The Effects of Helminth Infections on Child Physical and Cognitive Development: An Integrated Pathophysiological and Socioeconomic Approach

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ARTICLE INFO

Article history:
Received: January 15, 2015
Revised: March 28, 2015
Accepted: August 10, 2015
Available online August 26, 2015

Keywords:
Helminth infections
Pathophysiology
Socioeconomic

ABSTRACT

Ascaris lumbricoides, Trichuris trichiura and hookworm make up the three most prevalent helminth species in humans. Helminths infect on average 1.8 billion people internationally with the vast majority being children under the age of 18. Being parasitic worms, these helminths feed off the child’s body, absorbing nutrients from the gastro-intestinal tract and from blood vessels. This leaves a child malnourished and anaemic especially in lower socioeconomic communities where access to a nutritious and varied diet is neither readily available nor accessible. This paper examined the relationship between the socioeconomic and pathophysiological impacts of helminth infections on a child’s physical and cognitive developments. It looked at the role that poverty and malnutrition played in the onset of cognitive and physical developmental delays. It also discussed the role of parasitic infection intensity on the severity of the poor growth outcomes. A causal loop diagram was used to demonstrate the intricate relationship between STH infection, poor sanitation, negative growth outcomes and the vicious cycle of reinfection. The paper demonstrated a vast consensus of sources are in agreement that soil transmitted helminths are driven by poor sanitation and hygiene, often a result of poor socioeconomic standings, and have major impacts on a child’s physiological and cognitive growth. This paper concluded because of the socioeconomic drivers, the pathophysiological impacts of helminth infections are far greater on children from low socioeconomic backgrounds than on children from upper socioeconomic backgrounds. Furthermore, it concluded that if any intervention is to be successful in reducing the prevalence and intensity of these infections, sanitation, hygiene and health education concerns need to be addressed in order to effectively disrupt the vicious reinfection cycle.

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1. Introduction

Helminth infections are amongst the world’s most prevalent infections as well as one of the most neglected infections to be targeted (Drake et al., 2000). These infections enter the body by the ingestion of eggs often released into the soil via the urine (schisosomes) or stools (soil transmitted helminths) of those infected. After infection, helminths line themselves along the...
intestinal walls and absorb essential nutrients from the host’s consumed food and blood vessels (Bethony et al., 2006). This leads to severe malnutrition among children in low and middle income socioeconomic backgrounds, where access to a nutritional and varied diet is restricted due to poverty (Robertson et al., 1992). This type of helminth induced malnutrition can potentially impact a child’s cognitive and physical development (Kung’u et al., 2009). The studies examined have demonstrated a link between helminthiasis and the physical and cognitive under-development of children due to malnutrition and poor schooling attendance resulting from children feeling lethargic (Ahmed et al., 2012). The most commonly acknowledged helminth infections are the soil transmitted helminths (STH) and thus the ones that will be discussed in this review are Ascaris lumbricoides (round worm), Trichuris trichiura (whipworm) and Necator americanus and Ancylostoma duodenale (hookworm) (de Silva et al., 2003b; Bethony et al., 2006). For the purpose of this review all references to helminths and helminth infections should be regarded as STH infections unless otherwise stated.

This paper will attempt to clarify the relationships and roles that STH infections play on a child’s cognitive and physical development. This review paper aims at clarifying the causal pathway that links helminth infections to child developmental impairment, with a primary focus on the cognitive and physical developments of children from families from lower socioeconomic backgrounds. This will be analysed within an integrated pathophysiological and socioeconomic context rather than separately as most studies have done. This relationship will be demonstrated through a causal loop diagram, which incorporates identified sociological and physiological factors that relate to the impact of helminth infections on child’s cognitive and physical development. An attempt will be made to establish a relationship between helminth infections and their impact on a child’s cognitive ability, physical health and their potential future socioeconomic standing. Thus this paper will aim to map out the potential impacts of helminth infections on a child’s life course and future pathways.

Public health academics have labelled helminth infections as being a neglected tropical disease; however in endemic nations these infections are being given full acknowledgment due to their impact on the people. As will be demonstrated in this paper, the impacts of helminth infections on the cognitive and physical development can be devastating. Thus this research will aim to demonstrate the relationships between pathophysiology and socioeconomic systems in driving helminth infections.

International aid agencies, bilateral and multilateral agencies and local charities have been utilising mass drug administration (MDA) strategies in an attempt to control and eliminate STH infections in endemic regions (Goldman et al., 2007; Stolk et al., 2013; Supali et al., 2013; Webster et al., 2014). MDA programmes are designed to deliver anthelminthic drugs, mainly Albendazole, to all children in endemic areas, annually.

It is anticipated that the information derived within this paper may be used to develop adequate and effective public health policies for interventions in helminth endemic settings. Though some of this information is already well known, the visual portrayal of the aforementioned relationships with STH infections will help better conceptualise the relationships between poverty, sanitation and poor health outcomes in children with STH infections.

2. Burden of Disease

STH infections affect approximately 1.8 billion people internationally (Drake and Bundy, 2001; de Silva et al., 2003b; Bethony et al., 2006; Brooker et al., 2006; Mascarini-Serra, 2011; Sun et al., 2011;
Ziegelbauer et al., 2012; Naing et al., 2013) with up to 4.2 billion people at risk of infection per year (de Silva et al., 2003b). People at risk of contracting STH infections are those that live in regions where poor sanitation and hygiene practices are most common. The epidemiology and demography of each type of worm infections vary considerably based on different sources due to data being collected from various international settings. However, most sources agree that *Ascaris lumbricoides* has the highest infection rate ranging from 800 million to 1.2 billion people per year (Bethony et al., 2006; Sousa-Figueiredo et al., 2012), with 34% being 14 years and younger (de Silva et al., 2003b). Table 1 shows a breakdown of infections based on age groups and helminth type.

