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The Impact of Malnutrition and Post Traumatic Stress Disorder on the Performance of Working Memory in Children

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Abstract

Malnutrition is accepted to have a negative impact on the school performance of children and adolescents. Malnutrition also has a negative impact on cognitive development and a potentially lasting effect on (some) cognitive functions. This paper focuses on the effects of malnutrition and Post-Traumatic Stress Disorder (PTSD) on short-term-working-memory on children. These effects are important since defective working memory capacities limit the learning ability of young children and thus the success of investment in human capital. The study is based on an empirical study among 80 children (boys and girls) aged between 9 and 13 years old in Banda Aceh, Indonesia, conducted in 2010 in cooperation with UNICEF. The study involved testing the children on a number of working memory tests (Digit Span, Coding and Bourbon-Vos) and the Raven SPM intelligence test. Malnutrition was measured as stunting. The population of children living in Banda Aceh had been exposed to severe stress during the tsunami of December 2004 and its aftermath, and during the long-lasting violent conflict in the region. The study measured the degree of Post-Traumatic Stress Disorder (PTSD) using the Child PTSD Symptoms Scale (CPSS). PTSD is proved to have similar effects on brain development as malnutrition and thus the effects of malnutrition on the working memory of children have to be controlled for the potential effects of PTSD. According to the results of the study, malnutrition is associated with a decrease in performance on the working memory tasks. On the contrary, intelligence measured by Raven's SPM was not associated with the decrease in performance on the working memory tasks, while it was found that a high score on the CPSS was indeed associated with a decrease in the performance on the three working memory tests. The study concludes with a discussion of the policy relevance of the results and sets out an agenda for further research.

Key words: PTSD, working memory, malnutrition, tsunami

JEL: I14, I21, I24

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Acronyms

CPSS	Child Post Traumatic Stress Disorder Syndrome Symptoms Scale
DSM IV	Diagnostic and Statistical Manual of Mental Disorders 4th Edition
EEG	Electroencephalography
fMRI	Functional Magnetic Resonance Imaging
GAM	Gerakan Aceh Merdeka (Free Aceh Movement)
MRI	Magnetic Resonance Imaging
PTSD	Post-Traumatic Stress Disorder
Raven SPM	Raven Standard Progressive Matrices
UNICEF	United Nations Children's Fund
WISC	Wechsler Intelligence Scale for Children
WM	Working Memory

Introduction

The effects of malnutrition on school performance among children have been studied extensively and found both considerable and long lasting (Taras, 2005). While the studies are important enough to focus policy interventions on avoiding malnutrition, they teach us little about how exactly malnutrition affects the functioning and behaviour of children and leads to a poorer performance at school compared to adequately nourished children. It is important to understand the consequences of malnutrition for brain development, working memory and the learning capacity of children in order to design policy interventions that minimize the effects of early malnutrition on subsequent investment in human capital and consequent economic prospects in later life. These policy interventions are still a topical issue since unfortunately malnutrition is still important in many countries, and recent and foreseeable food crises are expected to increase considerably the number of malnourished children (World Bank, 2011). It is important to be better informed about how to assist children who have been exposed to malnourishment. This study brings together some pieces of the puzzle by investigating the relationship between malnutrition, working memory and intelligence among a group of children in Banda Aceh, Indonesia. The results are a "by-product" of a study on the effects of Post-Traumatic Stress Disorder on the working memory of children (de Neubourg, 2010).

First, a review of the current literature investigating the link between malnutrition, working memory and the developing brain will be given. Secondly, the choice of the research location will be explained, followed by a description of the research methods. The results will be reviewed statistically and finally discussed in the light of future research and policy implications.

