological and phonological processing in English monolingual, Chinese-English bilingual, and Spanish-English bilingual children: An fNIRS neuroimaging dataset”. For a list of the Deep Blue files and contents, see Table 1.

Table 1. Full list of the Deep Blue Data files and contents

| Data/Measure | File Name in Deep Blue          | Data/Measure Content                                                                 |
|--------------|--------------------------------|--------------------------------------------------------------------------------------|
| fNIRS imaging | Chinese_NIRSfiles.zip        | .nirs files by ID and task for Chinese-English bilinguals                             |
|              | English_NIRSfiles.zip        | .nirs files by ID and task for English monolinguals                                   |
|              | Spanish_NIRSfiles.zip        | .nirs files by ID and task for Spanish-English bilinguals                              |
|              | NIRSfile_Readin_Plot.m       | A Matlab script that helps import and plot .nirs files into the Matlab program        |
| Task performance | Task_Performance_Data.zip | Excel spreadsheets including behavioral task performance (1 file), fNIRS task accuracy (2 files) and reaction time (2 files) |
Demographics

Participant_Demographics.xlsx

Demographic information, including age of testing, gender, grade, etc.

Language and literacy backgrounds

Language_and_Literacy_Background (ILQ, BOQ).xlsx

Itemized data for the In-Lab Questionnaire and the Bilingual Outcomes Questionnaire.

In-Lab_Questionnaire_ILQ.pdf

Full In-Lab Questionnaire (ILQ)

Bilingual_Outcomes_Questionnaire_(BOQ)_English.pdf

Full Bilingual Outcomes Questionnaire (BOQ) in English, Spanish, and Chinese

Bilingual_Outcomes_Questionnaire_(BOQ)_Chinese.pdf

Behavioral measures

Self-developed_Behavioral_Measures.zip

All self-developed behavioral measure items

Neuroimaging data are raw data files with block stimuli marks that signify on-task periods task condition. The neuroimaging data folder was organized by participant group and task. Specifically, under the folder “NIRS files”, subfolder “Chinese” includes all fNIRS data for the Chinese-English bilingual children, subfolder “English” is for the English monolingual children, and subfolder “Spanish” is for the Spanish-English bilingual children. There are two folders in the “English” subfolder, and four folders in the “Chinese” and “Spanish” subfolders that include data for specific tasks. For example, folder “English Morphology” includes the fNIRS data for the English morphological awareness task, folder “Chinese Phonology” includes the fNIRS data for the Chinese phonological awareness task. Under these folders, each fNIRS file is stored in an individual folder named after participant ID. For example, file “3007_CH_MA.nirs” is stored in folders “NIRS files” – “Chinese” – “Chinese Morphology” – “3007” and it is the fNIRS file for participant 3007 during their Chinese morphological task. All fNIRS neuroimaging data are .nirs files and can be easily read into most Matlab scripts. Table 1 shows the number of participants who completed each neuroimaging task by language group.

The “Task Performance Data.zip” includes all behavioral performance for the neuroimaging and behavioral assessments, presented with excel sheets. Neuroimaging task accuracy and reaction time are presented in two Excel sheets, named “R01_E-Prime Accuracy.xlsx” and “R01_E-Prime Reaction Times.xlsx”, respectively. The neuroimaging task items are included in the sheets (see the “read me” sheet in the excel files). Raw and standard scores for the behavioral assessments are also provided in an Excel sheet named “R01_Behavioral Measures.xlsx”. All self-developed behavioral assessments are presented in “Self-developed Behavioral Measures.zip”.

Demographic and language background data are presented in two Excel sheets, named “Participant_Demographics.xlsx” and “Language_and_Literacy_Background(ILQ, BOQ Data).xlsx”. The latter data sheet includes data from two questionnaires, and the full list of questionnaire items are presented with two word documents, named “In-Lab Questionnaire (IBQ).docx” and “Bilingual Outcomes Questionnaire(BOQ).docx”.

