Caregiver-Reported Early Development Instruments

Data Management & Scoring Manual

January 16, 2024

INTRODUCTION

The **Caregiver Reported Early Development Instruments (CREDI)** were designed to serve as a population-level measure of early childhood development (ECD) for children from birth to age three. As the name suggests, the CREDI exclusively relies on caregiver reports (most often a parent of the child), and thus primarily focuses on milestones and behaviors that are easy for caregivers to understand, observe, and describe.

This **Data Management & Scoring Manual** was developed to help users (1) plan an organized data collection effort, (2) calculate different types of CREDI scores, and (3) use these scores responsibly and accurately interpret them. Users can collect data and prepare it for scoring either using electronic data collection methods (recommended) or on paper. Users can then generate scores either by uploading data to the CREDI Scoring App, an easy-to-use web-based application, or by downloading the *credi* package and scoring data locally using the statistical software R. Because the CREDI Scoring App is the preferred option for scoring, we cover it in detail in this document. Technical users preferring the *credi* R package should refer to additional documentation available on GitHub. Both the CREDI Scoring App and the *credi* R package use the responses on each CREDI item (question) to generate CREDI **overall**, **domain**, and **norm-referenced scores** for use in later analysis. In addition, users have the option of reporting **d-scores** and related metrics in conjunction with the CREDI team's participation in the Global Scales for Early Development (GSED) project[1].

As we detail in the *Interpretation* sections below, there are several considerations to keep in mind when using the CREDI scores. Depending on whether Long Form or Short Form data are used, users will get different sets of scores.

1. Data collected via the **CREDI Short Form** will produce an "overall" score that summarizes children's developmental status based on skills across multiple domains. The CREDI scoring package produces both an overall **raw scaled score** (whose units are not easily interpretable, but are most appropriate for hypothesis testing) and an overall **norm-referenced standardized score** (which can be interpreted as a Z-score in comparison to a reference group). **Note: the current Z-scores calculated from Short Form data have some technical issues that we are working on. See the FAQs for more information.**

2. Data collected via the **CREDI Long Form** will produce an "overall" score comparable to the overall score reported with Short Form data. In addition, data collected on the Long Form will produce domain scores for each of the four CREDI domains: Motor, Cognitive, Language, and Social-Emotional[2]. Both **scaled scores** and **norm-referenced standardized scores** are provided by the scoring package.

[1] See Global Scales for Early Development (GSED) v1.0 (who.int) for more information.
[2] Note that the CREDI scoring algorithm does not produce Mental Health scores. See **Appendix D** for more information

GUIDANCE FOR PAPER-BASED AND ELECTRONIC DATA CAPTURE SYSTEMS

CREDI data can be collected either on paper or electronically and through interviews or with caregivers filling forms themselves. Most administrations of CREDI to date have utilized CAPI (computer assisted personal interview) software to collect data through face-to-face or phone interviews. For most users, the CREDI team recommends electronic data entry due to the streamlining of administration rules, minimization of invalid and incorrectly coded data, and time savings relative to human data entry.

A complete package of materials for CAPI usage is provided for both the Long Form and the Short Form. This package includes survey coding software in XLSForm and assorted media files. These materials were optimized for use on KoBo Toolbox but should work with very minor modifications on any Open Data Kit (ODK) based platform such as ODK Collect, Survey CTO, and ONA. Additional languages can easily be added to the form using our existing translation repository. While the primary supported survey language for CREDI is the XLSForm standard used by ODK-based platforms, we also have user-supplied versions of CREDI for use in RedCap.

The existing survey code is designed for CREDI interviews conducted by an assessor. In cases where respondents will be completing the CREDI using a written survey format, minor modifications are required. Refer to the CREDI User Guide section on *Mode of Assessment* for more information.

If users wish to use a non-XLSForm based platform for data collection, it is important to keep in mind several considerations when designing and deploying the survey as listed below.

- Several variables are required for scoring and administering the survey and should be included in the survey:
    - A unique ID variable named `ID` that uniquely identifies the child must be included. This can be input manually or created after data collection.
    - An age variable named `AGE` must be included which identifies the child's age in months. This can be input manually or (ideally) calculated based on the date of the survey administration relative to the child's birthday.
    - All CREDI items should be named according to one of the accepted CREDI conventions listed in **Appendix A**. We recommend using the latest Long Form or Short Form naming conventions as they correspond directly to the names of items in the most recent tools.
    - CREDI questions should each have "Yes" "No" and "Don't Know" response options. These should be coded as:
        - Yes = 1
        - No = 0
        - Don't Know = 9 (or any other number)

        - **Note:** Two CREDI Long Form questions are reverse-coded (LF9 and LF102). The response options should be reversed for these two questions OR the user should note that the data are not reverse coded while using the Scoring App.

- Survey skip logic is a powerful tool to improve the usability of CAPI surveys and streamline the flow of the interview.
    - Use the child's age to determine the starting CREDI item.
    - Code the stop rules directly in the survey to avoid accidentally skipping relevant items or making the interview last too long.

- All CREDI items must be included verbatim exactly as they appear in the tool, with two exceptions:
    - It is acceptable to replace "**the child**" with the child's name.
    - It is acceptable to replace "**his/her**", with the child's gender-relevant pronoun.

- Illustrations must be used as part of CREDI administration. These illustrations can either be embedded directly in the form itself or can be printed out and shown to the respondent. Instructions to the assessor to show media to the respondent if the printed option is chosen should be included in the form.

If the standardized XLSForms are used to collect data, downloaded data should already be in a format that is ready for scoring. Be sure to download data using the "XML values" options rather than using the labels from the form. Prior to scoring the data, be sure to remove all personally identifiable information that should not be uploaded to the CREDI servers.

If paper data collection is used, data should be entered using in a way consistent with the CREDI Long Form and Short Form data entry forms. These forms attempt to minimized data entry errors by restricting input to 0 (No), 1 (Yes), and 9 (Don't Know) for CREDI items and by shading cells prior to the start-item for each child. **Do not "fill in" item responses to items that were not administered**. Items that are shaded or that were not completed should be left blank prior to scoring.

USING THE CREDI SCORING APP

As noted above, raw CREDI data can be scored using either the *credi* package in R or the CREDI Scoring App. Most users are likely to find using the CREDI Scoring App the easiest way to score their data. Below, the steps necessary for preparing data for the Scoring App are described in detail.

1. Name CREDI variables correctly

Data that are scored with the Scoring App must conform to proper variable naming conventions. Your data must have an `ID` variable, an `AGE` (in months) variable, and properly named **CREDI variables**. Note that users who have used the standardized XLSForm survey coding or who have input data using the Data Entry forms, this step is unnecessary.

Four types of variable naming conventions for the CREDI variables are accepted by the Scoring App. Your data should include a maximum of one type of naming convention.

a) **Long Form (29 Jan 2018)** variable names starting with `LF`
b) **Short Form** vakeriable names (these are the default variable names included in the KoBo/ODK template) starting with `CREDI_A1`, `CREDI_B1`, etc.[3]
c) **Long Form (April 2017)** variable names which start with `CREDI_LM`, `CREDI_LC`, etc.
d) **CREDI Pilot 4** variable names which start with `QC`, `QS`, and `QM`

See **Appendix A** for a more detailed overview of the alignment of variable names across CREDI versions.

2. Ensure variables are coded properly

Data that are scored with the Scoring App must conform to proper variable coding conventions.

a) CREDI variables must be **numeric** and should take one of three values:
   i. 1 for "Yes" [4]
   ii. 0 for "No" [5]
   iii. Any other numeric value for missing or Don't Know

   The Scoring App will only pay attention to items that are scored as 1 or 0. Any other numeric codes will be ignored and treated as missing data. It is also acceptable to leave unanswered items blank.