Malnutrition and the brain

Malnutrition is the consequence of a combination of inadequate intake of protein, carbohydrates, micronutrients, and frequent infections (Kar, Rao, & Chandramouli, 2008). Understanding of how malnutrition early in life affects the development of the brain has evolved considerably since the mid-1960s (Levitsky & Strupp, 1995). At the time, it was feared that malnutrition endured during certain sensitive periods in early development would produce irreversible brain damage possibly resulting in mental retardation and impairment in brain function. Research evidence today shows that most alterations in the growth of various brain structures eventually recover, although permanent alterations in the hippocampus and cerebellum remain (Levitsky & Strupp, 1995). These permanent alterations may affect the functioning of working memory during childhood. Despite the fact that biologically some brain structures overcome the negative effects of malnutrition in the longer term, it is important to study the shorter term impact on the performance of working memory in children because, as explained below, reduced working memory performance endangers the learning capacity of affected children by hampering their concentration, the depth by which cognitive tasks are understood, and the speed at which they are performed. This means that malnourished children run the risk of having a reduced capacity to comprehend and to learn and thus may drop out from, or lag behind at, school considerably. This reduces the effectiveness of the investment in human capital which in turn will depress their earning potential in later life. Even if the brain damage caused by malnutrition is less severe than feared, still its direct effects on schooling, work and careers may be dramatic.

Malnutrition is associated with both the structural and functional pathology of the brain. Structurally, malnutrition results in tissue damage, growth retardation, disorderly differentiation, reduction in synapses and synaptic neurotransmitters, delayed myelination and reduced overall development of dendric arborization of the developing brain (Kar et al., 2008). Rather than merely showing an overall cognitive dysfunction as compared to adequately nourished children, those who suffered from chronic protein energy malnutrition show changes in the development of cognitive processes during childhood years. In particular, the rate of development of attention and executive functions like working memory is severely affected by protein-energy malnutrition in childhood years, a period that is marked by the rapid ongoing development of cognitive functions (Kar et al., 2008).

Working memory represents a limited capacity to store information to be retained over the short term and to be used for performing mental operations on the content of the stored information (Gazzaniga, 2000). Differences in children's working memory influence differences in their performance in problem solving, reasoning, reading comprehension, acquiring new vocabulary, learning to spell, following directions and taking notes in the classroom. Baddeley (1974) formulated a widely accepted definition of working memory and constructed a three part model containing a central executive mechanism for controlling two subordinate systems. The two subordinate systems are the phonological loop and the visuospatial sketchpad. The phonological loop is a hypothesized mechanism for acoustically coding information in working memory (Gazzaniga, 2000). The visuospatial sketchpad is based on short term representations that parallel the phonological loop and permit information storage in either purely visual or visual spatial codes (Gazzaniga, 2000). The central executive mechanism is a command and control centre that presides over the interaction between the two subordinate systems and the long term memory. Following Baddeley, the concept of a central executive system was conceived to be a supervisory attentional system that overrides routine execution of acquired behaviours when novel circumstances require modified actions; it also coordinates and plans activities (Norman & Shallice, 2000). All these functions are crucial in defining the learning capacity of children. Several functional MRI (fMRI)[1] studies showed that working memory maintenance facilitates encoding of these items into long term memory by activating rehearsal processes in the hippocampus (Axmacher, Elger, & Fell, 2009). See appendix A for a review of the studies.

Gathercole, Pickering and Ambridge (2004) investigated changes across the childhood years in the capacity of individual components of the Baddeley (1974) model of working memory.

The developmental functions for measures associated with the phonological loop, the central executive, and the visuospatial sketchpad were found to be very similar, showing linear increase in performance from four years of age through to adolescence. The working memory subsystems corresponding to the central executive, the phonological loop and the visuospatial sketchpad are in place by six years of age at least (Gathercole et al., 2004). The central executive was found to be linked closely with both the phonological loop and the visuospatial sketchpad, which are themselves relatively independent. This structural organisation of working memory remains more or less constant over the childhood years (Gathercole et al., 2004).

Given the above it is highly likely that malnutrition affects the performance of working memory among children; this study explores that relationship among a group of children in Banda Aceh, Indonesia in 2010.

The Children in Banda Aceh

As stated above, this study is a "by-product" of a study on the impact of Post-Traumatic Stress Disorder (PTSD) on the working memory of children. To investigate the relationship between childhood PTSD and working memory performance, a location with potentially high

[1] (Functional) Magnetic Resonance Imaging involves a research technique that measures signal changes in the brain that are due to changing neural activity.

levels of childhood PTSD was sought and the city of Banda Aceh, Indonesia was selected. Banda Aceh is, however, also an area with relatively high levels of malnutrition.

