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CHILDHOOD MALNUTRITION: EXPORTING VIOLENCE OR HAPPINESS?

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Half of all child deaths are associated with under-nutrition, with devastating impacts and far-reaching health consequences. Left unchecked, under-nutrition will potentially create an inter-generational, self-reinforcing pathogenic cycle of violence and behavioural disruption, that can spread around the world through human migration. Eradicating malnutrition requires that more nutritious food is accessible to the poor and vulnerable. Beyond this, there is a deeper question.

Is it possible to restore the cognitive loss resulting from malnutrition, using new artificial intelligence and cognitive models?

The Global Nutrition Situation

Malnutrition is one of the most pervasive and insidious aspects of poverty. It remains a colossal and universal problem, with one in three people on the planet affected by some form of malnutrition. It creeps across communities as part of the general set of issues comprised of food insecurity, lack of access to healthcare, education, clean water and sanitation, climate change and loss of ecosystem functioning. Malnutrition at its extremes can be a matter of life and death, and in the long term can hold back people and countries, undermining economies and development.

The figures are startling and shocking.

We estimate that just over 815 million people do not have enough food every day to lead a normal, active life. That's one in nine people. For children it is even worse[1].

Nearly 46% of deaths in children under 5 are attributable to undernutrition. This translates into the unnecessary loss of about 3 million young lives a year. 20 million children suffer annually from severe acute malnutrition; and 160 million from stunting. Malnourished children have lowered resistance to infection; they are more likely to die from common childhood ailments like diarrhoeal diseases and respiratory infections. For those who survive, frequent illness saps their nutritional status, locking them into a vicious cycle of recurring sickness, faltering growth and diminished learning ability.

Current trends also mean that the number of stunted children aged under 5 years will be 128 million in 2025, versus a World Health Organisation target of 100 million[2]. And the current rates of wasting will require a near 40% reduction to achieve the global target of 5% by 2025.

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[1] Resolution WHA65.6. Comprehensive implementation plan on maternal, infant and young child nutrition. In: Sixty-fifth World Health Assembly Geneva, 21–26 May 2012. Resolutions and decisions, annexes. Geneva: World Health Organization; 2012:12–13 (http://www.who.int/nutrition/ topics/WHA65.6_resolution_en.pdf?ua=1, accessed 6 October 2014).

[2] World Health Organization. Global targets 2025. To improve maternal, infant and young child nutrition (www.who.int/nutrition/topics/nutrition_ globaltargets2025/en/, accessed 6 October 2014).

Linked to this is the prevalence of anaemia in women of reproductive age - currently nearly 30%, versus the WHO target for 2025 14.7%, and the persistent rates of low birth weight, which mean that for the 2025 target of a 30% reduction to be achieved a lot will need to happen. Breastfeeding can compensate for undernutrition. but today, less than 40% of infants worldwide are exclusively breastfed for the first 6 months of life. The rates are increasing very slowly but have stagnated in some countries, meaning again that we will fall short of the World Health Organisation's 50% 2025 global target.

And at the other end of the scale, the rate of children aged under 5 years who are overweight continues to increase across the world.

Definitions of Malnutrition

So what is malnutrition?

Malnutrition refers to deficiencies, excesses or imbalances in a person's intake of energy and/or nutrients. It covers 2 broad groups of conditions. One is 'undernutrition'—which includes stunting (low height for age), wasting (low weight for height), underweight (low weight for age) and micronutrient deficiencies or insufficiencies (a lack of important vitamins and minerals). The other is overweight, obesity and diet-related noncommunicable diseases (such as heart disease, stroke, diabetes and cancer).

The double burden of malnutrition is the coexistence of undernutrition - stunting, wasting, vitamin and mineral deficiency – along with overweight, obesity and diet-related Non-Communicable Diseases, within the same households and populations.

The developmental and economic impacts of all forms of malnutrition are extremely serious and last throughout lives and between generations. Although it is low and middle-income countries that bear the greatest burden, even here in London we can find malnutrition at rates that are very surprising.

Often in times of famine we will see images of starving, emaciated children and in times of war we can see the devastating effects on adults.