[3] Data which includes Short Form variable names will only generate Short Form scores.
[4] Note that if using a form that already reverse-codes items during data collection, then LF9 and LF102 as well as several Mental Health Items will code 1 as "No" and 0 as "Yes". Pay careful attention when using the app to note that your data is already reverse coded.
[5] Some users may choose to code 1 as "No" and 0 as "Yes" for different reasons (e.g., to program stop rules). If that is the case, please make sure to re-code items such that 1 = "Yes" and 0 = "No" before scoring the data.

b) The `ID` variable must be unique for each observation/row. There cannot be observations with missing `ID` values. If you have data with duplicate IDs, you will need to either recode observations, or drop duplicates.
c) The `AGE` variable with only numeric values that indicates the child's age in months. Observations with missing `AGE` values will not result in an error; however, scores *will not* be calculated for these children. Please note that the Scoring App currently only creates scores for children under the age of 3 years (36 months).

3. Remove personally identifiable information from your data

Please **DO NOT** upload any personally identifiable information (PII) to the CREDI App. The CREDI team regularly flushes temporary files of its servers, but we cannot guarantee data security. To prevent any issues with data protection, please remove any PII from your data. Save this information in a separate file including the ID to facilitate re-merging with your original data later.

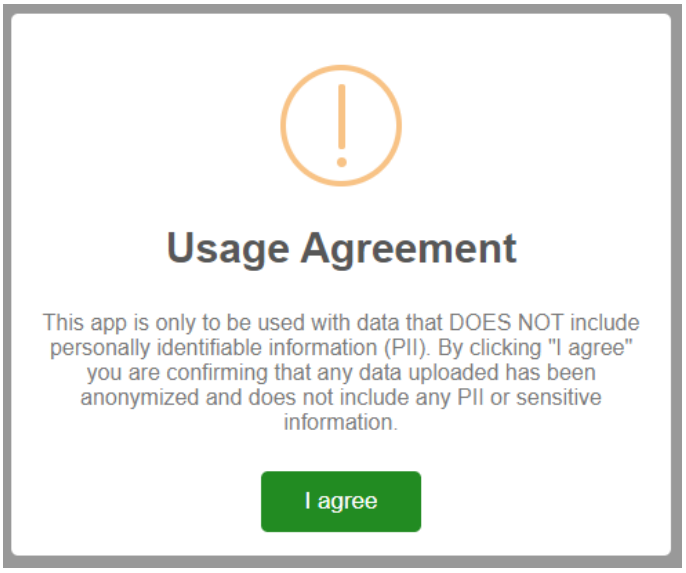
By using the CREDI Scoring App you are confirming any data uploaded have been anonymized and do not include any PII or sensitive information.

4. Save your data as an .xlsx or .csv file

The Scoring App accepts Excel workbooks and Comma Separated Files. Ensure that the first row of your data is the variable name.

5. Access the CREDI Scoring App

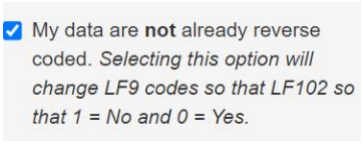
Confirm that your data does not have any PII by Clicking "I agree"



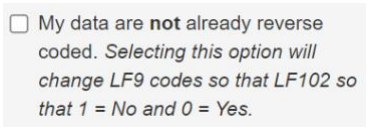
6. Indicate whether your data are already reverse-coded or not

Several items on the CREDI are *negatively* worded, so that responding "Yes" means that the child should get a lower score – e.g., "LF2: Does the child hold his/her hands in fists all the time?" and "LF102: Does the child frequently act impulsively or without thinking (e.g., running into the street without looking)?" Some users code all "Yes" responses as 1 and all "No" responses as 0, whereas other users may have reverse-coded their data earlier. The user must indicate whether the data are *already* reverse-coded to ensure these items are scored properly.

a) If you coded all "Yes" responses as 1 and all "No" responses as 0, then you should select "My data are **not** reverse coded".



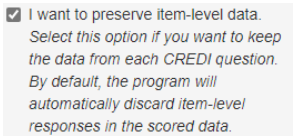
b) If you already re-coded the negatively worded items so that "Yes" is 0 and 1 is "No", then you should NOT select this option. **If you used the default KoBo/ODK form to collect data, then your data are already reverse coded and you should leave this box empty.**



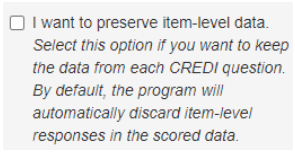
7. Indicate if you wish to preserve item-level responses

Users can select to preserve the item-level responses (i.e., the responses to individual items) in the downloaded data, or to only export the composite scores.

a) Select "I want to preserve item-level data." if you want the resulting dataset to include the original responses to individual CREDI items in addition to the composite scores.



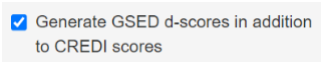
b) Do not select "I want to preserve item-level data." if you only want to include composite scores.



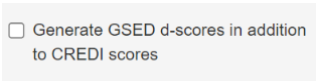
8. Indicate if you wish to calculate GSED d-scores along with CREDI scores

Users have the option to calculate Global Scales of Early Development (GSED) d-scores based on items that are shared across the CREDI and the GSED Short Form.

a) Select this box if you wish to produce d-scores, DAZ, and SEM for d-scores. Selecting this box will not affect the CREDI scores generated by the app.

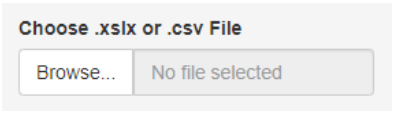


b) Leave this box empty if you do not wish to calculate d-scores.



9. Upload and score data

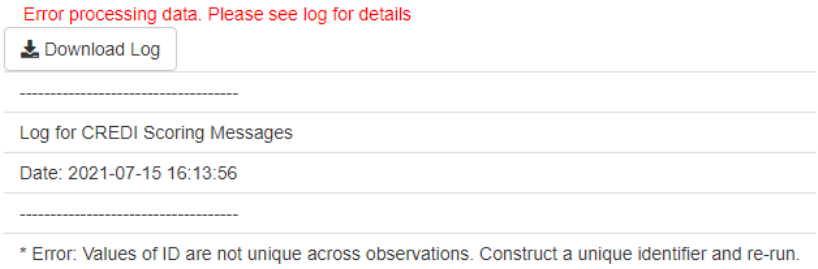
a) Click the "Browse…" button and select the .csv or .xlsx file that you saved in Step 4.



b) Data will begin processing automatically after you upload your file. Note that scoring CREDI data can take up to a minute. While the program is running, a blue bar will flash on the screen to let you know the program is still working.

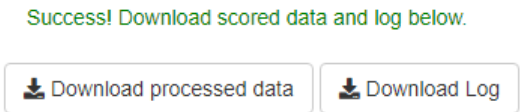
10. Download data or diagnose and correct errors

a) If your data were unable to be scored, an error message will appear along with log output that should help you diagnose the error. For example, in the screenshot below, the `ID` variable was not unique across observations, leading to an error. You can also download the log in order to easily share this information with others.



If you are unable to resolve errors using the message in the log, please get in touch with the CREDI team at jseiden@g.harvard.edu describing your error and providing a copy of the anonymized dataset.

b) If your data were scored successfully, a success message will appear along with two buttons with download links.



i. The "Download processed data" button will initiate the download of an .xlsx file with the CREDI composite scores merged back into your data. See *Interpreting*

CREDI Scores, below, for more information on understanding the various composite scores produced by the Scoring App.

ii. The "Download Log" button will initiate a download of a .txt file that includes information about the performance of the scoring algorithm. This provides details about which (if any) observations were unable to be scored and why.