The December 2004 earthquake and tsunami that struck the Indonesian province of Aceh was an unprecedented tragedy both for the scale of human loss and destruction of infrastructure. It affected a 500 km-long and 2-6 km - wide area along the West and North coasts of the province. A relatively high number of children died during the tsunami. The most common immediate consequence among the children who survived was physical separation from their families due either to the high mortality rate, or the physical dislocation of the children (Sechi et al., 2007). However, while this tragedy devastated the region, the tsunami also set the stage for political stability. It was precisely the tsunami that triggered peace in Aceh; the 30-year armed conflict between the Government of Indonesia and the Free Aceh Movement (GAM) came to an end with the signature of the Helsinki agreement, a promising basis for peace (Sechi et al., 2007). Children in Aceh were affected by the armed conflict in a myriad of ways, including the loss of lives (more than 15,000 casualties among both military and civilians), the destruction of property and family livelihoods, violence and abuse. The loss of parents or caregivers and the displacement and disruption of daily life affected many children psychologically (UNICEF, 2009). Children were also involved in violence through their association with the parties to the conflict. During the conflict, poverty in Aceh worsened; the delivery of minimum public services was prevented, contributing to Aceh being the fourth poorest province in Indonesia. The tsunami further exacerbated poverty in the area; in 2004 an estimated 1.2 million people in Aceh (28.5 per cent of the total population) were living below the poverty line (Sechi et al., 2007). One of the consequences of high rates of extreme poverty is the high prevalence of malnutrition among the children of Banda Aceh.

Methods: participants, procedures and measurements

Participants

The test population of this study consists of, boys and girls aged between 9 and 13 years old, living and going to school in Banda Aceh, Indonesia. As explicit memory function has occurred by age four, it was necessary that - at a distance of five years from the tsunami - participants should be aged at least nine. All the children tested lived in the city of Banda Aceh, Indonesia and went to UNICEF child friendly primary schools where grades 5 and 6 were targeted. The participants in this study were recruited with the cooperation of the UNICEF office of Banda Aceh, Indonesia.

Procedures

The study was conducted in two phases. During the first phase of the research the level of PTSD was assessed with the use of a self-report questionnaire, the Child PTSD Symptoms Scale (CPSS) (see below and appendix B). This assessment took place in seven different UNICEF schools in grade 5 and 6 classes as they fit the age requirement of the tests specified above and could possibly have been affected by the tsunami. All schools were contacted and asked for prior permission to carry out the field work. The children in Banda Aceh have a virtually homogeneous background regarding culture, religion and socio-economic status. In total, ten classes of grade 5 and nine classes of grade 6 were visited.

The CPSS scores of the children formed the basis for the next step in the procedure. Consistent with the findings of previous research in similar circumstances (John et al., 2007), this study also found an extremely high percentage of children diagnosed with PSTD using the standard cut-off point of 11 (namely 86.7 %). The main hypothesis of this study assumes a relationship between the level of PTSD and the performance of the working memory. In order to avoid too few observations with very low and high values of the PTSD scores, however, it was decided to select the children for further testing from the entire range of CPSS scores by forming three groups and selecting an equal number of observations (30) in each group. The selection of the three groups (90 children in total) was also gender based in order to distribute the number of boys and girls equally in each group.

The first group had a score equal to or lower than 11 on the CPSS. This group was labeled 'non-PTSD' and consisted of 47 children out of the original sample of 481. Of this group 30 children were randomly selected for further testing (16 girls and 14 boys). The average age of this group was 11.1 years old (SD: 0.8).

The second group had a score between 12 and 28 on the CPSS. This group was labeled the 'mild-PTSD' group and consisted of 341 children. Of this group 30 children were randomly selected for further testing. The test group consisted of 15 girls and 15 boys. The average age was 11.1 years old (SD: 0.7).

The third group had a score of 29 and higher on the CPSS. This group was labeled the 'severe-PTSD' group and consisted of 46 children out of the original sample of 481. Of this group 30 children were randomly selected for further testing. The test group consisted of 15 girls and 15 boys. The average age of this group was 11.3 years old (SD: 0.9).

All 90 selected test subjects completed all tests. After a first review of the data one child was excluded from further data analysis as an outlier due to an extreme high score on the CPSS (50) meaning that this child had a positive score on all 14 questions which is very unlikely to be an observable outcome.