There are two common forms of undernutrition - Kwashiorkor and Marasmus. The differences are easy to see. In children suffering from marasmus the skin is dry and lose hanging over the glutei, with a loss of fat tissue from normal areas of the body such as the buttocks and the thighs. The hair has alternated layers that are pigmented and non-pigmented. The child is usually irritable and has an exceptionally strong appetite.

A patient with kwashiorkor suffers from damaged absorption and may also display abnormal burns, nephrosis or chronic liver disease. The child often has a loss of muscular mass, oedema or other immunodeficiency symptoms and suffers from vomiting, infections and diarrhoea.

Marasmus is caused by a severe nutritional deficiency in general and is usually found in very young infants and very young children. It can be prevented by breastfeeding. It is actually caused by the total or partial lack of nutritional elements in the food over a period of time. Marasmus usually affects very young children.

Kwashiorkor is the result of a lack of protein in the diet. It is different from marasmus, which is a total lack of nutrition or calories in the diet. The term kwashiorkor is derived from an African term which means 'first- second child'. This is because it usually affects children who are weaned away because of the birth of a second child. Kwashiorkor is usually rampant where babies become deficient in proteins because of their weaning habits and where there is a lack of protein and an excess of carbohydrates. In other words, the diets are not lacking in calories.

Treatment of Undernutrition

In times of emergency, authorities need to act quickly and efficiently through food drops and the use of RTUF and monies to people affected so that they can but food locally rather than wait for large-scale food deliveries from international organisations (see for example the use of blockchain technologies for secure transfer of funds to Isiolo after extreme flooding in 2018)[3]. But in the longer run, we need to tackle chronic malnutrition in a more systematic way if we are to reduce levels across the world.

In the case of Kwashiorkor and marasmus, Kwashiorkor is usually treated with the addition of protein in the diet, usually in the form of dried milk. It also includes a nutritious diet where at least 12% of the calories come from protein and 10% from fat. Marasmus is usually treated by adding vitamin B and following a nutritious diet in general.

However, recent research shows that providing energy food is not enough. First, there has also be the right mix and sufficient levels of vitamins and minerals as well as the right environmental conditions. Today, two billion people worldwide suffer from vitamin or mineral deficiencies alongside the 150 million children who are undernourished. Studies on individual micronutrients, including omega-3 fatty acids, vitaminB12, folic acid, choline, iron, iodine, and zinc, and single aspects of diet have not provided conclusive evidence of their individual impacts, but the few studies of associations between dietary patterns and cognitive development suggest that this should be the focus of a well-designed set of interventions.

However, there are also issues around the general health and environment conditions that seem to play a crucial role in malnutrition.

Despite decades of research, the precise cause of growth failure in children is still unknown. In recent years, research funders have invested heavily in a number of interventions, which focus heavily on improving water quality, sanitation, hand washing (WASH) and infant nutrition[4] and the Sanitation Hygiene Infant Nutrition Efficacy (SHINE). These are based on the idea that a major cause of child stunting and anaemia is Environmental Enteric Dysfunction (EED). This is a subclinical disorder of the small intestine, which is virtually ubiquitous among asymptomatic people living in low-income settings throughout the world and which facilitates microbial translocation into the systemic circulation and triggers chronic immune activation. The primary cause of EED is infant ingestion of faecal microbes related to living in conditions of poor quality and quantity of water, sanitation, and hygiene.

Unfortunately, these studies have done little to reduce stunting in low-income countries. However, stunting resolves quite rapidly as countries become wealthier. Recently, the Medical Research Council in the Gambia has found that better housing with piped water into the home and keeping animals away from the domestic space are the pivotal factors that would lead to improving childhood growth[5]. This is important as previously it was thought that simply improving food access and hygiene education would be sufficient. In other words, there is a higher threshold of hygiene and housing needed to enable children to grow properly and to their best potential, it is not simply a matter of education, incomes and guaranteed access to good food. The results are almost certainly linked to the fact that improved housing and piped water help tackle environmental enteric disease and that this inequality in health is key to achieving many of the malnutrition targets. New clinical trials are now underway to test these ideas further[6].

What are the impacts of malnutrition in children and can they recover?