The prevalence of *Trichuris* is slightly less than that of *Ascaris* (Bethony et al., 2006) which could be a result of significantly fewer eggs laid by the female *Trichuris* worm in comparison to the *Ascaris* female (Bethony et al., 2006). Trichurisis infections range from 600 – 795 million infections per year (de Silva et al., 2003b; Bethony et al., 2006). *Necator americanus* and *Ancylostoma duodenale* are both different species of hookworm. Unfortunately, 17 out of 17 articles relating to hookworm reviewed grouped hookworm into a single category and did not specify the prevalence of *Necator americanus* and *Ancylostoma duodenale* separately. This may be due to similarities between these species in terms of life cycle and physical features such as the eggs produced from both parasites are indistinguishable at low to moderately powered microscopes which are often used in field stool examinations (Bethony et al., 2006; Tchuem Tchuenté, 2011). One main discerning feature between the two parasites is the number of eggs laid per day, which for *Necator americanus* is up to 10,000 eggs per day and for *Ancylostoma duodenale* is up to 30,000 eggs per day (Bethony et al., 2006). Together hookworms infect approximately 740 million per year (de Silva et al., 2003b).

Routes of transmission for ascarisis and trichurisis have been identified as being through the oral ingestion of STH eggs from soil contaminated (Robertson et al., 1992; Taylor-Robinson et al., 2012). Hookworms, unlike round and whip worms, exist in larval form in the soil and enter the body by burrowing through the skin and travelling through blood and lymphatic vessels before reaching the oesophagus and being swallowed into the gastro-intestinal tract (Jukes, 2003; Bethony et al., 2006) after which they feed off the blood and its nutrients directly. This often results in higher incidences of anaemia and malnutrition (Robertson et al., 1992).

Studies have shown that the demographic most at risk of contracting one form of these three helminths are those aged 15 years and under (de Silva et al., 2003b; Bethony et al., 2006; Jardim-Botelho et al., 2008). This is because children at this age are more prone to exposure from contaminated soil and low hygiene/poor sanitation settings such as classrooms, playgrounds and agricultural land where exposed soil and favourable environmental conditions increase the risk of contracting of one or more of the STH parasites (Bethony et al., 2006).

### 3. Methods of Research

This literature review was conducted using the following databases including Medline, Ovid, PubMed, ScienceDirect, the Lancet and the Cochrane library for publications on helminth infections and child development. These databases, along with others that were used, were accessed using the University of Sydney’s electronic database library as well as the University of Queensland’s electronic library catalogue. Though numerous databases exist which may have been used to obtain more data, only databases which were accessible through the aforementioned electronic database libraries were used. Other appropriate literatures were sourced from Google Scholar search engine and state library catalogues. All key words used were in English and no other language was used for the compilation of the database of articles used in this paper. The following key words and their varied combinations
were used in the search: helminth + child development, cognitive development, geohelminths, helminthiasis, malnutrition, mental development, helminth infections, IQ, child development, mental ability, worm infections, ascariasis, trichuriasis, hookworms, economics, socioeconomic, pathophysiological impact, immunity, maternal, infants, school age, development, growth, stunting, wasting, anaemia and demographics, school performance, pathophysiology, developing countries, low income nations, middle income nations, and physical development.

Search results revealed and examined were not limited to journal articles but also included news reports, reviews, books, journal articles, lab reports and randomly controlled trials (RCT) reports. A total of 70 articles have been reviewed relating to helminth infections and their impacts on a child’s physical and cognitive development as well as malnutrition, anaemia and the role of maternal health on a child’s health.

A time frame limit was implemented whereby no articles on the role of helminths in cognitive and physical development predating 1990 were used. This was done to minimize historical inaccuracies regarding the infections and the out-dated methods of treatment that would have also been used to justify arguments in such articles. This time frame was also used to coincide with the Millennium Development Goals (MDGs) baseline date as they provide adequate baseline on malnutrition, infectious disease and infant morbidity data which are all related to helminth infections. Relevant epidemiological data on infectious disease induced malnutrition and their impact on infant mortality and morbidity may be correlated with helminth infection data to help identify whether a link exists among these conditions and their potential impacts on child mortality and morbidity rates.

Further data analysis has been done to determine impacts on a child’s cognitive and physical development within a framework that discusses pathophysiological and socioeconomic determinants.

Figure 1 shows a flowchart documenting the process in which the articles were selected, exclusion criteria used and how the final articles were included.

4. Limitations of Methods

Although several articles that are originally in languages other than English were used, priority was given to English translations for the purpose of this paper. This is a limitation because articles that
have been published in languages other than English primarily focus on helminths in their respective national settings and thus may contain critical insights on the role of helminth infections on a child’s development in a specific contextual setting. Thus a contextual comparison is not possible at this stage, however desirable it might be.

Furthermore, only the above mentioned databases were used to search for articles. Due to the volume of databases, relevant articles that may have existed in unsearched databases have been excluded from this review.

5. Results

Out of the 70 articles reviewed, 52 focused on helminth infections, 30 of these focused on ascariasis and trichuriasis whilst 22 focused on hookworm infections. The other 18 articles discussed issues relating to helminth infections such as malnutrition, socioeconomics, maternal health, natural cognitive and physical development of a child, cognitive testing of a child and epidemiological data.

Based on the literature reviewed, 5 key themes have emerged which relate to both socioeconomic and pathophysiological relationships of helminth infections and a child’s physical and cognitive development. These themes are as follows:

1. Pathophysiological impacts on child development

2. Pathophysiological impacts based on developmental milestone

3. Socioeconomic impacts of helminth infections

4. Pathophysiological and socioeconomic relationships of helminth infections

5. Effects of parasitic loading on child development

Regarding the first theme - pathophysiological impacts on child development, 14 articles looked at the direct impact of helminth infections on a child’s physiology and the concurrent impact on development. All 14 sources concluded that helminth induced malnutrition was responsible for developmental delays to a child’s physiology. Contentious issues observed in these articles were: what drives these pathophysiological responses and why these three different helminths affected the body differently. All of these articles attributed poor sanitation and poor hygiene to the proliferation of helminth infections.

Similar to the first theme, the second theme elaborated and dwelled deeper onto the pathophysiological impacts of helminth infections based on three distinct developmental milestones of a child’s life, namely: the perinatal phase, the infancy phase and the school age phase. Thirty articles were reviewed which tied into these three phases. These articles looked at the pathophysiological impact of these parasites at each of these three phases, and described the roles of mothers, schools and environments in either promoting or hindering a child’s healthy development. The key issues observed were how to effectively assess the cognitive ability and percentage of impairment of a child infected with helminths and how to establish an appropriate and culturally sensitive baseline for these tests.