The 90 selected participants all went through the same procedure of testing which was carried out individually. Five research assistants were contracted to administer the tasks in the native language of the participants (Bahasa Indonesia). The research assistants were students at the University of Banda Aceh with no prior knowledge of the research design, and they were unaware of the distribution of the children into three groups.[2]

The participants were contacted during school hours. In agreement with the teacher, the child to be tested was excused from the class (no further consent of caregivers was asked).

Testing took place at the local schools of the children. In random order the children were asked to complete four cognitive tasks. The tasks tested their working memory performance, concentration, and ability to solve problems with the use of logic. To control for probable malnutrition the participants' height and weight were measured and the nutritional status was determined according to the World Health Organization height-for-age tables for children between 5 and 19 years of age (World Health Organisation, 1995).

Measurements

Malnutrition

To establish nutritional status, weight and height were measured, using standardized digital weighing scales (World Health Organisation, 1995) and standardized measurement boards.

[2] This was done in order to secure a blind testing situation where no bias could be transferred from the research assistant to the participants.

On the basis of the height of the participants an index for stunting was calculated indicating insufficient height relative to age. Tested children were defined as either “stunted” (implying long term malnutrition and poor health) or “non-stunted”.

PTSD

The level of PTSD was evaluated with the use of a self-report questionnaire. The Child PTSD Symptoms Scale (CPSS) was designed to assess PTSD diagnosis and symptom severity in children aged 8 to 18 who have experienced a traumatic event (Foa, Johnson, Feeny, & Treadwell, 2001). It contains one question for each of the 17 DSM IV PTSD symptoms to ascertain their frequency in the past month. Answers are on a 4-point Likert-type scale, ranging from 0 (not at all) to 3 (almost always). Seven additional items that inquire about daily functioning follow the first part. These seven items are scored dichotomously as absent (0) or present (1). The minimum score on the CPSS is 0 and a maximum of 51. A cut-off score equal to or greater than 11 on the CPSS total severity score (part1, first 17 questions) yielded 95% sensitivity and 96 % specificity (Foa et al., 2001). A second cut-off score to facilitate identifying severe PTSD was calculated using the mid-point between the first cut-off score (11) and the maximum scored value. This cut-off point was set at 28.

Working memory performance

Three cognitive tasks were used to assess working memory performance.

Digit Span task:

This is a sub-task of the Wechsler Intelligence Scale for Children (WISC) (Wechsler, 1974). The Digit Span task requires to immediate repetition of a series of digits that are read aloud. The task has two parts: digits forward, which contains series ranging in length from two digits to nine digits , and digits backwards, which contains series ranging in length from two to eight digits which has to be repeated in reverse order. The Digit Span task is primarily a measure of short-term sequential auditory memory and attention (Kline, 2000). For each correct repeated series of digits one point is added to the score, resulting in two sub scores, one for the digit forward and one for the digit backwards (Wechsler, 1974). The minimum and maximum score on the Digit forward are 0-16. On the digit backwards the minimum and maximum score are 0-14.

Bourdon-Vos task:

Selective attention was measured by the Bourdon-Vos task which measures sustained selective attention by measuring simple reaction time. This goal is achieved by selective reaction to four-dot targets in two different patterns (square and diamond) and by ignoring non- target items (three- and five-dot targets). The test consists of 33 lines, each with 24 configurations. Omissions, as a parameter of accuracy, and the time of each line, which indicated speed, were recorded (Vos, 1988).

Coding task:

This is a subtask of the WISC (Wechsler, 1974).

The Coding task requires the participant to copy symbols paired with other symbols; it assesses the child's ability to learn an unfamiliar task. The test involves speed and accuracy of visual motor coordination, speed of mental operations, attention skills, visual acuity, visual scanning and tracking, short term memory for new learning and cognitive flexibility. The Coding task can be conceptualized as an information-processing task involving the discrimination and memory of visual pattern symbols (Kline, 2000). The test consists of 119 boxes containing a number from "1" to "9" in the upper part; the lower part is empty. Each number is paired with a different symbol. The goal of the task is to write in the empty box the symbol that is paired with the number in the upper box. There is a time limit of 2 minutes (Wechsler, 1974). The total number of boxes correctly filled in is obtained by subtracting the number of errors from the number of the last box reached.