11. Examine scoring outcomes

After your data have been successfully scored, the CREDI Scoring App generates a series of tables and plots to help you review your results.

a) The **Results by Age Band** table summarizes the total number of observations (children) by age band and indicates what percentage of these observations were able to be scored. If the percentage scored is below 100%, then this means that at least one observation in this age band had fewer than 5 observed CREDI items that were scored with a "Yes" (1) or a "No" (0). When there are fewer than 5 total non-missing CREDI items, the scoring package produces no scores for this observation.

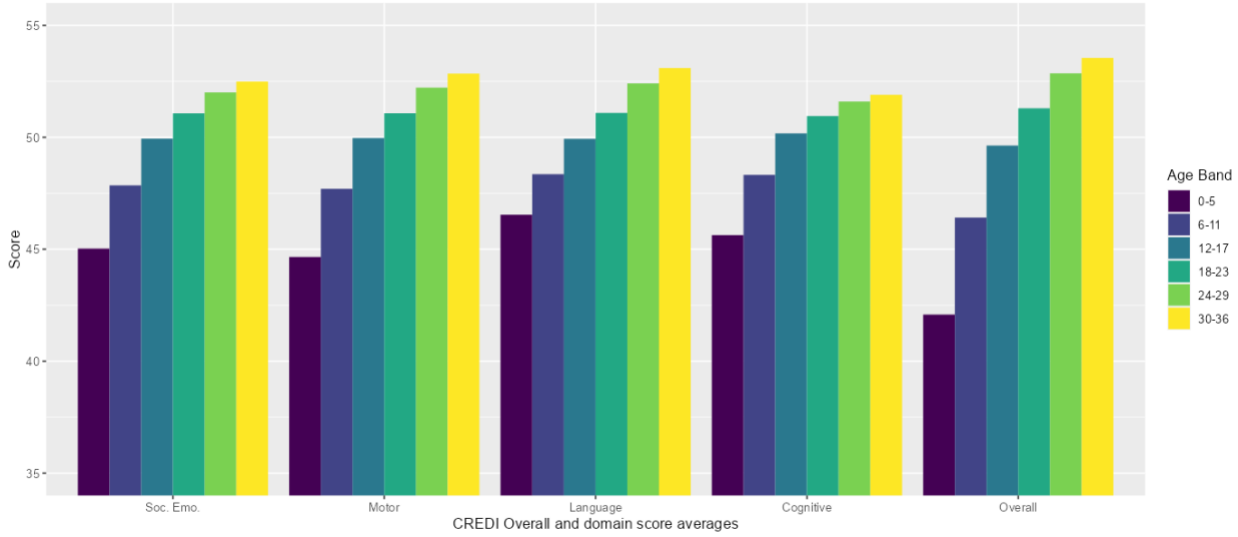
Age Band	Total obs	% scored	Average Overall Score
0-5	195	100%	41.15
6-11	476	100%	44.09
12-17	201	100%	46.53
18-24	6	100%	47.45
25-29	1	100%	54.11

b) The **Flagged Observations** table indicates the proportion of observations within each domain that have been flagged due to a low response rate for users of the CREDI Long Form. As long as an observation has at least 5 non-missing CREDI items, the CREDI Scoring App will calculate scores for all domains regardless of response rates, but observations with fewer than 5-domain relevant items responded to are flagged. See the downloaded data and the `_flag` variables to determine which observations had a low number of items responded to. See **Appendix C** for more information on how to deal with flagged observations.

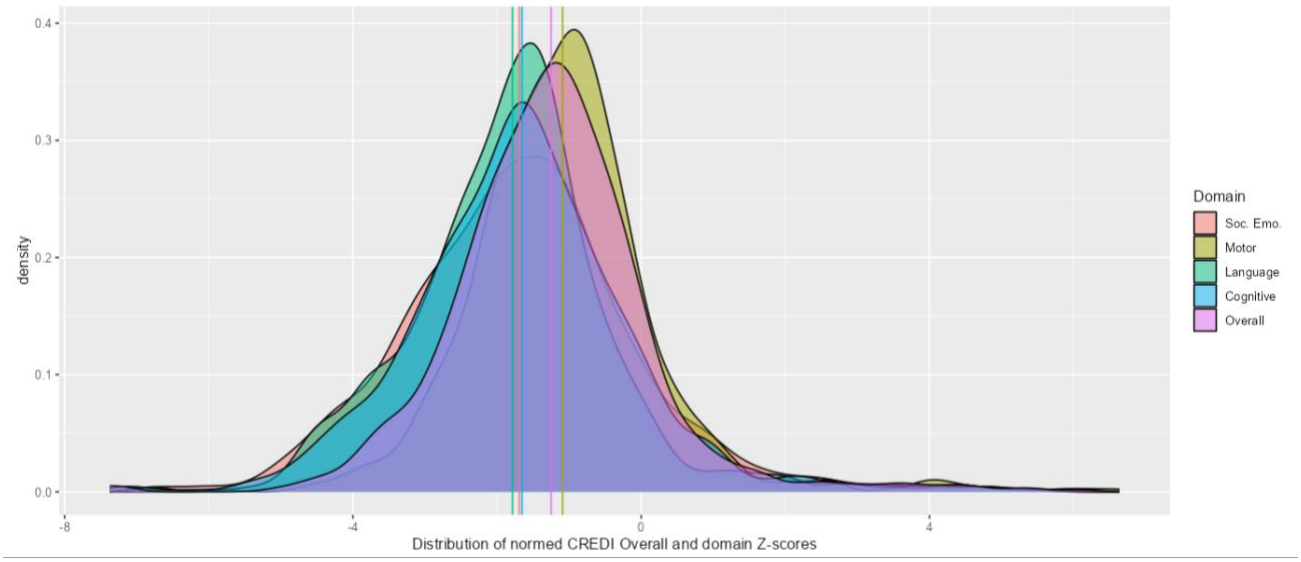
Domain	Flagged observations
Soc. Emo.	31.4%
Motor	0%
Language	31.4%
Cognitive	4.7%
Overall	0%

c) The **CREDI Domain Score Averages** plot is a visual representation of the average score by age band on the Overall and CREDI domain raw scaled scores. (Note that Short Form data will only produce one bar chart of the Overall score.) In this case,

consistent with expectations, we see that older children have consistently higher raw scaled scores than younger children.



d) The **Distribution of normed CREDI Z-scores** displays the spread of the norm-referenced Z-scores as well as a line for the average of the Z-scores for each domain in the sample. In this case, we can see that the average score for most domains was far below the CREDI reference sample average (0). However, the Motor domain was relatively higher in Z-scores compared to the Language and Cognitive domains. Since Z-scores control for age, we include children of all ages in these density plots.



USING AND INTERPRETING CREDI SCORES

Background

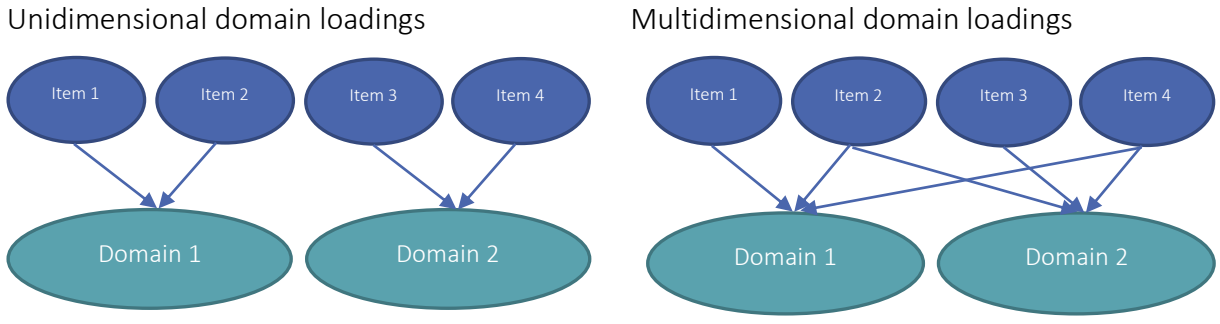
Before going into the details of the variables the Scoring App provides and how to use and interpret them, we first explain the basic logic behind the calculation of the CREDI scores. Two different models are used to generate CREDI scores.