Seven articles were reviewed for the third theme which looked at the socioeconomic impact of helminth infections on children and their families. This section examined the contributions of Disability Adjusted Life Years lost due to helminth infections and correlated this to loss of income and loss of potential. Issues raised were region specific and cannot be generalised across all cultural settings. It also highlighted the role of poor sanitation, poor hygiene and poor governance in contributing to
these negative impacts.

The fourth theme attempted to highlight the relationships between the socioeconomic and pathophysiological impacts of helminth infections on a child’s physical and cognitive development. This was done through a causal loop diagram. Nineteen articles were reviewed in the formulation of this section each drawing on a single element of the causal loop diagram. One prominent issue was the use of a valid assessment for the potential impact of helminths on a child’s future.

The last theme looked at the roles of parasitic loading on a child’s physical and cognitive development. It examined the relationships between all three helminth species and their impacts on a child’s health. Twenty eight articles were reviewed for this theme. A salient point raised in all articles was that the impact of helminths on a child’s health was maximised when the child was infected with more than one helminth. Another key issue highlighted here was the potential for helminths to be utilised for positive benefits in a child’s body.

6.1. Pathophysiological Impacts on Child Development

Although STH infections are not a deadly infection, they do however deprive the host of essential nutrients from the blood due to the parasites’ affinity for these nutrients and its need to reproduce inside a host (Robertson et al., 1992) consequently resulting in a higher morbidity rate rather than a
mortality rate. Helminths reproduce inside the hosts’ gastro-intestinal tract and release their eggs into the faeces as they pass through their site of attachment in the gastro-intestinal tract. In resource poor settings, where lack of basic sanitation infrastructure is most common, this often results in large scale contamination of soil with infected faecal matter thus resulting in a much greater risk of infection either by the faecal-oral transmission route (round worm and whip worm) or the permeation through exposed skin (hook worm).

Helminth parasitic loads are associated with the number of eggs present per gram of faecal matter and these values vary between parasites (Degarege et al., 2009). These values can be seen in table 2.

As table 1 demonstrates, the majority of those infected with helminths are children under the age of 18. With this in mind, one must look at how these helminths may interact with a child’s developing body and what potential impacts they might have on a child’s cognitive and physical development. STH infections in children under 18 years of age pose a significant threat to their physical development as every growing milestone that a child passes through on their journey to becoming an adult occurs before the age of 18 (Alice Sterling, 1999; Smith, 2001; Oller et al., 2006). The malnourishing nature of helminth infections in children furthermore poses a threat to a child’s mental ability as he/she will lack the ability to concentrate and retain information due to helminth induced lethargia (Drake et al., 2000). Therefore it is necessary to examine the effects of helminth infections on a child’s development through three distinctive phases and the impacts these infections will have on these milestones.

Child development in this context will refer to the physical and cognitive development of a child based on 3 phases of life. Physical development will be based on the WHO nutritional guidelines of child development which include height for weight, weight for age and height for age anthropometric measurements (Gage and Zansky, 1995). Intellectual development will be based on a child’s overall ability and performance in schooling environments (Stoltzfus et al., 2001; Jukes, 2003).

6.2. Pathophysiological Impacts Based on a Child’s Developmental Milestones

The three phases of child development to be examined in this review paper will be reliant on the age of the child and in some instances will also include the nutritional status of the mother. The first phase will be the perinatal (maternal phase). In the perinatal (maternal phase), the review will look at the peri and neonatal stage of life and the roles of maternal health on the child’s development in-utero and post-partum (Kung’u et al., 2009).

The second phase will be the infancy stage which ranges from the moment the child is no longer reliant on the mother’s breast milk for food and before the child starts mainstream education. The ages are roughly 2 to 4 years of age (Alice Sterling, 1999). This phase will also take into consideration capacity of family to provide nutritional diets and the overall socioeconomic status of the family.

The final stage that will be discussed is the school aged phase in which the child’s health status will be examined based on their nutritional index as well as the child’s school attendance and performance (Jukes, 2003). These three phases will be examined individually and their causal relationships to child development and helminth infections will be established to aid with the drawing of the causal loop diagram.

Phase 1: Perinatal Phase

The Perinatal phase of a child’s development is one in which the mother’s health, dietary habits and nutritional status are of paramount importance (Rondo and Tomkins, 1999; Engebretson and Littleton-Gibbs, 2002; Hassan et al., 2011). Because
of the child’s heavy dependence on the mother’s milk for nutrition and sustenance, a malnourished mother is less likely to be able to provide the child with the required nutrients to help sustain growth. Furthermore, studies have shown that a mother’s parasitic load determines whether or not a child can contract a helminth infection from their mother (Bethony et al., 2006). Additionally, an anaemic and malnourished mother is less likely to produce enough nutritious breast milk for the child (Miranda et al., 1983; Kung’u et al., 2009; Hassan et al., 2011), often leaving the child hungry, undernourished and lacking the key nutritional building blocks for their physical and mental growth (Dauby et al., 2012).

There is a significant lack of articles and research into the perinatal phase. Out of all the articles reviewed, there were only three articles (Bethony et al., 2006; Kung’u et al., 2009; Dauby et al., 2012) which touched upon the role and interactions of helminth infections on foetal and newly born children. This lack of research poses a major threat to the understanding of helminth infections and the role the mother, who is often malnourished, plays in the physical and cognitive development of the child. There is extensive evidence which suggests that a child’s developmental ability is directly proportional to the mother’s nutritional status (Rondo and Tomkins, 1999).

It has been demonstrated that the mother’s health is critical in the development of the foetus as well as the development of the child after birth (Rondo and Tomkins, 1999; Hassan et al., 2011). There is a directly proportional correlation between the health of the mother and the health of the child. If the mother is healthy then it is highly likely that the child will also be healthy and if the mother’s health is poor then it is also likely that the child will also be of poor health (malnourished (undernourished), stunted, wasted and underweight). (Rondo and Tomkins, 1999)

In a low and middle income setting where rates of helminthiasis are relatively high and concurrently the birth rate is also high; for example, such as in Brazil or Bolivia and most Sub-Saharan African Nations mothers are often undernourished and anaemic due to lack of access to a nutritional and varied diet (Jardim-Botelho et al., 2008; Lobato et al., 2012; Mbu and Nembu, 2013; Akanni et al., 2014). Combining this malnutrition with a helminth infection such as hookworm, which even in a light infection load can be detrimental to the health of a person, the pregnant mother is often left underweight and almost wasted thus increasing her risk of maternal complications as well as increasing the risk that her child will be born underweight and pre-term (Miranda et al., 1983; Rush, 2001; Moore and Davies, 2005). Some sources argue that this is one of the reasons why maternal deaths and child mortality rates (as projected by the MDGs) are still quite high in such countries (Rush, 2001).