Intelligence

To control for the influence of general intelligence an additional test was used:

Raven's Standard Progressive Matrices (SPM):

The Raven's SPM is a test of a person's capacity to apprehend meaningless figures presented for his/her observation at the time of the test, see the relation between them, conceive the nature of the figure completing each system of relations presented, and by doing so, to develop a systematic method of reasoning. Raven's SPM was designed to cover the widest possible range of mental ability and to be equally useful with persons of all ages, whatever their education, nationality or physical condition (Raven, 1993).

The task consists of 60 problems divided in five sets of 12. In each set the first problem is almost self-evident. The problems following become progressively more difficult (Raven, 1993).

Results

The prevalence of malnutrition

Among the 89[3] children tested in the second phase of the study, 13 were found stunted and 76 were non-stunted. Note that the relatively large difference between 'stunted' and not stunted' is due to the fact that the primary concern of the sampling was to guarantee that there should be enough children in each of the PTSD (Post Traumatic Stress Disorder) groups in order to study effectively the impact of PTSD on working memory (see also below, discussion and further research).

The characteristics of the sample used for the testing (see Procedure section) are summarized in Table 1.

Table 1 - Participant population

Group	No.	Boys (%)	Girls (%)	Age Mean	CPSS mean (S.D.)	Stunted[1] N (%)
Non-PTSD	30	46.7	53.3	11.1	7.4 (0.5)	6 (20)
Mild-PTSD	30	50.0	50.0	11.1	17.8 (0.7)	5 (16.7)
Severe- PTSD	29	51.7	48.3	11.3	31.5 (0.5)	2 (6.9)

[1] Stunted according WHO height for age, implying long term malnutrition and poor health.
Note: age in years

[3] From the original 90 children tested the results for one child were disregarded because of an anomalous score in the CPSS test (see text).

The relationship between malnutrition and working memory

A summary of the mean values and standard deviations per group of respondents (stunted – non-stunted) for the various tests conducted are summarized in Table 2.

Table 2 - Mean values of test variables by group

Variable	Stunted group mean (S.D.)	Non-stunted group mean (S.D.)
Digit Span Forward	7.77 (2.28)	9.33 (2.14)
Digit Span Backward	3.62 (2.02)	4.42 (1.86)
Bourdon-Vos avg. time per line (s)	17.92 (1.94)	17.25 (4.82)
Bourdon-Vos TT (s)	579 (69.18)	553 (157.1)
Bourdon-Vos Standard Deviation	4.92 (1.9)	3.53 (1.47)
Bourdon-Vos Error	1.92 (1.61)	1.50 (2.23)
Raven's SPM corrected TS	25.0 (10.2)	31.16 (10.4)
Raven's SPM grade	5.55 (1.44)	4.52 (1.56)
Coding Error	1.08 (2.25)	1.13 (5.18)
Coding BR	17.62 (9.5)	41.33 (11.62)
Coding TS	36.54 (9.39)	40.22 (11.13)

Note: Bourdon-Vos TT: Bourdon-Vos Total Time; Raven's SPM TS: Raven's SPM corrected Total Score; Coding BR: Coding Box Reached; Coding TS: Coding Total Score; S.D.: Standard Deviation

A one-way ANOVA was conducted to compare the scores on all the variables mentioned in Table 2 between the two groups (Stunted – Non-Stunted). There was a significant main effect of group on the variable Digit Span Forward at the $p < .05$ level. There was also a significant main effect of group on the variable Bourdon-Vos Standard Deviation at the $p < .05$ level. In addition there was a significant difference between the stunted and non-stunted groups in Raven's test results (grade at $p<.05$ and corrected total score at $p<.10$). A test for the homogeneity of variance did not reveal problems for the test scores (for a table with full results of the ANOVA see appendix B).

It should be noted that almost all the test results show the expected difference between the stunted and non-stunted groups with the stunted group performing consistently worse than the non-stunted group (exceptions are the Bourdon-Vos average time per line and the Coding

Error; both show almost no difference between the 2 groups). However, because of the large numerical difference of the groups and the relatively small number of stunted children in the sample, standard deviations are much bigger in the non-stunted group leading to few significant results when tested.