CREDI Overall scores produced by the Short Form and Long Forms are calculated using a standard two-parameter logistic (2PL) item response theory (IRT) model[6]. This model allows CREDI items to vary in terms of their *difficulty* and their *discrimination*. An item's difficulty tells us whether the item is typically passed by less or more developed children. An item's discrimination tells us how well that item is able to distinguish between children of lower and higher development. Overall scores are produced using a Maximum Likelihood Estimation (MLE) process. The scoring algorithm considers the child's age, the item parameters, and the items responses to generate a Bayesian Maxim A Posteriori (MAP) score. Overall scores can be considered the most likely true CREDI score given the child's age and scoring response pattern.

The process used to generate domain scores utilizes a more complex multidimensional factor analysis process[5]. Most early childhood assessments assume that a question/item (or an activity) is related to one domain of early childhood development. This assumption is made for practical reasons and makes calculating scores easier. However, developmental psychologists agree that domains are highly interrelated in reality. Being able to complete a developmental milestone often requires skills from numerous domains of early development simultaneously.

As illustrated below in Figure 1, by using multidimensional domain loadings, the CREDI attempts to reflect this complexity by allowing individual items to contribute information about multiple domains of development. For example, CREDI item "LF90. Can the child count up to five objects (e.g., fingers, people)?" loads onto both the Cognitive *and* the Language domains.

Figure 1: Unidimensional vs. Multidimensional domain loading



[6] See McCoy et al., 2018 for a technical description of CREDI overall scores and Waldman et al., 2021 for a technical description of the item factor analysis used to create the CREDI domain scores.

The loadings of items onto domains that were used to score the CREDI were determined after both a rigorous review by subject matter experts *and* an empirical analysis of more than 14,000 children whose caregivers had responded to the CREDI. Although many items on the CREDI load onto two or even three domains, some items only contribute information about a single domain.

Similar to the calculation of the overall scores, the CREDI scoring algorithm generates individual-level scores using MLE in order to find the MAP score—the true CREDI domain score most likely given the child's age, the responses on each item, and how the items load onto different domains of development.

CREDI Scores

The Scoring App generates an .xlsx file with the following variables. When scoring Short Form data, only variables in **red** are generated. When scoring Long Form data, all variables are generated[7].

COG	A raw scaled (factor) score for the Cognitive domain
LANG	A raw scaled (factor) score for the Language domain
MOT	A raw scaled (factor) score for the Motor domain
SEM	A raw scaled (factor) score for the Social-Emo. domain
OVERALL	A raw scaled (factor) score for Overall development (all items)
Z_COG	A norm-referenced standardized Z-score for the Cognitive domain
Z_LANG	A norm-referenced standardized Z-score for the Language domain
Z_MOT	A norm-referenced standardized Z-score for the Motor domain
Z_SEM	A norm-referenced standardized Z-score for the Social-Emo. domain
Z_OVERALL	A norm-referenced standardized Z-score for Overall development (all items)
COG_SE	The standard error of measurement of the Cognitive domain raw scaled score
LANG_SE	The standard error of measurement of the Language domain raw scaled score
MOT_SE	The standard error of measurement of the Motor domain raw scaled score
SEM_SE	The standard error of measurement of the Soc.-Emo. domain raw scaled score
OVERALL_SE	The standard error of measurement of the Overall development raw scaled score
COG_flag	An indication that fewer than 5 Cognitive items had non-missing responses
LANG_flag	An indication that fewer than 5 Language items had non-missing responses
MOT_flag	An indication that fewer than 5 Motor items had non-missing responses
SEM_flag	An indication that fewer than 5 Soc.-Emo. items had non-missing responses
OVERALL_flag	An indication that fewer than 5 items had non-missing responses
NOTES	Notes about the scoring of the observation generated by the application

Raw scaled scores (also called Maximum a Posteriori [MAP] factor scores, ability estimates, or person location estimates) do not include a prefix or suffix in their variable name and are reported in **COG**, **LANG**, **MOT**, **SEM**, and **OVERALL**. The units for these scores are specific to the

[7] If a user chose to score d-scores as well as CREDI scores, a d-score, DAZ, and d-score standard error of measurement will also be produced. Please refer to the d-score book for more information on interpreting and using these scores.

CREDI, and do not correspond to any particular metric (e.g., standard deviations, IQ points, etc.). Average raw scaled scores increase with age, reflecting developmental progressions.

It is almost always more appropriate to use the (raw) scaled scores for hypothesis testing (e.g., regression analysis, ANOVA, etc.) instead of using the z-scores. This is because hypothesis tests require that variables exhibit interval properties of measurement, which the raw scaled scores do. An interval scale is one where the difference between values is meaningful and consistent across the range of values (e.g., the difference between 54 and 55 on the raw scaled scores is the same as the difference between 49 and 50). A practical example of an interval scale is temperature—the difference between 5 and 8 degrees Celsius is the same as the difference between 17 and 20 degrees Celsius. Although we are confident that the raw scaled scores demonstrate an interval scale, the transformation required to generate the z-scores described below almost certainly results in a non-interval scale. These z-scores are therefore less trustworthy for hypothesis testing.

Norm-referenced standardized scores are marked with a prefix **`z_`**. These scores are constructed by comparing the raw scores of any given sample to the raw scores of a CREDI reference sample consisting of 4,652 children with "advantageous" home environments[8]. Specifically, we subtract the average raw score of children of the same age from the CREDI reference sample from the observed raw score of a child and then divide the difference by the age-specific standard deviation. A Z-score of 0 thus means that a given child has a similar developmental status on that domain as the average child in the CREDI reference sample of the same age. A score of -1 means that the child's raw score is 1 standard deviation below the same-age average of the reference sample. These scores are useful for generating effect size metrics, as each "unit" can be interpreted as a reference-group standard deviation. They can also be used for across-age and across-domain comparisons.

Preliminary analysis of the CREDI database suggests that the norm-referenced scores are generally normally distributed around the mean value at each age. However, as discussed further in **Appendix B**, our confidence in estimates for very young children (under the age of six months) is lower given a smaller sample size in our reference sample and noisier estimates of the mean and standard deviation for these children. We believe that the norm-referenced standardized score between +/-2 roughly translates to a region where 95% of the scores *from the same-age reference group* are located. The norm-reference scores therefore behave similar to typical "Z-scores."

Appendix B has additional information on the reference group, how it was constructed, and where the children included in the reference group come from.

Standard error of measurement (or conditional standard error of measurement) variables are marked with a suffix **`_SE`**. These variables refer to the estimated precision of the raw scaled score estimates described above. We recommend using these variables as weights when

[8] The CREDI reference population comprises children in the cross-country CREDI database with advantageous home environments. To be included in the reference group, maternal educational attainment (completed secondary school or higher), as well as through the number of activities done by adults with the child in the last three days (at least 4 out of the 6 MICS home stimulation activities).

conducting statistical tests comparing scores across groups (see **Appendix C**). The smaller the standard error of measurement, the more precise the estimate of an individual child's score. In Item Response Theory, "extreme" scores at the tail of the distribution of scores (i.e., a raw scaled score below 40 or above 55) are generally less precise than scores near the mean of the distribution of scores (i.e., a score around 45-55). Missing responses to age-appropriate items can also decrease precision. By weighting analyses by the inverse of the squared standard error of measurement ($\frac{1}{SE^2}$), more precise group mean values can be obtained.