Thus it is an essential part of the helminth causal pathway equation that must be considered in any intervention that is to take place. The risks posed to underweight mothers and their children are extensive and are in most instances life threatening especially if the mother is anaemic. The risk of haemorrhaging during and after birth coupled with risks for infections grow exponentially with the decline in the mother’s nutritional status, weight and haemoglobin levels (Engebretson and Littleton-Gibbs, 2002). Furthermore, her potential to properly nourish her child will be severely hindered thus also increasing the risk of infections for her child (Miranda et al., 1983).

**Phase 2: Infancy Phase**

The infancy phase primarily begins when the child is no longer reliant on the mother’s breast milk for sustenance and can begin obtaining their nutritional requirements from other sources. Fortuitously, wider research has been conducted on children of this age as compared to children in the phase 1 developmental cycle. According to numerous articles
(Crompton and Savioli, 1993; Stephenson et al., 2000; Stoltzfus et al., 2001; Jardim-Botelho et al., 2008; Kung’u et al., 2009; Soares Magalhães and Clements, 2011; Sousa-Figueiredo et al., 2012), these children are at risk of malnutrition related developmental delays. Furthermore due to the children being at an age where the testing of cognitive progression is fairly difficult because there is no established baseline for the child (Neisser et al., 1996; Sternberg, 2004), it is therefore even more difficult to establish the true impact of this helminth induced malnutrition on the child’s cognitive development (Preston, 2005). The impacts of helminths on a child’s physical development are well documented as it is identical to poverty induced malnutrition. In fact often the helminth induced malnutrition only exists because of contextual poverty and lack of access to a nutritious and a varied diet (Bethony et al., 2006; Hotez, 2008; World Health and Infections, 2012). The only documented instances of malnutrition in children from an average income family bracket are that of children with heavy ascariasis, trichuriasis and hookworm infections (Bethony et al., 2006). This demonstrates that ascariasis and trichuriasis related delays in physical and cognitive ability are actually preventable as these problems stem from socioeconomic issues with significant pathophysiological implications. Although ascariasis, trichuriasis and hookworm infections affect a child’s development, the incidence of the heavy parasitic load needed for ascariasis and trichuriasis is rare (0.35% prevalence) (Drake and Bundy, 2001; Meltzer, 2006). The issue with hookworm infections and their role in child developmental delays lie in their route of infection and their preferred source of feeding in the gastrointestinal tract. Hookworms prefer to feed directly from blood vessels in the duodenum and the large intestine thus draining the body of essential blood borne nutrients and iron, often resulting in severe anaemia as well as a moderate level of malnutrition (Bethony et al., 2006; Hotez, 2008). This is why even with a light parasitic load, hookworm can be detrimental to a child’s health and their ability to grow mentally and physically (Bethony et al., 2006). The avenue related to cognitive delays with hookworm is associated with the child’s reduced ability to attend school due to malnutrition induced lethargia and the body’s natural physiological response to anaemia and malnutrition to preserve all available vital nutrients for survival rather than for growth and development (Stephenson et al., 2000; Jardim-Botelho et al., 2008; Mbuh and Nembu, 2013). A child with helminth induced under nutrition is likely to be more than 2kg under the average weight for age measurement, 5cm under the average height for age, and belonging to the underweight spectrum for the height for weight measurement (Graham et al., 1982).

**Phase 3: School Age Phase**

School age children are mostly at risk of helminth infections (de Silva et al., 2003b; Cooper et al., 2004; Albright et al., 2005; Jardim-Botelho et al., 2008; Mbuh and Nembu, 2013) and as such in a poverty setting where a varied diet is not available are also prone to malnutrition, anaemia and thus associated cognitive developmental delays. However according to 55% of sources (Robertson et al., 1992; Gage and Zansky, 1995; Sternberg et al., 1997; Drake and Bundy, 2001; Stoltzfus et al., 2001; Jukes, 2003; Albright et al., 2005; Bethony et al., 2006; Ahmed et al., 2012; Lobato et al., 2012) these delays are reversible and with the right interventions after deworming, the child can regain most of their delayed mental and physical capabilities (Drake et al., 2000; Lobato et al., 2012; Taylor-Robinson et al., 2012). The impacts of these infections on puberty are more profound with more permanent stunting taking place with heavy helminth infections (Richardson, 1977; Modan-Moses et al., 2003; Leenstra et al., 2005). Extensive research has been conducted on this phase of a child’s life cycle with the impacts of helminth infections on a child’s development in this phase well documented (Shang
et al., 2010). However there is much contradiction in the findings of these papers on the true impact of helminths on the development of a child of this age. There is a significant lack of conclusive evidence on the true impact of helminth infections on the cognitive development of a child with some articles such as Taylor-Robinson et al (Taylor-Robinson et al., 2012) Cochrane library article arguing that there is no significant impact on a child’s cognitive development at all, whilst other articles such as Stoltzfus et al’s article which demonstrates a weak but evident relationship between helminth infections and cognitive development (Stoltzfus et al., 2001). Furthermore, most authors have agreed that helminth infections almost always impact on a child’s physical development (Stephenson et al., 2000; Bethony et al., 2006; Dauby et al., 2012; Lobato et al., 2012; Taylor-Robinson et al., 2012) with the main culprit being helminth induced and socioeconomically driven malnutrition and anaemia.