From the study it also became clear that Post Traumatic Stress Disorder had a similar significant negative impact on the working memory performance of the children tested; Appendix C summarizes the results; a full discussion of these results is found in de Neubourg (2010). The question is whether malnutrition and PSTD had separate impacts on the working memory performance of the children. Moreover it was expected that intelligence itself had no separate impact on the working memory performance of children. In order to control for the simultaneous effects of malnutrition, PTSD and intelligence as explanatory variables, post hoc OLS regressions were estimated. A regression model was conducted using the significant test results for the differences between the PTSD groups (see appendix C - Digit Span Forward[4]) as dependent variables, the individual CPSS score, nutritional status (stunted, non-stunted) and intelligence (Total score Raven's SPM) were used as independent variables. Previous analysis of the data showed no significant correlation between PTSD and malnutrition (-0.112; p = 0.295), nor is there a significant difference in the correlation between the significant different test scores for the stunted/non-stunted group and the level of intelligence as measured by Raven's test. The results of the regression models showed that the score on the CPSS and nutritional status significantly predicted the Digit Span Forward score (Table 3). The higher on the CPSS, the lower the score on the Digit Span Forward (t = -2.075; p = 0.042). If a child is stunted this has a significant negative effect on performance on the Digit Span Forward (t = -2,148; p = 0.036). The total score on Raven's SPM has no significant coefficient (t = 1.099; p = 0.276) (Table 3).

No significant results are found for the Bourdon-Vos Error test.

[4] The regression was estimated for the Digit Span Forward since the results for that test were significant for both malnutrition and PTSD.

Table 3 - Summary for linear regression analysis for Digit Span Forward

Variable	B	SE(B)	β	t	sig. (p)
CPSS	-0.054	0.026	-0.248	-2.075	0.042
Nutritional Status	-1.576	0.734	-0.260	-2.148	0.036
Raven's SPM	0.029	0.026	0.133	1.099	0.276

Note: $R^2 = 0.155$

Discussion

The aim of this study was to investigate the effect of malnutrition on working memory performance among children. The study was undertaken as part of a larger study on the impact of Post-Traumatic Stress Disorder (PTSD) on working memory performance in Banda Aceh, Indonesia, in 2010.

The results in the previous sections show a negative effect of stunting on the performance of working memory among children as measured by at least two of the tests. A decrease in performance on working memory task was found to be positively related to malnutrition.

The main hypothesis of this study was that malnutrition among the children in Banda Aceh could be associated with a decrease in working memory performance and have a negative impact on the level of intelligence. A review of the results of this study confirms the initial hypotheses. More specifically, stunting is associated with lower scores on the Digit Span Forward and with lower scores on the Raven's corrected scores and Raven's grades. The results are not significant for the Digit Span Backwards, the Bourdon-Vos, and Coding speed tests.

The positive association of lower performance in working memory with higher levels of malnutrition among the children was expected to be observed even if the influence of PTSD was taken into consideration. No correlation between PTSD and malnutrition was found, consequently PTSD is not associated with being malnourished, though both PTSD and malnutrition had a negative effect on working memory performance.

The results show that if a child was stunted, there was a significant negative effect on performance on the Digit Span Forward. This means that malnutrition, as well as PTSD, does have an effect on the performance of working memory. This finding confirms the hypothesis, pointing to the fact that malnourishment is a severe condition in the cognitive development of children.

This study did not find a significant effect of intelligence on working memory performance. This is an important finding since it indicates that poor performance in working memory tasks is not related to an overall poor intelligence. It is also important from a policy perspective in that it may point to the fact that if the working memory performance could be improved by either dedicated training at school (or adjusted teaching methods for all children at schools), treatment or both. Malnourished children could be assisted to overcome some of the deficiencies they experience throughout their lives because of prolonged malnutrition at earlier stages in their childhood. However, before being able to conclude with this more optimistic note, the weaknesses of the current study must be overcome in future research.

The strength of the research design is its specificity in terms of the impact of PTSD but showed weaknesses when the effects of malnutrition were analysed. All children went through the same testing procedure and no experimental design was used. The first large explorative sample of 473 children provided a solid impression of the test population which, in turn strengthens the findings of the study. This research design was chosen to study the relationship between PTSD and working memory under circumstances wherein the stressor had a "collective" (natural disaster) rather than an "individual" (abuse, maltreatment) nature. This ensured that the potential number of children affected by PTSD was large enough to allow meaningful testing. It was decided to focus on the procedures on the PTSD aspects because a full study distinguishing six subgroups in the population (3 PSTD groups x 2 malnutrition groups) would have stretched the time- and budget- constraints of the study beyond its limits. It is clear, however, that the results invite further studies.