There is no doubt that the first 1000 days of life are crucial for human physical and mental development. However, a key question is if the developmental damage caused by poverty-related insults - especially malnutrition, during this period of time can be reversed through interventions that start after 2 years of age, and if so, to what extent.

[3] http://kenya.iom.int/article/iom-distributes-shelter-and-non-food-items-nfis-isiolo-county
[4] WASH http://www.washbenefits.net/; SHINE https://clinicaltrials.gov/ct2/show/NCT01824940
[5] https://mrc.ukri.org/news/browse/good-housing-may-be-key-to-eliminating-childhood-malnutrition/
[6] https://clinicaltrials.gov/ct2/show/NCT01824940

The "Young Lives" study followed the growth trajectories of children recruited at 1 year of age in very different socioeconomic and cultural contexts in Ethiopia, India, Peru, and Vietnam where the average maternal education ranged from 3 grades in Ethiopia to 7.8 grades in Peru, and followed them up at 5 and 8 years of age[7]. As expected, height-for-age z score (HAZ) at 1 year was positively associated with child cognitive development (mathematics, vocabulary, and reading) and schooling (age-for-grade) outcomes at 8 years confirmed the fundamental importance of the first 1000 days for subsequent child development.

The most innovative finding from this study, however, is that post-infancy linear growth, uncorrelated with Height for Age score at 1 year, was positively associated with child cognition and school performance. Specifically,

- linear growth between 1 and 8 years was positively associated with improved cognitive and schooling outcomes in early elementary school, independent of attained length at 1 year;
- preventing stunting during infancy and throughout the pre-elementary and early elementary school period gave the most protection against poor cognitive and schooling outcomes at 8 y; and
- recovery from stunting after infancy (compared with persistent stunting) may protect children's cognition and schooling performance, although protection was only partial when compared with never-stunted children.

Childhood development occurs naturally and at an extremely fast rate. One aspect of development that occurs throughout childhood and even as an adult are executive functioning skills. These are the set of abilities that are essential for emotions, thinking and completing tasks. They are the skills that allow us to problem solve, initiate and complete tasks, and sustain attention to complete a task. Executive functioning skills are needed for every multi-step activity we do. They are present in our working memory, planning, organization, time management, metacognition and in our behaviours, and in our executive function skills in response inhibition, emotional control, sustained attention, task attention, goal persistence and flexibility.

At different stages, these start to develop. So at 6-12 months of age we see:

Response inhibition for example "stranger danger" when a baby responds to one adult but not another. *Working Memory* babies begin to recognize familiar faces. They recall and remember those familiar faces utilizing working memory. They can store that information and retrieve it when they see a face. Attachment that begins in the infancy stages of life also are influenced by working memory. Favourite toys and soothing items such as preferred pacifiers, blankets, and soothing positions are influenced by working memory.

Emotional Control- although infants do not have the ability to control their emotions, this is a skill that is just beginning to develop as babies are able to be settled down by certain individuals they are familiar with. Attachment and responding to one adult but not another, is influenced by the initial development of emotional control as infants feel safe and loved by members of their family.

Attention- this executive functioning skill begins as an infant is able to make eye contact and follow objects with their eyes. Attention is developed greatly in the first year. Consider the length of time a one year old can sustain their attention on a preferred toy.

From 12-24 months, infants develop: *Flexibility* although the ability to inhibit impulses, sustain attention, control emotions, and utilize flexibility in thought are very low at this age. Working memory, emotional control, attention, task initiation, and goal persistence all develop throughout the second year of life. Later on, children exhibit increasing

[7] https://www.younglives.org.uk/ and Benny, L., Boyden, J., & M. Penny (2018) *Early is best but it's not always too late: Evidence from the Young Lives study in Ethiopia, India, Peru and Vietnam,* Summative Report. Oxford: Young Lives.

impulse control where there are rules in place until they eventually show emotional regulation, response inhibition, goal persistence, flexibility sustained attention in response to tasks.