Unlike children in the first 2 phases of their development, children at a school age level are significantly more prone to helminth infections due to increased exposure to contaminated soil via play time during school hours (Drake et al., 2000; Bethony et al., 2006). This increased risk of infections as well as the increased prevalence of helminth infections at a school age level coupled with the often poor sanitation and hygiene conditions present in many low income primary and secondary schools often means that there is a high possibility that the soil within the school grounds will be contaminated with faecal transmitted helminth. Since children by nature are more likely to play in these contaminated sites, their risk of contracting a helminth infection either by ingestion or via their skin is exponentially greater than that of a person who is not exposed to contaminated soil (Cooper et al., 2004; Shang et al., 2010; Lwanga et al., 2012; Taylor-Robinson et al., 2012). Furthermore, the child’s potential to transmit these infections to the rest of their family and other peers is also very high especially in instances of poor sanitation and poor hygiene practices. Soil contamination via public defecation is highly prevalent (Drake and Bundy, 2001).

6.3. Socioeconomic Impacts of Helminth infections:

Helminth infections are very much poverty driven diseases. They are highly more prevalent in the developing world and are most common in areas where sanitation and hygiene are very poor, indicating that this disease is very closely linked to the socioeconomic standing of a place (29, 38, 46) (Asaolu and Ofoezie, 2003; Jimenez-Cisneros and Maya-Rendon, 2007; Ziegelbauer et al., 2012).

It has been estimated that globally since the year 2000, on average helminths account for 39 million DALYs (Disability Adjusted Life Years Lost) (Stephenson et al., 2000) with hookworm infections contributing to 22.1 million DALYs, ascariasis 10.5 million DALYs and trichuriasis 6.4 million DALYs (Stephenson et al., 2000). This very large DALY scores for STH infections are indicative and inclusive of all comorbidities associated with STH infections such as anaemia, poor growth outcomes and higher risks of bacterial infections. This correlates to billions of dollars’ worth of lost income to impoverished households and millions of productive and innovative years lost because of these parasites. Stephenson argues that a primary reason for this large number is because of the severity of the helminth induced malnutrition and anaemia these parasites have been known to cause. This reinforces Prescott and Jancloes argument that helminths are a poverty driven disease and primarily a burden of the poor (Prescott and Jancloes, 1984). Furthermore, this solidifies the argument that the socioeconomic standing of a household ultimately determines whether or not a person becomes heavily disabled due to the impact of helminth induced malnutrition and anaemia on their lifestyle.

Moreover, an individual’s ability to access nutritious
and adequate amounts of food and their ability to access medical services all ultimately decide whether this person will contribute only 1 DALYs or 20 DALYs to the international statistics.

Helminth induced malnutrition has a great potential to impact the future life course of a child if not addressed properly. A malnourished child is less likely to attend school, less likely to attend a higher education provider and is less likely to obtain and maintain a long term well-paying job. Helminths ultimately lock a child’s future into a vicious poverty cycle (Fabiyi, 1987; Peña and Bacallao, 2002; Delisle, 2008; Atinmo et al., 2009), where their quality of life and ability to contribute to society are severely limited due to chronic lethargy, poor concentration and respiratory and cardiac problems associated with severe malnutrition and anaemia. Thus the socioeconomic implications of helminth infections are long lasting and are closely correlated with the physiological implications of helminth infections and their impact on a child’s development.

Although it is assumed that helminth infections are reserved for the developing world, it has been discovered that urban slums, ghettos and indigenous populations in more developed and higher socioeconomic nations are also prone to helminth infections, especially if hygiene practices and access to proper sanitation are poor (Crompton and Savioli, 1993). This is especially true in nations such as India, and the United States where urban slums are quiet common and where hygiene practices and sanitation practices are poor and subpar for a higher socioeconomic nation (Mascarini-Serra, 2011; Taylor-Robinson et al., 2012).

This reiterates the idea that the driving force behind the high prevalence and incidence of helminth infections in endemic areas are socioeconomic issues such as the lack of proper sanitation infrastructure, poor hygiene practices and poverty leading to an inability to access a nutritionally rich and varied diet contributes to a child’s inability to naturally grow both mentally and physically.

6.4. Pathophysiological and Socioeconomic Relationships of Helminth Infections:

In order to visually demonstrate the relationship between the pathophysiological and socioeconomic impacts of helminth infections on child development a causal loop diagram will be used. This causal loop diagram was drawn using computer simulation software called Vensim (Ventana Systems Inc.) which is commonly used to develop Bayesian networks Though the causal loop diagram is an element of Bayesian networks, this diagram was not intended to be a Bayesian network analysis but rather capture the flow and directionality of the STH infection cycle and the impacts of helminths on the pathophysiological and socioeconomic outcomes of an infected child. If future Bayesian network analysis on this relationship is to be conducted, this causal loop diagram can act as the foundation to this analysis and as such this software can be used to easily expand on this diagram. Furthermore, input of variables in order to produce a Bayesian flow diagram is made easier for future use.

The causal loop diagram (figure 1) demonstrates the relationship between helminth infections, anaemia, malnutrition, poverty, income, and sanitation infrastructure and soil quality (exposed and contaminated soils increase risk of infections). It also looks at the potential impact of these on a child’s life course and future outcomes in terms of career, education and contributions back to society. This causal loop diagram is a tool used to visually display the relationship of all pathophysiological and socioeconomic factors related to helminth infections and their role in either promoting or hindering a child’s cognitive and physical development.

This diagram demonstrates the intricate relationship between the impacts of poverty and opportunity on the health of a child. Furthermore it emphasizes the role that helminths play in the
continued poverty cycle. The loop also fascinatingly demonstrates the ideal locations for interventions to be conducted which would allow for the disruption of the loop.

The loop demonstrates the impacts of socioeconomic on the pathophysiological systems of a child's life. It also demonstrates the impacts of the pathophysiological effects of helminths on the socioeconomic situation of a child and their potential future. All data used in the drawing of this loop were derived from articles mentioned in this paper.

With helminth infections being so widespread internationally, there is a dire need for the further study of the true effect of helminth infections on the cognitive and physical development of a child. As the causal loop demonstrates there are numerous factors which need to be considered when studying the impacts of helminth infections, thus studying their effects through either a purely socioeconomic or purely pathophysiological perspective is redundant as this will always exclude critical elements responsible for the physical and cognitive delays in development in children. The causal loop diagram also demonstrates the interconnected nature between socioeconomics, pathophysiology and their impacts on a child’s life path. This relationship is critical in better understanding how to best address helminth infections in children and more importantly how to address this critical contributing factor to the poverty cycle.