Table 2. Number of Participants by fNIRS Neuroimaging Task by Language Group

| Task                        | Monolingual Chinese | Bilingual Spanish | Bilingual Chinese |
|-----------------------------|---------------------|-------------------|------------------|
| Number of Participants (N) |                     |                   |                  |

2. Experimental Design, Materials, and Methods

2.1 Participants

Participants included \( N = 343 \) children aged 5 to 11 (\( M_{\text{age}} = 8.08, SD_{\text{age}} = 1.64 \), 161 girls). Participants were divided into three groups according to their language experience. All monolinguals were born to native English speakers and exposed to English-only language environments. Bilingual participants had at least one parent as a native speaker of either Chinese or Spanish and were exposed to the language at home, from birth. The English monolingual group included \( N = 135 \) children aged 5.4 to 11.9 (\( M_{\text{age}} = 8.46, SD_{\text{age}} = 1.65 \), 64 girls); the Chinese-English bilingual group included \( N = 102 \) children aged 5.1 to 11.5 (\( M_{\text{age}} = 7.51, SD_{\text{age}} = 1.67 \), 46 girls); and the Spanish-English bilingual group included \( N = 106 \) children aged 5.7 to 11 (\( M_{\text{age}} = 8.13, SD_{\text{age}} = 1.44 \), 51 girls). Within the English monolingual group, \( N = 8 \) were delayed in reading (\( M_{\text{age}} = 9.22, SD_{\text{age}} = 1.16 \), 2 girls), as indicated by their standard scores below 85 in at least two of the four reading tasks (i.e., Word Reading, Word Attack, Reading Comprehension, and Reading Fluency); and \( N = 20 \) had dyslexia (\( M_{\text{age}} = 9.45, SD_{\text{age}} = 1.61 \), 11 girls), as indicated by their 1) standard scores below 85 in at least two reading tasks, and 2) PPVT standard score 2 standard deviations (30 points) higher than word reading.

2.2 Behavioral assessments and the demographic information

Participants completed behavioral assessments in each of their languages while their parents filled out demographic questionnaires. The behavioral testing assessed key language and literacy skills including phonological awareness, morphological awareness, vocabulary, single-word reading, nonword reading, passage comprehension, and sentence reading fluency. The format of the heritage language measures maximally paralleled the English tasks. In addition, a backward digit span task was administered in English (WISC-V, Wechsler, 2014[1]). Details of language and literacy measures are shown in Table 2. All self-developed measures can be found in the data repository.

| Language                  | Morphological Awareness | Phonological Awareness |
|---------------------------|-------------------------|-----------------------|
| English                   | 131                     | 99                    |
| Chinese                   | 114                     | 98                    |
| Spanish                   | /                       | 89                    |
| Note: This table displays the number of participants in the fNIRS task. The numbers mostly but not fully align with the behavioral task. |
**Table 2. Language and literacy measures by language**

| Construct               | English Measure                                                                 | Reference                  | Spanish Measure                                                                 | Reference                  | Chinese Measure                                      | Reference                  |
|-------------------------|--------------------------------------------------------------------------------|----------------------------|--------------------------------------------------------------------------------|----------------------------|-----------------------------------------------------|----------------------------|
| **Phonological awareness** | Comprehensive Test of Phonological Processing Elision                          | Wagner et al. (1999)[2]    | Test of Phonological Processing in Spanish (TOPPS)                             | Francis et al. (2001)[5]   | Self-developed Syllable and Phoneme Elision task    | Newman et al. (2011)[3]; Sun et al. (2021)[4] |
|                         | Self-developed Early Lexical Morphology Measure (ELMM)                          |                            | Self-developed Early Lexical Morphology Measure -Spanish (ELMM-S)              | Modelled after the English task | Self-developed Morphological Construction Test      | Song et al. (2015)[7]; Sun et al. (2021)[4] |
| **Vocabulary**          | Peabody Picture Vocabulary Test-5 (PPVT)                                       | Dunn (2015)[8]             | Test de Vocabulario en Imágenes Peabody (TVIP)                                  | Dunn et al. (1986)[10]     | Peabody Picture Vocabulary Test-Revised            | Lu & Liu (1998)[9]        |
| **Nonword reading**     | Woodcock Johnson-4 Word Attack Subset (WJ-WA)                                  |                            |                                                                               |                            | /                                                   | /                         |
| **Single-word reading** | Woodcock Johnson-4 Letter-word Identification Subset (WJ-LWID)                 | Schrank et al., 2018[11]  | Batería III Woodcock-Muñoz Identificacion de letras y palabras                  |                            | Self-developed Character Recognition and Reading Task | Sun et al. (2021)[4]    |
| **Passage comprehension** | Woodcock Johnson-4 Passage Comprehension Subset (WJ-PC) |                            | Batería III Woodcock-Muñoz Comprehension de textos                           | Muñoz-Sandoval et al. (2005)[12] | /                                                   | /                         |
| **Sentence reading fluency** | Woodcock Johnson-4 Sentence Reading Fluency Subset (WJ-SRF)               |                            | Batería III Woodcock-Muñoz Fluidez en la lectura                              |                            | Self-developed Sentence Reading Fluency Task        | /                         |
2.3 fmRI S imaging tasks