Informational variables are variables that are not intended for use directly in analysis, but are provided to help users understand the resulting scores and any issues that might arise for individual responses. The **`NOTES`** variable is a human-readable summary of any issues that arose during the scoring process that resulted in either 1) a score not being able to be processed for a given child or 2) questions about the degree of confidence of the obtained score. Children will not receive a CREDI score if they are missing an **`AGE`** value or have fewer than five non-missing responses. A total of five items must be responded to with a 1 or a 0 for the Scoring App package to produce a score.

Variables with the **`_flag`** suffix also represent a warning to users about specific scores, even when they were successfully calculated and reported. In particular, observations where the **`_flag`** variable is coded as 1 are observations that had fewer than five non-missing responses available to calculate a given score. For example, if a caregiver responded with either "yes" or "no" to only 4 motor items for a given child (with the rest of motor items coded as missing), the **`_flag`** variable should include a value of 1. In cases like this, a score for the given domain was produced, but since so few valid item responses were available, we may have lower confidence in these scores. See **Appendix C** for more guidance about interpreting domain scores with a low number of responded items.

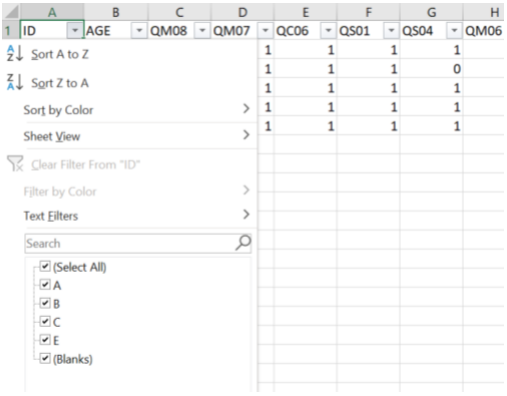
FREQUENTLY ASKED QUESTIONS

Q: I have missing data due to the CREDI start and stop rules. In particular, I am missing responses on items that come before the start point and after the stop point. Is this OK? Should I fill in these missing items with "Yes" or "No"?

A: The CREDI algorithm automatically adjusts for the missing responses and is designed to generate scores even when there is missing data on some items. You should leave these responses as blank or missing—there is no need to fill in these items.

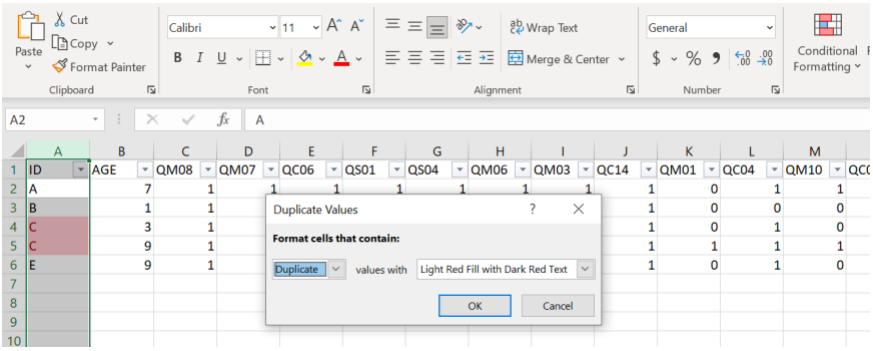
Q: I get the following error about missing ID when I upload my data. What should I do?

A: At least one of the observations in your dataset is missing an `ID` variable. The Scoring App will consider each row an observation in your data unless that row is completely missing. Try "filtering" your data in Excel and click the dropdown on your `ID` variable. If you see (Blanks) as an option, select and correct these rows.



Q: I get the following error about unique ID when I upload my data. What should I do?

A: At least one of the observations in your dataset has a duplicated `ID` variable. Try selecting your `ID` column in Excel and applying Conditional Formatting to identify duplicated ID values.



Q: Can I compare raw scores across domains?

A: It is *not possible* to directly compare raw scores across domains. The four domains in CREDI have different age-specific means and standard deviations, which means that a score of 57 in the motor domain and a score of 55 in the Cognitive domain does not necessarily mean that the child is more developed in the motor domain than in the cognitive domain. If you want to compare differences across domains, you can use Z-scores – they tell you how each domain-specific score compares to the reference sample.

Q: Are the Overall scores the same as the average of the domain scores?

A: No. The Overall score calculated from Short Form and Long Form data represents a single developmental score, which captures the overall development of the child[9]. This overall score will be highly correlated with all four domains, but is computed based on a model combining all items, and cannot be directly computed from the domain-specific scores.

Q: Can I use norm referenced CREDI Z-scores in hypothesis testing (e.g., t-tests to examine mean differences between groups) since Z-scores offer better interpretability?

A: No. The transformation required to generate the norm referenced Z-scores described above results in a non-interval scale. This is because the transformation uses the age-specific standard deviation, which varies across age groups. As a result of this transformation, the difference between values is no longer consistent across the range of values and depends on specific age groups. Therefore, the Z-scores are less trustworthy for hypothesis testing. We recommend testing for statistical differences with a model that uses the scaled scores controlling for age and then running the same model on the Z-scores to produce more interpretable estimates of the size of the coefficients.

Q: It doesn't look like the Scoring App is producing a mental health score. Why not?

[9]See McCoy, Waldman & Fink (2018) for a technical description of the item response theory (IRT) analysis used to create the CREDI overall scores.

A: The CREDI Scoring App does not produce a score for the mental health items because the CREDI team has not yet been able to identify a reliable, cross-culturally valid approach for scoring these items. See **Appendix D** for guidance on how users might go about using these items.

Q: **I only care about some of the domains of CREDI. Can I omit items from other domains to only generate scores about the domains I want to study?**

A: Maybe. See **Appendix E** for details on guidance for users that do not want to focus on the entirety of CREDI.

FOR MORE INFORMATION

A. ACADEMIC PAPERS

For a broad overview of the goals of CREDI, limitations of the tool, and intended uses of scores, see:

McCoy, D. C., Seiden, J., Waldman, M., & Fink, G. (2021). Measuring early childhood development: Considerations and evidence regarding the Caregiver Reported Early Development Instruments. *Annals of the New York Academy of Sciences*, 3–10. https://doi.org/10.1111/nyas.14598

For information on the technical validation of the multidimensional item factor analysis approach derived to create CREDI scores, see below. (Note also that this publication should be cited as the validation paper for the CREDI Long Form.)

Waldman, M., McCoy, D. C., Seiden, J., Cuartas, J., CREDI Field Team, & Fink, G. (2021). Validation of motor, cognitive, language, and socio-emotional subscales using the Caregiver Reported Early Development Instruments: An application of multidimensional item factor analysis. *International Journal of Behavioral Development*, 23(1), 1–10. https://doi.org/10.1177/01650254211005560

For preliminary psychometric work on the validation of the items used in the CREDI in a large cross-country validation sample, see below. (Note also that this publication should be cited as the validation paper for the CREDI Short Form.)