This diagram is composed of four separate loops, three reinforcing loops indicated by the + sign with an anticlockwise arrow around it and a balancing loop indicated by the − sign and the counter-clockwise arrow around it. The reinforcing loops reinforce the growth of a trend whilst the balancing loop attempts to balance the system to maintain equilibrium. Furthermore, in the loop arrows with a + move in the same direction as the next variable, for example public defecation increases the concentration of helminth eggs in the soil, whilst arrows with a – move in the opposite direction of the original variable, for example, helminths absorbing iron and nutrients from the blood decrease the amount available for the body to use.

Causal loop A demonstrates the greater outer ring of the diagram. This loop looks at how lack of sanitation available to communities promotes the contamination of soil with STH eggs and larvae.

It also captures the wider impact of STH infections on a child’s development and future outcomes.

Causal loop B represents the biological processes for the infection and reinfection of children in at risk environments; loop C details how helminth infections may cause malnutrition and induce anaemia. Loop D details how STH infections may contribute to cognitive and physical growth delays and how they start the vicious cycle of economic hindrances and decay for the infected families.

The two stars represent the sites where MDA programmes are most likely to stop the cycles from progressing. Because MDA programmes alone only help reduce the prevalence and intensity of infections without completely eliminating the parasites from the environment, the disruptions to the causal loops are primarily focused on the reduction in co-morbidities such as the onset of anaemia and the development of cognitive delays. This disruption though is enough to give a child a chance at implementing the necessary political and economic changes needed at a later stage in life. This is because the child no longer has the debilitating comorbidities preventing them from achieving their educational and economic potentials, thus reducing the value and weighing of DALYs being contributed per child.

Thus through the diagram and the existence of 3 reinforcing loops to only 1 balancing loop, it is evident that unless this cycle is disrupted by another balancing loop, the incidence and prevalence of
Soil-Transmitted helminths contaminated soil
Infected food sources consumed by the public

+ Children infected with intestinal helminths
  
  Adults reproduce
  
  Helminths absorb nutrients from blood supply
  
  Body deprived of essential macro and micro-nutrients
  
  Child becomes malnourished
  
  larvae line the gut of child
  
  reduces blood iron levels
  
  reduces blood flow levels (Hg concentration)
  
  childs brain is deprived of glucose and other essential nutrients
  
  Child becomes malnourished
  
  onset of lethargy prevents physical activity and growth

Figure 1: Causal Loop Diagram of Socioeconomical and Pathophysiological Impacts of Helminths on a Child's Development
helminth infections and their negative impacts of a child’s development will only continue to grow. Furthermore, through the relationships demonstrated in the causal loop diagram it has become evident that helminth infections do not only affect a child’s childhood growth but in fact impact greatly on a child’s entire life course if they are not addressed accordingly.

Although 30% of studies suggest that helminth infections have no impact on a child’s cognitive development, the evidence suggesting that helminth infections, depending on the severity and socioeconomic background, can cause malnutrition are extensive with 70% of sources stating such. Furthermore, the same sources indicate that this helminth induced malnutrition is also responsible for the physical developmental delays observed in infected children. This is indicative of the pathway in which STH infections potentially cause cognitive delays (Gage and Zansky, 1995; Sternberg et al., 1997; Easton, 1999; Drake et al., 2000; Stephenson et al., 2000; Drake and Bundy, 2001; Bethony et al., 2006; Bleakley, 2007; Jardim-Botelho et al., 2008; Kung’u et al., 2009; Ahmed et al., 2012; Lwanga et al., 2012; Mbuh and Nembu, 2013).

In numerous instances, children with light ascariasis or trichuriasis parasitic loads became malnourished due to the lack of access to a varied and substantially nutritious diet. In a non-impoverished scenario, children with such a load did not demonstrate any signs of malnutrition or developmental delays as their bodies were still receiving the essential nutrients from their varied diets (McKay, 2006; Scholte et al., 2012), enough to feed both their bodies and the worms inside them. This is an important element to be addressed if any attempt to eradicate or even address helminths is to be undertaken (Mascarini-Serra, 2011). This is also one of the reasons why helminth infections have low prevalence rates in more developed economic settings. Access to adequate health services exacerbate an already prominent problem, as the cost to treat such helminth infections might exceed the daily income of a household in an impoverished setting (Hotez, 2008).

Thus this causal loop diagram demonstrates the intricate nature of socioeconomic factors in manipulating the pathophysiological nature of helminth infections and how together they impact a child’s physical and cognitive development.

6.5. Effects of Variable Parasitic loads on a Child’s Development

Studies have shown that a light ascariasis parasitic load can actually have a protective effect on a child, protecting them from cerebral malaria as well as increasing their immune response to other pathogens (McKay, 2006; Degarege et al., 2009; Wammes et al., 2010). However this is heavily reliant on the nutrient intake of the child and conditional upon the fact that a child is required to have a stable and substantially healthy diet in order for this effect to take place. The fact that this specific genus of helminth can have positive impacts on the physiology of a child is a very insightful issue regarding the role that ascariasis can play in the long term sustainability of this strain in helminth infections in the world today. Out of the three different classifications of worms, roundworm, whipworm and hookworm, ascariasis demonstrated the least impact on a child’s cognitive and physical development in light to moderate loads and in heavy
loads demonstrated a lesser impact on the growth of a child when compared to trichuriasis and hookworm infection (Drake et al., 2000; Jukes, 2003; Bethony et al., 2006).

The impact demonstrated by ascariasis on the cognitive development and ability of a child in a light to moderate load was statistically insignificant (Taylor-Robinson et al., 2012). In fact, in one study the children lightly to moderately infected with ascariasis out-performed their uninfected counterparts in numerical and non-verbal reasoning but underperformed in the verbal language skills when compared to their uninfected counterparts (Jukes, 2003). In this study, children deemed to have a heavy parasitic load demonstrated a significant reduction in their cognitive ability in all the tests conducted in comparison to the uninfected counterparts. This demonstrated that children who are infected with ascariasis in a light to moderate load are in fact not necessarily at a higher risk of delayed cognitive development, but rather the impact only infected a single avenue of the child’s cognitive ability with other studies (Jukes, 2003). These developmental delays were found to be reversible after treatment, but were highly reliant on the child remaining worm free after their treatment (Stephenson et al., 2000; Gilgen and Mascie-Taylor, 2001; Stoltzfus et al., 2001; Ahmed et al., 2012). Unfortunately no time period has been specified for this worm free period after treatment for which the child would be able to recover their delayed cognitive ability.