On the other hand, results have to be interpreted carefully because of some limitations grounded in the same research design. By choosing a school situation and not a neutral location to administer the tests, not all outside influences could be controlled. The current study also chooses to use of a self-reporting questionnaire to determine the severity of the PTSD symptoms; this method was chosen because of the possibility of reaching a large number of children. The instrument used (CPSS) is well established and is used in other studies, but by using standardized questionnaires instead of interviews, the personal connection between the researcher and the children tested was lost in the process. The potential loss of information caused by this procedure was largely compensated for by the possibility of testing a relatively large sample of children, thus leading to more reliable estimates. Specifically for malnutrition it should be repeated that the difference in the numbers of children in the stunted/non-stunted groups is striking. Future research must ensure that the groups are more equal. It can be expected on the basis of the results of this study that this should lead to more significant differences in the test scores.

This study has other weaknesses that further research should and can overcome. Malnutrition could be measured by more than one indicator and more specific data could be used. Measurement of cognitive and neurobiological variable developments could also be improved. The test results in this study reveal certain associations, but using improved tests on the one hand and applying neuro-imaging techniques (fMRI, EEG) might enhance our understanding of the underlying processes. The seeming lack of association between intelligence and working memory performance found in this study is very interesting in this respect and raises hopes that one may be dealt with separately from the other.

It is important to carry out further research on the impact of malnutrition on the lives of children as it may teach us how the impact of malnutrition could be mitigated by specific treatment and by specific educational approaches for the children and/or their teachers and caretakers. If training or (medical or psychological) therapy could be designed, or if school and education systems could be reformed to compensate for aspects of the impact of malnutrition on working memory, intelligence and other aspects of cognitive development, then malnutrition does not need to have such a devastating impact on the lives of malnourished children in later life. Clearly, avoiding malnutrition is imperative, but hope should be given to those who have already suffered from malnutrition and those who will be victims of it in years to come. To raise this hope, we need more insights into the specificities of its impact, and therefore more basic research. The results as set out in this paper deserve to be tested on a larger scale, placing malnutrition at the heart of the research design, but with the ability to collect data on other possible variables (potentially even PTSD again) with an impact on intelligence and working memory. Only larger scale studies will permit us to fully explore the impact of interactions between malnutrition on the one hand and individual characteristics, especially the surroundings (households, families, communities), of individual children on the other hand. Full scale studies could reveal a set of indicators that would be instrumental in designing policy interventions to help children and adolescents who once suffered from malnutrition.

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Appendix A

Working memory and the brain

Axmacher et al. (2009) investigated the role of the hippocampus in working memory performance by exploring the neural signature underlying multi-item working memory. They combined intracranial electroencephalogram (iEEG) and fMRI. Their data suggest that working memory for individual items is related to a hippocampal deactivation (hippocampus independent working memory) and that this deactivation is reduced during working memory for multiple items (hippocampus dependent working memory) (Axmacher et al., 2009). The study does not answer the question whether hippocampal involvement differs depending on the nature and verbalization of the stimuli (van Vugt, Schulze-Bonhage, Litt, Brandt, & Kahana, 2009). To address these questions, van Vugt et al. (2009) analysed a large iEEG dataset collected during working memory tasks for two classes of stimuli: faces and letters. They demonstrated that hippocampal gamma oscillations increase with the number of faces or letters being maintained in working memory. This supports the emerging view that the human hippocampus supports a broad range of memory processes including those involved in working memory maintenance (van Vugt et al., 2009). fMRI was used to identify regions involved in working memory retrieval (Öztekin, McElree, Staresina, & Davachi, 2009). This study examined the neural activation during two WM tasks: an item recognition task (which can be mediated by a direct-access retrieval process) and a judgment of recency task that requires a serial search. The authors found data implying that the hippocampus and the left inferior frontal gyrus play a role in retrieval from WM, complementing their established role in long-term memory (Öztekin et al., 2009).

Appendix B

Result of the one-way ANOVA that was conducted to compare the mean scores on all the variables obtained from the used tests (see Table 2) between the two groups (Stunted/Non-Stunted).