Now let's consider the limbic system – this is the autonomous nervous system – which underpins these developments. We know that there are 4 major elements of interest in child behaviour: the hypothalamus, amygdala, thalamus and the hippocampus. The hippocampus is the part of the brain that is involved in forming, organizing, and storing memories. It is particularly important in forming new memories and connecting emotions and senses to memories. In the first 1000 days, there is evidence that malnutrition impacts on the development of the hippocampus. The hypothalamus, occupying just 1% of the brain, regulates the majority of functions of the autonomous nervous system and especially emotions through the endocrine system – the fight or flight and the rest and digest states.

Now in malnourished children we can see from their MRI scans that there are large areas of white – i.e. under developed areas. This is true for both types – kwashiorkor and marasmus. If the malnourished child receives the right types of nutrition before the 1000 days is over, then there are strong signs that the brain can recover. But looking at other situations outside the developing world, Washington University researchers found that poor children with parents who were not very nurturing were also likely to have a smaller hippocampus than those raised by more attentive parents.

What could be the implications of damage to or under-development of the hippocampus?

Inducing and experiencing emotions about another person's mental and physical circumstances is thought to involve self-relevant processing and personal memories of similar experiences. The hippocampus is important in this during recall and prospection in other words we often use our own self-knowledge as a basis for understanding others and as a platform for evaluating and appropriately reacting to the emotional implications of others' situations. Emotions related to others' accomplishments and predicaments, such as admiration or compassion, along with their corresponding feelings, are inherently complex, and often invoke personal memory as a source of information from which to evaluate the situation and respond[8].

Emotions about others' mental states are an important foundation for social interaction and behaviour, as they are cornerstones of social responsibility and of important aspects of morality. These emotions involve evaluating the psychological implications of others' situations, making inferences about others' mental qualities and experiences, and reacting appropriately to the contents of these inferences. If these are missing or diminished, then reactions in situations of high uncertainty are likely to be poorly controlled and even reactionary and likely to reflections the person's own experiences. So the hippocampus is vital in this – as it is the structure with established roles in recall, prospection, and personal emotional experience and contributing to the processing of social emotions with moral and emotional relevance.

Imagine then a situation where a young person, who has had a history of malnutrition that was not rectified, finds himself or herself in the midst of a large angry mob. The most likely reaction will not be to respond calmly with all executive functions in control. Rather the individual is likely to respond in kind to those around him or her. Taking this one step further, the scenes of young people in a very poor country where malnourishment is rampant, running through the streets brandishing sticks and stones in the aftermath of an election is much more likely to be a reflection of poor cognitive development than a true ideological logic.

Cost-Effectiveness of Investments in Nutrition and Early Child Development

The idea that young people do not have the basis upon which to develop should concern governments. Malnutrition has long-lasting consequences – indeed the evidence is there to show that stunting and other features of undernutrition

[8] Immordino-Yang, M. H., & Singh, V. (2011). Hippocampal contributions to the processing of social emotions. *Human brain mapping*, *34*(4), 945-55.

can carry on through to the next generations. If we want young people to take on the future economic and social developments around the world, feeding them, ensuring proper access to food and healthy living conditions will pay off more than potentially any other intervention.

The levels of investment compared to benefits have been shown by the World Bank to be extraordinary. Eleven USD invested yields to address stunting generating 417 billion USD in benefits; 35 USD for breastfeeding to generate 298 billion USD; 12 USD for anaemia to generate 110 billion USD and 4 USD for wasting to generate 25 billion USD.

Early treatment is vital, but there could still be opportunities for repair using artificial intelligence and deep learning as tools to guide damaged limbic systems, especially the hippocampus.

The Future

The root cause of malnutrition is both biophysical and political. With the latest evidence from the climate change community spelling out the danger of extreme changes if we do not urgently reduce carbon emissions and find ways to mitigate or capture them, it is clear that millions of people in vulnerable regions will be exposed to the exigencies of drought, flooding, famine and migration. All of which adds up to a greater chance of children being exposed to malnutrition. Put with this the growing numbers of obese children and we have a powerful cauldron of young people, with many suffering from poor cognitive development.

Is this then the moment when we need to consider a future where we see the map of migration through this lens – one which brings with it the seeds of unrest. Or will we see our leaders and ourselves recognizing the dangers and addressing it through proper nutrition and healthy environments for all young people. The choice is ours to take.