Research (Stoltzfus et al., 2001; Bethony et al., 2006; Ahmed et al., 2012; Taylor-Robinson et al., 2012) has demonstrated that children go through a physical and cognitive growth spurt after their deworming. However the amount of potential growth lost is difficult to accurately calculate and thus it is unsure how much physical and cognitive growth potential the child may have lost due to this infection. In comparison, a heavy infection load of ascariasis will leave a child, regardless of nutritional and economic background, malnourished, often stunted and cognitively delayed (Crompton and Nesheim, 2002). Seventy five percent of articles reviewed have stated that the most common infection loads are the light to moderate loads representing a total of 97% of infection rates, whilst heavy parasitic loads are rare representing only 3% of the total infected population (Drake et al., 2000; Bethony et al., 2006; Jardim-Botelho et al., 2008).

Finally, treatment for ascariasis and trichuriasis are more economical ie less than $0.03 per child compared to treatments for hookworm infections (Hall et al., 2009). Though the same drug is used for all three parasites in MDA programmes, Albendazole, the efficacy of the drug on trichuriasis and hookworm infections are lower than that on ascariasis (Smits, 2009; Tchuem Tchuenté, 2011). However the only issue with the treatment of ascariasis, as well as with other worm infections, and as demonstrated in the causal loop diagram is that it is relatively easy to be reinfected with these worms if the sources of the infections, being poor sanitation and inadequate hygiene practices, are not addressed properly. Since helminths are transmitted via the contamination of soil with infected faecal matter as well as transmission from the faecal-oral route, addressing these avenues coupled with mass deworming of adults and children will significantly limit and decrease the incidence and prevalence of helminth infections in endemic areas and will cost less than the long term deworming of children who continuously contract these worm infections after being treated (Asaolu and Ofoezie, 2003).

According to the literature reviewed (Stephenson et al., 2000; Bethony et al., 2006; McKay, 2006) trichuriasis has a greater impact on a child’s cognitive and physical development compared to ascariasis but is lesser than hookworm infections. Interestingly, trichuriasis impacts the body differently to ascariasis, and can cause numerous secondary problems such as asthma, cardiac problems and the increased risk of respiratory
infections (Bethony et al., 2006). Trichuriasis has been demonstrated to cause cases of asthma as a secondary interaction of the helminth infection with the physiology of the body (Bethony et al., 2006). Like ascariasis, little to no significant changes in a child’s cognitive ability and development were demonstrated or observed in children with light to moderate infection loads (Drake et al., 2000; Jukes, 2003; Bethony et al., 2006). However the impact of light and moderate infection loads on their physical development was much more dramatic than that of ascariasis. Children on average were significantly shorter (+/- 7cm) and weighed lighter (+/- 2kg) than their uninfected counterparts.

Furthermore the impact of a heavy parasitic load was devastating on a child’s physical development, with the rapid onset of anaemia, lethargy and severe malnutrition (under nutrition) demonstrated in children with a heavy infectious load (Drake et al., 2000; Stephenson et al., 2000; Jukes, 2003; Bethony et al., 2006; Degarege et al., 2009). Similar to ascariasis, the distribution of infection loading is very bottom heavy with only approximately 2% of the total infected population carrying a heavy parasitic load (Hall et al., 2009; Shang et al., 2010; Ahmed et al., 2012). Children with heavy trichuriasis loads demonstrated a significant reduction in their cognitive ability as compared to their uninfected and lightly to moderately infected counter parts (Sternberg et al., 1997; Drake et al., 2000; Jukes, 2003; Lobato et al., 2012), suggesting again that although helminth infections can impact a child’s physical development with light to moderate loads, it is not until they reach a heavy load that their cognitive ability and development is hindered, thus reinforcing the notion that the impact on their cognitive abilities and development is proportional to the impact of these infections on a child's nutritional status.

Mass treatment programmes targeted all STH’s together rather than each individually, as economically speaking it was more worthwhile to target both together using a broad spectrum anti-helminthic (Guyatt et al., 1993; Hall et al., 2009). Evidence suggests that trichuriasis is actually much more potent in its impact on a child’s physical and cognitive development when coupled with another helminth infection (Drake and Bundy, 2001; Meltzer, 2006), with ascariasis and trichuriasis co-infections being more common but less potent than a trichuriasis and hookworm co-infection (Drake and Bundy, 2001; Meltzer, 2006). Multiple helminth infections have been unanimously agreed upon as being a key route of stunted child physical and cognitive development (Drake et al., 2000; Drake and Bundy, 2001; de Silva et al., 2003b; Jukes, 2003; Cooper et al., 2004; Bethony et al., 2006; Dauby et al., 2012; Lobato et al., 2012). According to these sources, this is because the nutritional demands of these co-morbid helminth infections such as having ascariasis as well as trichuriasis or trichuriasis and hookworm infection or having all three helminth infections at the same time are so great that it leaves the body severely malnourished. However considering that humans are the optimal hosts for helminth infections (Crompton and Nesheim, 2002; de Silva et al., 2003a; Bethony et al., 2006), it is usually not in the helminths nature to kill their host whom they require for their survival, instead they slowly drain the body of its essential nutrients and increasing the child’s DALY significantly (Stephenson et al., 2000), thus heavily contributing to high morbidity rates rather than high mortality rates.

Hookworm is by far the most notorious of helminth infections, as its avenue for obtaining nutrients is directly from blood vessels rather than from intestinal absorption (Bethony et al., 2006; Hotez, 2008) leaving the child severely anaemic as well as severely malnourished (Stephenson et al., 2000; Jardim-Botelho et al., 2008; Kung’u et al., 2009). Unlike ascariasis and trichuriasis, hookworms have demonstrated an impact on a child’s physical and cognitive development in all 3 levels of infection
loading (Stephenson et al., 2000; Jardim-Botelho et al., 2008; Kung’u et al., 2009) and their route of infection is not necessarily reliant on the faecal-oral route. Instead hookworms, infect the body through burrowing into exposed skin upon contact with the larvae (Bethony et al., 2006). It then travels through the blood vessels and lymphatic system and finally makes its way to the duodenum and gastrointestinal tract, where it will latch on to blood vessels and feed directly on the bloods’ nutrients and iron, thus creating an iron and nutritional deficiency in the body of the infected individual (2).