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Digit Span Forward	Between Groups	27,006	1	27,006	5,772	,018
	Within Groups	407,084	87	4,679		
	Total	434,090	88			
Digit Span Backwards	Between Groups	7,206	1	7,206	2,038	,157
	Within Groups	307,603	87	3,536		
	Total	314,809	88			
Bourdon Vos time per line in sec.	Between Groups	5,029	1	5,029	,242	,624
	Within Groups	1807,173	87	20,772		
	Total	1812,202	88			
Bourdon Vos time per line Standard Deviation	Between Groups	21,323	1	21,323	9,003	,004
	Within Groups	206,061	87	2,369		
	Total	227,384	88			
Bourdon Vos Total Time in sec.	Between Groups	7414,071	1	7414,071	,338	,562
	Within Groups	1907805,165	87	21928,795		
	Total	1915219,236	88			
Bourdon Vos Omissions	Between Groups	26,726	1	26,726	,066	,798
	Within Groups	35282,218	87	405,543		
	Total	35308,944	88			
Bourdon Vos Error	Between Groups	1,987	1	1,987	,428	,515
	Within Groups	403,923	87	4,643		
	Total	405,910	88			
Bourdon Vos Total error	Between Groups	14,138	1	14,138	,034	,853
	Within Groups	35844,064	87	412,001		
	Total	35858,202	88			
Raven Correct	Between Groups	348,245	1	348,245	3,238	,077
	Within Groups	6883,527	64	107,555		
	Total	7231,773	65			
Raven Grade	Between Groups	9,708	1	9,708	4,079	,048

	Within Groups	154,709	65	2,380		
	Total	164,418	66			
Coding Error	Between Groups	,033	1	,033	,001	,970
	Within Groups	2075,607	87	23,858		
	Total	2075,640	88			
Coding Box Reached	Between Groups	153,091	1	153,091	1,187	,279
	Within Groups	11217,853	87	128,941		
	Total	11370,944	88			
Coding Total Score	Between Groups	150,763	1	150,763	1,268	,263
	Within Groups	10340,428	87	118,855		
	Total	10491,191	88			

Appendix C

Test results for the three PTSD groups

Mean values of test variables by group

Variable	Non-PTSD group mean (S.D.)	Mild-PTSD group mean (S.D.)	Severe PTSD group mean (S.D.)
Digit Span Forward	9.20 (2.11)	9.73 (2.41)	8.34 (1.97)
Digit Span Backward	4.43 (1.88)	4.30 (1.86)	4.17 (1.98)
Bourdon-Vos avg. time per line (s)	17.17 (4.63)	17.97 (4.89)	16.90 (4.02)
Bourdon-Vos TT (s)	550.80 (153.42)	578.07 (159.75)	543.83 (129.85)
Bourdon-Vos Error	14.33 (17.65)	20.93 (19.90)	16.76 (22.89)
Raven's SPM TS	31.58 (11.12)	30.10 (9.25)	28.59 (11.25)
Coding Error	0.37 (0.71)	0.57 (1.53)	2.48 (8.26)
Coding BR	38.73 (11.66)	39.87 (6.71)	43.86 (14.26)
Coding TS	38.37 (11.54)	39.30 (7.03)	41.45 (13.42)

Note: Bourdon-Vos TT, Bourdon-Vos Total Time; Raven's SPM TS, Raven's SPM Total Score; Coding BR, Coding Box Reached; Coding TS, Coding Total Score.

A one-way ANOVA was conducted to compare the scores on all the variables mentioned in Table 3 between the three groups (Non-PTSD, Mild-PTSD, Severe PTSD). There was a significant main effect of group on the variable Digit Span Forward at the $p < .05$ level [$F (2,86) = 3.064$, $p < 0.05$]. There was also a significant main effect of group on the variable Bourdon-Vos Error at the $p< .05$ level [$F(2,86) = 6.334$, $p < 0.01$]. A post hoc multi comparisons Bonferroni test revealed that for the Digit Span forward test the intergroup differences were only significant at the $p< .05$ level for the differences between the mild PTSD group and the severe PTSD group, meaning that the severe PTSD group had a significantly lower score on the digit span forward compared to the non and mild PTSD group. The differences between the three groups on the Bourdon-Vos error were significant at the $p< .05$ level .

Source: Neubourg de, E. (2010), *Waves of Trauma: the effect of PTSD on Working Memory in Children exposed to a Natural Disaster*, Maastricht Mimeograph.

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