McCoy, D. C., Waldman, M., & Fink, G. (2018). Measuring early childhood development at a global scale: Evidence from the Caregiver-Reported Early Development Instruments. Early Childhood Research Quarterly, 45, 58–68. https://doi.org/10.1016/j.ecresq.2018.05.002

For initial psychometric work on the initial validation of the items used in the CREDI in Tanzania, see:

McCoy, D. C., Sudfeld, C., Bellinger, D. C., Muhihi, A., Ashery, G., Weary, T. E., Fawzi, W., & Fink, G. (2017). Development and validation of an early childhood development scale for use in low-resourced settings, *Population Health Metrics, 15*(3).

For background on the motivation and goals of creating the CREDI, see:

McCoy, D. C., Black, M., Daelmans, B., & Dua, T. (2016). *Measuring population-level development in 0-3. Early childhood matters.* The Hague, Netherlands: Bernard van Leer Foundation.

B. WEBSITE

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APPENDIX A: NAMING CONVENTIONS

Table 1: Long Form naming conventions allowed in the CREDI Scoring App

Pilot 4	Long Form 20 Apr 2017	Long Form 29 Jan 2018	Reverse Coded Item (i.e. negatively worded)
QM08	CREDI_LM01	LF1	FALSE
QM07	CREDI_LM02	LF2	FALSE
QC06	CREDI_LC01	LF3	FALSE
QS01	CREDI_LS02	LF4	FALSE
QS04	CREDI_LS01	LF5	FALSE
QM06	CREDI_LM03	LF6	FALSE
QM03	CREDI_LM04	LF7	FALSE
QC14	CREDI_LC02	LF8	FALSE
QM01	CREDI_LM05	LF9	TRUE
QC04	CREDI_LC03	LF10	FALSE
QM10	CREDI_LM06	LF11	FALSE
QC05	CREDI_LC04	LF12	FALSE
QS17	CREDI_LS03	LF13	FALSE
QM12	CREDI_LM08	LF14	FALSE
QC08	CREDI_LC06	LF15	FALSE
QM09	CREDI_LM09	LF16	FALSE
QC09	CREDI_LC05	LF17	FALSE
QM05	CREDI_LM07	LF18	FALSE
QC07	CREDI_LC08	LF19	FALSE
QM11	CREDI_LM10	LF20	FALSE
QC11	CREDI_LC07	LF21	FALSE
QC10	CREDI_LC11	LF22	FALSE
QC13	CREDI_LC10	LF23	FALSE
QC12	CREDI_LC09	LF24	FALSE
QM14	CREDI_LM12	LF25	FALSE
QM16	CREDI_LM11	LF26	FALSE
QM20	CREDI_LM14	LF27	FALSE
QM13	CREDI_LM13	LF28	FALSE
QM15	CREDI_LM15	LF29	FALSE
QC15	CREDI_LC12	LF30	FALSE
QM19	CREDI_LM16	LF31	FALSE
QM22	CREDI_LM17	LF32	FALSE
QM23	CREDI_LM18	LF33	FALSE
QM18	CREDI_LM19	LF34	FALSE
QC21	CREDI_LC13	LF35	FALSE
QM17	CREDI_LM20	LF36	FALSE
QC20	CREDI_LC14	LF37	FALSE
QS07	CREDI_LS04	LF38	FALSE

QS20	CREDI_LS06	LF39	FALSE
QM21	CREDI_LM21	LF40	FALSE
QM24	CREDI_LM22	LF41	FALSE
QS06	CREDI_LS05	LF42	FALSE
QC18	CREDI_LC15	LF43	FALSE
QM26	CREDI_LM23	LF44	FALSE
QC22	CREDI_LC16	LF45	FALSE
QS14	CREDI_LS07	LF46	FALSE
QM25	CREDI_LM24	LF47	FALSE
QC17	CREDI_LC17	LF48	FALSE
QM27	CREDI_LM25	LF49	FALSE
QC19	CREDI_LC18	LF50	FALSE
QM30	CREDI_LM27	LF51	FALSE
QM28	CREDI_LM26	LF52	FALSE
QC16	CREDI_LC19	LF53	FALSE
QM29	CREDI_LM28	LF54	FALSE
QS25	CREDI_LS08	LF55	FALSE
QC26	CREDI_LC20	LF57	FALSE
QC23	CREDI_LC21	LF58	FALSE
QM31	CREDI_LM29	LF60	FALSE
QS21	CREDI_LS12	LF61	FALSE
QC25	CREDI_LC23	LF62	FALSE
QC28	CREDI_LC24	LF64	FALSE
QM37	CREDI_LM30	LF67	FALSE
QS24	CREDI_LS11	LF68	FALSE
QM32	CREDI_LM31	LF69	FALSE
QC34	CREDI_LC26	LF72	FALSE
QC24	CREDI_LC28	LF73	FALSE
QC33	CREDI_LC25	LF74	FALSE
QS19	CREDI_LS18	LF75	FALSE
QC27	CREDI_LC29	LF76	FALSE
QM35	CREDI_LM32	LF77	FALSE
QM34	CREDI_LM33	LF82	FALSE
QC29	CREDI_LC32	LF83	FALSE
QM33	CREDI_LM34	LF86	FALSE
QC31	CREDI_LC34	LF88	FALSE
QC35	CREDI_LC37	LF92	FALSE
QM36	CREDI_LM35	LF93	FALSE
QM38	CREDI_LM36	LF98	FALSE
QM39	CREDI_LM37	LF105	FALSE
QS09	CREDI_LMH01	LFMH1	TRUE
QS23	CREDI_LMH02	LFMH2	TRUE
QS16	CREDI_LMH03	LFMH3	TRUE
QS11	CREDI_LMH04	LFMH4	TRUE

QS18	CREDI_LMH07	LFMH7	TRUE
QC37	-	LF81	FALSE
QC50	-	LF95	FALSE
QS43	-	LF56	FALSE
QC36	-	LF84	FALSE
QS46	-	LF85	FALSE
QS45	-	LF59	FALSE
QC42	-	LF87	FALSE
QS50	-	LF101	FALSE
QC46	-	LF89	FALSE
QC41	-	LF90	FALSE
QS58	-	LF91	FALSE
QC40	-	LF65	FALSE
QS44	-	LF66	FALSE
QC44	-	LF94	FALSE
QC47	-	LF108	FALSE
QC43	-	LF100	FALSE
QC39	-	LF97	FALSE
QC38	-	LF71	FALSE
QS30	-	LF63	FALSE
QS51	-	LF104	FALSE
QS29	-	LFMH6	FALSE
QS53	-	LF102	TRUE
QC45	-	LF107	FALSE
QS55	-	LFMH8	TRUE
QS41	-	LF78	FALSE
QS38	-	LF79	FALSE
QC49	-	LF96	FALSE
QS35	-	LF80	FALSE
QS33	-	LFMH5	TRUE
QS36	-	LF70	FALSE
QS57	-	LFMH9	TRUE
QC51	-	LF99	FALSE
QC48	-	LF106	FALSE
QS52	-	LF103	FALSE

APPENDIX B: REFERENCE GROUP CREATION

Evidence suggests that, for children benefiting from advantageous home environments including educated parents and exposure to stimulating activities, many cross-country differences in developmental trajectories are minimized[10]. Villar et al. (2019) find that "neurodevelopmental milestones and associated behaviours in early childhood are… likely innate and universal, as long as nutritional and health needs are met" (p. 1). Inspired by the usefulness of the World Health Organization's Weight-for-age and Height-for-age Z-scores (WAZ and HAZ) in framing the conversation around nutrition and development, the CREDI team wanted to create a reference group with which to create "development-for-age" Z-scores that would give information about how a given child's development compares with a group of same-age children with advantageous home environments.