Participants completed a morphological awareness and a phonological awareness task in each of their languages during fNIRS scanning. All of the tasks followed a block design and each lasted 7.2 minutes. Each task had twelve 30-second blocks and each block displayed 4 items, yielding 48 items in total. Blocks were separated by a 6-second break. All of the tasks had 3 conditions: 2 experimental conditions and 1 control condition. Each condition had 4 blocks (16 items). Blocks were presented with a fixed sequence and blocks of the same condition were not presented in succession. All task items followed the same paradigm: First, participants heard three words; next, they were asked to select which word of the last two matched the first (target) word by pressing a button. To help participants focus on the words they heard, the computer screen presented a colored box in place of the word stimulus (See Figure 1). All tasks were presented with E-Prime.

2.3.1. Morphological awareness task. The morphological awareness task asked participants to select the word that matched the meaning of the target word. For each item in the experimental conditions, the correct answer shared a morpheme with the target word while the distractor had a syllable that sounded identical but did not share a meaningful component with the target word. Experimental condition 1 was a compound condition that consisted of compound word targets. An English example is classroom, bedroom, mushroom; a Chinese example is 朋友 (peng2 you3/ friend), 好友 (hao3 you3/ good friend), 没有 (mei2 you3/ none); a Spanish example is mar (sea), marinero (sailor), mariposa (butterfly). Experimental condition 2 was a derivational condition that presented derivational word targets. An English example is runner, juggler, flower; a Chinese example is 读者 (du2 zhe3/ reader), 记者 (ji4 zhe3/ journalist), 或者 (huo4 zhe3/ or); a Spanish example is expresidente (expresident), exnovio (ex-boyfriend), examen (test). The control condition was a word recognition task. For each item, one of the last two
words would be identical to the target word. For example, *number, number, taxi*. The full list of items can be found in the Excel sheets for the neuroimaging task accuracy and reaction time.

2.3.2 Phonological awareness task. The phonological awareness tasks asked participants to select the word that matched the first sound of the target word. For each item in the experimental conditions, the correct answer would share the first sound with the target word, while the distractor would be semantically related but shared no initial sound with the target word. Experimental condition 1 was the *easy* condition. Words in this condition were less difficult: they did not have glides or diphthongs (in English and Spanish), and/or the distractor initial sounds were phonetically distant from the target words. An English example is *mother, major, father*; a Chinese example is 半夜 (/bàn yè/ midnight), 毕业 (/bì yè/ graduate), 深夜 (/shēn yè/ late night); a Spanish example is *salmón* (salmon), *camarón* (shrimp), *pantalón* (pants). Experimental condition 2 was the *hard* condition. Words in this condition were more difficult: they had either glides or diphthongs and/or the distractor initial sounds were phonetically similar to the target words. An English example with glide is *teeth, truth, mouth*; a Chinese example with a harder distractor is 帽子 (/mào zi/ midnight), 面子 (/miàn zi/ face), 脑子 (/nǎo zi/ brain); a Spanish example is *lunes* (Monday), *leones* (lions), *jueves* (Thursday). The control condition was identical to that in the morphological awareness task, but with different words. The full list of items can be found in the Excel sheets for the neuroimaging task accuracy and reaction time.

![Figure 2. fNIRS cap configuration. (A) how signal (red, letters) and detector (blue, numbers) sensors are located on a silicone-rubber band around the participant’s head, (B) map of the estimated brain regions covered by the cap design as digitized using AtlasViewer GUI (Aasted et al., 2015), (C) participant wearing the cap during data acquisition, (D) MRI version of the cap with vitamin-e capsules, and (E) visualization of vitamin-e capsules on the skull.](image-url)

2.4 fNIRS data acquisition

The fNIRS cap set-up included 12 emitters of near-infrared light sources and 24 detectors spaced ~2.7 cm apart, yielding 46 data channels (i.e., source-detector pairings; 23 channels per hemisphere; see Figure 2). The light sources and detectors were mounted onto a custom-built head cap constructed from 2 mm silicone rubber material with grommet attachments. The source
and detector alignments were placed precisely in a grid-like formation, ensuring full coverage of the participant’s frontal, temporal, and temporoparietal regions across multiple channels. The probes were applied as uniformly as possible for every participant using the international 10-10 transcranial system positioning (Jurcak, Tsuzuki, & Dan, 2007[13]); nasion, inion, Fpz, and left and right pre-auricular points, head circumference were measured and F7, F8, T3, and T4 were anchored to a specific source or detector. Once all optodes were placed on the cap, digital photos of the participant’s head and cap alignment were taken from the left, right, and center midline angles.