Children infected with hookworm in light, moderate or high loads, all demonstrated a significant reduction in their intellectual ability, and they also demonstrated a significant difference in their anthropometric measurements when compared to their uninfected and healthy counter-parts (Bethony et al., 2006; McKay, 2006; Hotez, 2008; Degarege et al., 2009). Furthermore, it has been reported that the treatment for hookworm on its own, is more expensive than the treatment for the other helminths with a dose per child costing up to $0.20 in order to effectively kill the hookworm infections (Hall et al., 2009). This however has posed a problem in the treatment of hookworms, similar to the problems in treatment against tuberculosis. Ensuring that the population has access to and are able to receive these treatments during specific times is a major hurdle in the treatment of hookworms (Waller, 1997).

A single study has suggested that hookworms have developed acquired resistance against currently used drugs in animals (Waller, 1997). This will mean that an often more expensive and less easily accessible drug will be required to be distributed in the fight against hookworm infections. This will be challenging for heavily burdened economies of low and middle income nations. Hookworm infections will continue to rise significantly over the years if development and distribution of a new drug becomes delayed (Hotez, 2008; Hall et al., 2009; Shang et al., 2010).

7. Recommendations

Based on the literature it has become increasingly clear that the ideal approach to dealing with helminth infections is to address the situations that create the spread of these helminth infections. These conditions are related to poverty and include poor sanitation, poor hygiene practices and the lack of education on best farming and sanitary practices. All intervention studies reviewed (Asaolu and Ofoezie, 2003; Mascarini-Serra, 2011; Lobato et al., 2012; Minamoto et al., 2012; World Health and Infections, 2012) suggested that the education of people coupled with deworming demonstrated a significant decrease in the rate of re-infection after deworming was successful. Education is by far the most cost-effective and effective (Asaolu and Ofoezie, 2003; Bethony et al., 2006; Jimenez-Cisneros and Maya-Rendon, 2007; Mascarini-Serra, 2011; Minamoto et al., 2012) approach to dealing with these parasitic infections and as such in a setting when poverty is rife such as in low and middle income nations, education needs to be the primary tool which complements deworming efforts to ensure that a) the children and adults remain worm free after deworming and b) the soil remains contaminant free from faecal matter, which will in turn allow for an easier and more natural eradication effort of helminth infections by simply killing off their routes of infection. However this education needs to be consistent and ongoing as studies have shown that they are effective in the short term because people forget what they have been intended for if left for too long (Asaolu and Ofoezie, 2003).

Improved hygiene and sanitation saw a corresponding decrease in the rates of infection and rates of reinfection of children (Asaolu and Ofoezie, 2003; Jimenez-Cisneros and Maya-Rendon, 2007; Mascarini-Serra, 2011; Soares Magalhaes et al., 2011; Ziegelbauer et al., 2012). Further study is also required to identify the best possible interventions
for severe malnutrition experienced by those infected with helminth infections, which will aim at answering questions such as will multi-vitamin supplementation be sufficient in preventing severe malnutrition? Will it be sufficient in addressing the delayed cognitive and physical growth of a child despite the helminth infection? And how should one best approach the eradication of helminth infections in very poor communities in endemic areas. Furthermore, due to some of the demonstrated health benefits of helminth infections especially ascariasis (McKay, 2006), more studies should be conducted on how to best derive benefits from these worms without exposing children and the general population to the harmful effects of helminth infections.

**8. Conclusion**

Helminth infections continue to be a major world problem contributing to widespread disability and are especially hazardous to the development of children. The good news is that with the right treatment and interventions most of these deficiencies caused by helminth infections are reversible (Stoltzfus et al., 2001; Lobato et al., 2012; Taylor-Robinson et al., 2012), and in some instances ascariasis has demonstrated protective measures against cerebral malaria in light to medium parasitic load cases. Further research will be required to support this positive effect of *Ascaris* against this fatal strain of malaria. However, although these treatments are effective, there still remains a problem with the rates and ease of reinfection especially due to poor sanitation and poor hygiene which are often closely linked to poverty. Though there were several limitations in the acquisition of data and development of this review paper, especially the identification of relevant articles to include in this study, the richness of databases available and the richness of available data, the purpose of this review article was not to be a systematic review nor a meta-analysis but rather to discuss the pathophysiological and socioeconomic impacts of STH infections on a child’s development.

The causal loop diagram demonstrated the relationships between the socioeconomic and pathophysiological impacts of helminth infections on a child’s health and future life course. This relationship locks a child into a vicious poverty cycle and severely limits his life expectancy. It is critical to allocate resources effectively and employ poverty reduction strategies for helminth infections. The cost to treat a child with helminths is very inexpensive on a national scale, and thus no excuse should be made as to not treat these diseases.

Although the true impact of these infections on the long term physical and cognitive development of a child are not well demonstrated nor have they been looked into comprehensively a significant link may be drawn between the parasitic infections and their effects on a child’s development within the context of poverty, co-morbidities and other causative determinants. In reality if any effective intervention is to be run it must consider the socioeconomic roles played in the spread of helminth infections and not only the pathophysiological impacts of helminth infections as the two are mutually reliant on each other. It is truly worrying to see that a child with a helminth infection from a high socioeconomic family may have a better health outcome than a child with a helminth infection from a low socioeconomic family. Although they have contracted the same pathological infection, the former may not be as badly impacted as the latter, who will most likely develop severe malnutrition and its complications impacting on their growth and development.

Finally further studies are required to look into the true impacts and possible benefits of helminth infections and the best avenue in dealing with them in highly endemic populations.

**References**

Ahmed, A., Al-Mekhlafi, H.M., Al-Adhroey, A.H., Ithoi,


Easton, A., 1999. Intestinal Worms Impair Child Health


Scholte, R.G.C., Freitas, C.C., Dutra, L.V., Guimaraes, R.J.P.S., Drummond, S.C., Oliveira, G., Carvalho, O.S.,
2012. Utilizing environmental, socioeconomic data and GIS techniques to estimate the risk for ascariasis and trichuriasis in Minas Gerais, Brazil. Acta tropica 121, 112-117.