The full cross-country CREDI database comprises 19,165 children from 17 countries. We selected a subset of these children for inclusion in the CREDI reference group based on our review of the literature and aiming to capture those children with advantageous home environments. To qualify for inclusion in our reference group, children had to have 1) a mother that completed secondary school or higher education and 2) be in a household where least one adult had engaged in 4 or more of the 6 "Play activities" from the Family Care Indicators with the child. These indicators are part of UNICEF's Multiple Indicator Cluster Survey (MICS) Questionnaire for Children Under Five and are commonly used as a measure of stimulating activities in the home[11]. As Table 2 shows, at total of 4,652 children (24% of our full cross-country sample) met the criteria for inclusion in the reference group, with broad representation across countries and contexts.

Table 2: Country distribution of children in reference group

Country	Number of children
Bangladesh	280
Brazil	1399
Cambodia	66
Chile	171
Colombia	215
Ghana	175
Guatemala	25
India	165
Jordan	35
Laos	43
Lebanon	72
Nepal	54
Pakistan	55

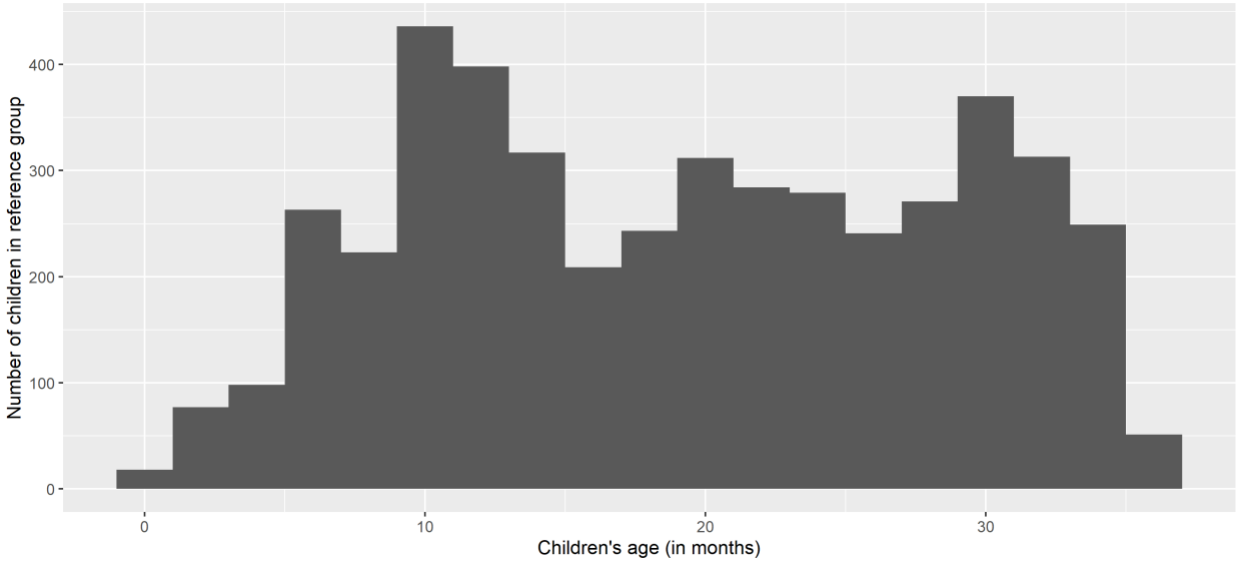
[10] See Fink, McCoy, and Yousafzai, 2020

[11] See Hamadani, et al., 2010; Kariger, et al., 2012; McCoy et al., 2016; and Cuartas et al., 2020 for examples.

Philippines	365
Tanzania	155
USA	793
Zambia	584
Total	**4,652**

In addition to geographical representation, Figure 2 displays the age distribution of children in the reference group. For children 6-35 months of age, there were at least 100 children in the reference group. This means our confidence in capturing an accurate mean and standard deviation is higher in this age range. We are slightly less confident in our estimates of younger children under six months of age, where we had fewer than 200 children in total with which to estimate the mean and standard deviation.

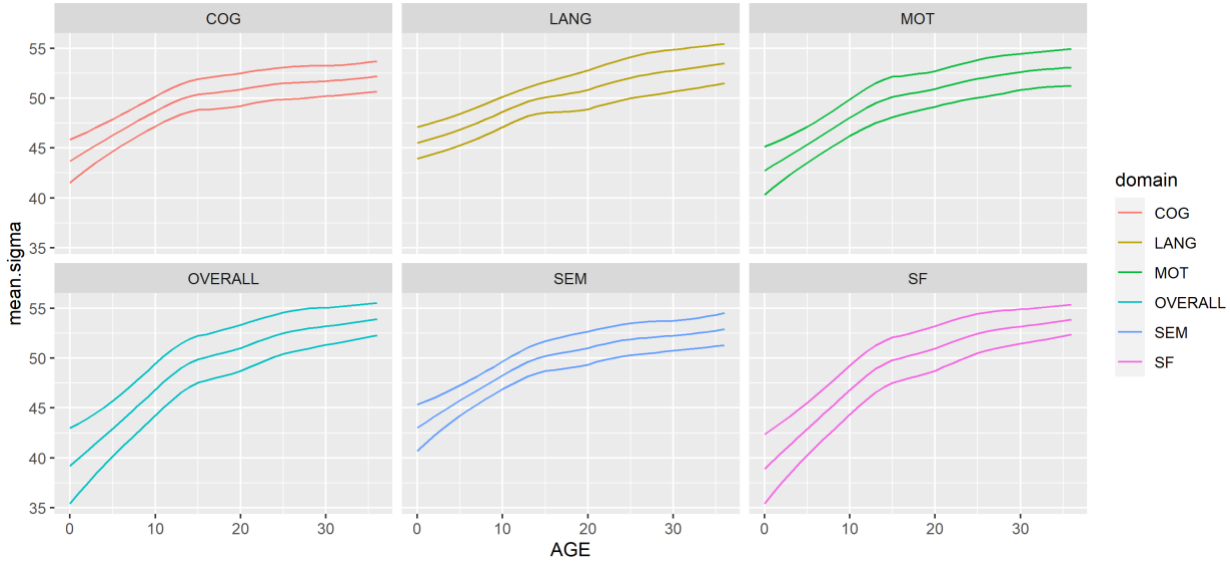
Figure 2: Age distribution of children in reference group



To estimate the reference group mean and standard deviation by age, we fit a loess model using the R package **`gamlss`** allowing the mean and the variance to vary as a function of the age of children unconstrained by a parametric form. Given the non-parametric nature of this analysis, we fit a k-fold validation procedure to select an optimal bandwidth for the loess function, and found that .4 minimized RMSE error in a test set.

Using our loess model, we then fit the mean and standard deviation for each domain, the Overall, and the Short Form scores. The results are presented below in Figure 3.

Figure 3: Estimated mean and standard deviation of CREDI scores as a function of age



As Figure 3 shows, the mean and variance function follow a monotonic but non-linear trend, with a steeper slope for young children in most domains, and variances that fluctuate slightly as children age. Using the models fit above, we then extract estimates of the mean and standard deviation for children 0-36 months old for each age group, and use these estimates to calculate normed reference Z-scores for children.

The subset of children used in this reference group analysis is a convenience sample and is not nationally representative of any countries included. Further, while we are confident that we have captured two important aspects of children's home environments critical to their development, we do not have any measures of nutritional status, physical health status, or other key predictors of healthy development. Despite the limitations of this convenience sample, we believe that the use of this reference group provides a reasonable (if conservative) estimate of typical developmental growth trajectories for children with advantageous environments. As more users collect data with CREDI, we will periodically update the CREDI reference group. As such, we recommend re-calculating scores based on raw data whenever attempting to compare Z-scores to newly scored data to ensure they are calculated using the same reference group.