TechEn-CW6 software signal-to-noise ratio (SNR) minimum and maximum were set to the standard 80 dB and 120 dB power range, respectively. Before the start of each experimental task, the data quality control check was completed by detecting the participant’s cardiac signal across key channels of interest and ensuring the fNIRS signals were within the power parameters. When required, the experimenters would adjust the positioning of the cap or participant’s hair to register an apt cardiac signal. Data were collected at a sampling frequency of 50Hz.

Ethics Statements
Informed consent was obtained from all participating children and their guardians. In addition, all research protocols were approved by the Institutional Review Board at the University of Michigan Ann Arbor and the protocol number is HUM00033727. The dataset has also removed all identifiable information to protect participant privacy.

CRediT author statement
Xin Sun: Measure development, Data curation, validation, writing - original draft;
Kehui Zhang and Rebecca Marks: Measure development, Data curation, validation, writing - review and editing;
Ioulia Kovelman: Conceptualization, Methodology, Supervision, Funding acquisition, writing - review & editing;
All others: Data curation, validation, writing - review and editing.

Acknowledgments
The authors thank members of the Language and Literacy Laboratory at the University of Michigan who helped with participant recruitment, scheduling, and data acquisition. We also thank the National Institutes of Health for funding this work (Kovelman, PI: R01HD092498).

Declaration of Competing Interests
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.
References
[1] D. Wechsler, Wechsler Intelligence Scale for Children-Fifth Edition (WISC-V), The Psychological Corporation, 2014.
[2] R. K. Wagner, J. K. Torgesen, C. A. Rashotte, & N. A. Pearson, Comprehensive test of phonological processing: CTOPP, Pro-ed, 1999.
[3] E. H. Newman, T. Tardif, J. Huang, & H. Shu, Phonemes matter: The role of phoneme-level awareness in emergent Chinese readers, Journal of Experimental Child Psychology. 108 (2011) 242–259. https://doi.org/10.1016/j.jecp.2010.09.001
[4] X. Sun, K. Zhang, R. A. Marks, N. Nickerson, R. L. Eggleston, C. L. Yu, T. L. Chou, T. Tardif, & I. Kovemlan, What’s in a word? Cross-linguistic influences on Spanish–English and Chinese–English bilingual children’s word reading development, Child Development, 93 (2021) 84-100. https://doi.org/10.1111/cdev.13666
[5] D. Francis, M. Carlo, D. August, D. Kenyon, V. Malabonga, S. Caglarcan, & M. Louguit, Test of Phonological Processing in Spanish, Center for Applied Linguistics, 2001.
[6] A. P. Goodwin, A. C. Huggins, M. Carlo, V. Malabonga, D. Kenyon, M. Louguit, & D. August, Development and validation of extract the base: An English derivational morphology test for third through fifth grade monolingual students and Spanish-speaking English language learners, Language Testing, 29 (2012) 265–289. https://doi.org/10.1177/0265532211419827
[7] S. Song, M. Su, C. Kang, H. Liu, Y. Zhang, C. McBride-Chang, T. Tardif, H. Li, W. Liang, Z. Zhang, & H. Shu, Tracing children's vocabulary development from preschool through the school-age years: An 8-year longitudinal study, Developmental Science, 18 (2015) 119–131. https://doi.org/10.1111/desc.12190
[8] D. M. Dunn, Peabody Picture Vocabulary Test 5, NCS Pearson, 2015.
[9] L. Lu, & H. S. Liu, The Peabody Picture Vocabulary Test– revised in Chinese, Psychological Publishing, 1998.
[10] L. Dunn, F. Padilla, D. Lugo, & L. Dunn, TVIP: Test Vocabulario Imágenes Peabody, American Guidance Service, 1986.
[11] F. A. Schrank, K. S. McGrew, & N. Mather, Woodcock-Johnson IV, Riverside, 2014.
[12] A. F. Muñoz-Sandoval, R. W. Woodcock, K. S. McGrew, & N. Mather, Batería III Woodcock-Muñoz, Riverside Publishing, 2005.
[13] V. Jurcak, D. Tsuzuki, & I. Dan, 10/20, 10/10, and 10/5 systems revisited: Their validity as relative head-surface-based positioning systems, Neuroimage, 34 (2007) 1600-1611. https://doi.org/10.1016/j.neuroimage.2006.09.024