APPENDIX C: DOMAIN SCORES & IMPRECISION

As noted in the main document, not all CREDI items load onto all domains. This can mean that even though a given observation (child) has responses to more than five items, it is possible that fewer than five items *loading onto a particular domain* were responded to. In this case, the Scoring App will calculate the scores for all domains, but we may have lower confidence in the scores obtained for some domains. Understanding this (potential) source of imprecision can be helpful when attempting to analyze CREDI data and interpret results

Flag variables

When fewer than five responses were recorded for items loading onto a particular domain, the domain **`_flag`** variable for the observation will contain a 1. The child's score will still be reported, but will rely more heavily on their age, potentially resulting in mean-bias in the estimated score.

The flexible start and stop rules of the CREDI Long Form can create scenarios where it is difficult to have at least five domain-relevant responses. That is because domain-loaded items are not evenly distributed through the assessment. CREDI Long Form items are ordered by "difficulty" (i.e., the expected level of development required to have a high probability of responding "Yes") and are responded to until 5 consecutive "No" responses are received. "Easier" items often load more on Motor development, whereas most Language items are more difficult. Starting at the given start point for each age group, the minimum number of items needed to progress through in order to ensure 5 domain-relevant items is listed in Table 3.

Table 3: Required number of item responses to avoid "flagged" domain scores by domain

Age Group	Motor	Cognitive	Language	Social-Emotional
0-5 months (starting at LF1)	7	21	35	23
6-11 months (starting at LF6)	9	16	30	37
12-17 months (starting at LF11)	9	12	25	36
18-23 months (starting at LF29)	6	18	15	40
24-29 months (starting at LF39)	11	12	15	30
30-35 months (starting at LF52)	13	8	10	17

Even many children in the CREDI reference group (see **Appendix B**) did not have the minimum required number of items observed to avoid a "flag". Specifically, whereas just 1.1% of children did not have sufficient observations to avoid a flag on the Motor domain score, 20.9% of Social-

Emotional Domain scores, 20.9% of Language domain scores, and 19.5% of Cognitive domain scores in the reference group had flags. Given this, we anticipate that "flags" will be common in most users' data.

Incorporating imprecision into analysis

Even though domains with a **_flag** may be less precisely estimated than those without, we **do not** recommend listwise deletion (i.e. dropping these observations) in analysis and restriction to non-flagged observations. Instead, we recommend incorporating the imprecision into the analysis through two approaches: 1) using the standard error of measurement and 2) conducting sensitivity analyses.

Weighting by the standard error of measurement. The main recommended approach to incorporating imprecision into the analysis is by weighting all analyses by the inverse of the squared standard error of measurement (variables marked with **_SE**). As mentioned in the main document, this weighting procedure downplays the influence of imprecise observations when calculating group statistics. Flagged domain scores will typically have a larger standard error of measurement because there are fewer observed items and the confidence in the estimated score is lower. To produce these weights, first calculate the inverse of the squared standard error of measurement ($\frac{1}{SE^2}$) for each domain/score and then use these weights when calculating any statistic[12]. While this procedure is recommended for all analyses of CREDI, it is particularly important when a high proportion of observations are flagged.

Conducting sensitivity analyses. Conducting a sensitivity analysis is also a good way to ensure that your results are not overly influenced by flagged observations. First run the analyses as described above with weighting and including all observations. Then run the same analyses, but with using listwise deletion and excluding flagged observations. Results are unlikely to change substantially, but in the event they do, it is an indication that imprecise observations may be clouding any conclusions your data may be suggesting. If this happens, we recommend reporting both full and restricted results, and highlighting the limitation of the imprecise data.

[12] Procedures to weight vary by statistical software used and statistic generated. A sample procedure to calculate the weighted mean for the cognitive domain would be (in Stata):

```
gen cog_weight = 1 / cog_se^2
summarize cog [aw=cog_weight]
```

In R, a similar result would be generated by

```
scores$cog_weight <- 1 / scores$cog_se^2
weighted.mean(x = scores$cog, w = scores$cog_weight)
```

APPENDIX D: SCORING MENTAL HEALTH DOMAIN

Currently, the Scoring App does not produce a score for the Mental Health domain. This is because our analyses of the Mental Health domain items have not revealed appropriate psychometric properties in our cross-national dataset. Most importantly, our analyses suggested low reliability (Cronbach's alpha) for the Mental Health domain, suggesting that the items do not share sufficient common variance to be considered as a single scale.

If it is important for you to have a Mental Health score using CREDI items, there are several approaches that you can consider:

1. Produce a simple sum score (after ensuring your items are properly reverse-coded).
2. Run a Principle Components Analysis (PCA) on the items to extract a factor score. PCA reduces the dimensionality in a more data-driven way.
3. Use Structural Equation Modelling (e.g., Confirmatory Factor Analysis) to create a measurement model. This is the most robust and also more complicated approach to generate scores for the Mental Health domain.

Note that if you choose to report a Mental Health score from CREDI items (using the above approaches or any other), you should do so in a way that clearly explains how the scores were created, and that this approach is not necessarily endorsed by the CREDI developers.

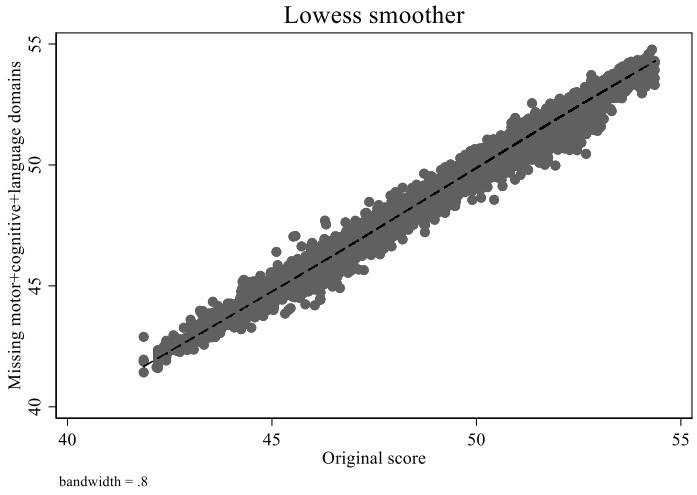
APPENDIX E: SCORING SINGLE CREDI DOMAINS

The Long Form of the CREDI provides domain-specific scores reflecting children's motor, language, cognitive, and social-emotional development. We are occasionally asked by users whether it is possible to collect only a subset of items targeting one specific domain (e.g., social-emotional development) to shorten the assessment and/or align it with specific study goals.

The answer to this question is **yes** – it is possible to collect data on and produce scores for only one domain using the CREDI Long Form. However, there are several important caveats to keep in mind.

First, collecting items for only one subdomain may only be done with the CREDI Long Form. The CREDI Short Form must always be administered in full. Second, using fewer items always means that scores are less precise. Using all of the items on the Long Form results in scores that have less measurement error and higher reliability. Third, our analyses suggest that the domain scores produced when administering a subset of items are *not the same* as those produced when administering the full set of items. We believe that the domain scores from the full set of Long Form items are more trustworthy and precise.

To arrive at these conclusions, we conducted a series of simulation studies. Please contact us if you would like to review the technical details of these studies. Below we share the result of the simulated Social-Emotional scores from the full assessment and when omitting items from other domains. While there is a strong correlation between the scores, it is not perfect and we lose precision when dropping other items.



As such, we recommend including all Long Form items whenever possible in order to produce precise and accurate domain scores. Nevertheless, if using the full CREDI Long Form is not of interest or practical in your study, you may focus on items from only one or two domains, recognizing that their scores may contain additional error compared to using the full set of items

from the Long Form. To support this process, please review the Domain Assignment spreadsheet to identify each item's domain categorization.