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Public Health Burden of Hearing Impairment and the Promise of Genomics and Environmental Research: A Case Study in Ghana, Africa

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Abstract

Hearing impairment (HI) is one of the most disabling conditions of major global health burden that contributes adversely to the social and economic development of a country, if not managed properly. A proper assessment of the nationwide burden and etiology of HI is instrumental in the prevention, treatment, and management of the condition. This article sought to perform an expert review of HI in Ghana to determine the present knowledge of its burden and possible causes of the condition. A literature search was conducted in PubMed using the following keywords: ''hearing loss'' OR ''hearing impairment'' OR ''deafness'' AND ''Ghana.'' The literature was scanned until July 20, 2017, with specific inclusion of targeted landmark and background articles on HI. From the search, 18 of out 5869 articles were selected and considered for the review. The results of the search indicated that there were no extensive studies to determine the national burden of HI in Ghana. However, the few studies assessed suggested that the disease is either acquired or inherited. The burden of acquired HI was higher in adults than children, women than men, and people working in a noisy environment. Regarding the genetic cause, specific founder mutations in *GJB2* gene (R143W, L79P, V178A, R184Q, A197S, I203K, and L214P) was the only identified genetic cause of HI in Ghana, but the other HI genes were not investigated. There has been some modest effort to study HI in Ghana, but comprehensive studies on the genetic and environmental etiologies (using the ''multi-OMICS'' approaches), classification, and burden of HI on Ghana are needed.

Keywords: hearing impairment, disease burden, genetics and genomics, biomarkers, gene-by-environment interaction

Introduction

Of all the congenital diseases that occur worldwide, hearing impairment (HI) remains the most disabling condition with the highest rate for age-standardized disability (Murray et al., 2015). Congenital HI has a global prevalence of about 1 per 1000 live births in developed countries, with a much higher rate in the developing world, as high as 6 per 1000 in sub-Saharan Africa (Olusanya et al., 2014). The inability of a child to hear can affect the child's cognitive development, including delayed speech development that eventually makes the child socially isolated. Therefore, childhood HI results in the child's underachievement in school and eventually dropping out of the mainstream school program.

Early diagnosis and intervention for children with HI are recommended to maximize their cognitive, social-emotional, speech, and language development (Barnard et al., 2015). However, in the absence of widely used new-born screening, the age at diagnosis is usually quite late in Africa, for example, 3.3 years in Cameroon (Wonkam et al., 2013). Approximately 360 million (5.3%) people are disabled in their ability to hear, with 32 million (9%) of these being children (WHO, 2014). According to the report from Stevens et al. (2013), the global prevalence of HI as in 2008 was 1.4% in children (5–14 years), 9.8% in females, and 12.2% in males (Stevens et al., 2013).

The most recent study reported the prevalence of HI to be about 6.8% (Wilson et al., 2017). HI is more prevalent in

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South Asia, Asia Pacific, and sub-Saharan Africa than the other parts of the world. In Africa, 6.8 million (1.9%) people are living with hearing loss defects (WHO, 2014), with environmental factors reported as the predominant cause of the disorder (Amedofu et al., 2006). Among the environmental factors, a study in Cameroon identified meningitis as the major cause of HI among other causes such as measles, mumps, and ototoxicity (Wonkam et al., 2013).

HI has been categorized based on the number of ears impaired: unilateral (only one ear affected) or bilateral (both ears affected), and/or the degree of hearing loss ranging from difficulty to understand soft speech (mild) to inability to hear very loud noises (profound) (Birkenhäger et al., 2007; Matsunaga, 2009; Schrijver, 2004). HI is also classified as conductive, sensorineural, or mixed based on the part of the auditory system damaged (Nyako, 2013).

Conductive HI occurs when there is improper conduction of sound in the middle ear, leading to an inability to hear faint sounds or a general reduction in sound levels (Nyako, 2013). In Ghana, this type of hearing disorder occurs more frequently in all kinds of otitis media in children (Amedofu et al., 2006). Damage to the inner ear (cochlea) or nerve pathways from the inner ear to the brain results in the condition known as sensorineural HI and it is the most common type of permanent HI that cannot be treated through surgery. Patients with sensorineural HI cannot hear loud sounds or the sound is unclear or muffled. Middle ear infections, excessive noise, inappropriate use of certain drugs, and problems during childbirth were identified as some of the factors that cause sensorineural HI (Smith et al., 2005). Mixed HI is the co-occurrence of both sensorineural and conductive impairments in the same ear. This condition may be caused by multiple factors or a single factor, and may result in a reduction in sound or inability to hear any sound (Amedofu et al., 2006).

The HI present before a child develops speech is referred to as prelingual HI, which is mostly congenital (present at birth). In general, children develop speech at 1 year of age; hence any HI before age 1 year is prelingual. Postlingual HI, on the other hand, occurs after an individual develops normal speech (Lebeko et al., 2015; Shan et al., 2010). The major causes of prelingual and postlingual HI can be grouped as genetic (inherited) or acquired (caused by environmental factors, e.g., an illness or injury). Over 50% of congenital HI is caused by genetic factors, with autosomal recessive (AR) HI being the most frequent cause of the condition (Lebeko et al., 2015; Shan et al., 2010). Acquired postlingual HI is usually caused by an accident or noise pollution, while the genetic factors that cause postlingual HI are mostly inherited in the autosomal dominant (AD) manner.

In HI of genetic etiology, many mutations occur in the genes that control the components of the human auditory system. Several facts about nonsyndromic hearing impairment (NSHI) have been proven over time, regardless of population: (1) half of congenital HI cases have a genetic etiology, of which 70% are nonsyndromic (Gorlin et al., 1995; Wonkam et al., 2013), (2) for NSHI, 77% of the cases are of AR inheritance, 22% display AD inheritance, $\sim$1% are X-linked, and <1% are mitochondrial (OMIM, 2017); (3) more than 1000 NSHI genes may remain to be identified based on diseases associated with HI and unique inner ear transcripts (Hertzano and Elkon, 2012).

To date, $\sim$170 NSHI loci have been mapped and 98 genes identified (Hereditary_Hearing_Loss_Homepage, 2017). In many populations of European and Asian descent, pathogenic variants in *GJB2* (connexin 26 gene) and *GJB6* are a major contributor to autosomal recessive NSHI (Chan and Chang, 2014). However, the prevalence of *GJB2*- or *GJB6*-related NSHI is approximating to zero in most sub-Saharan African populations and little is known about the contribution to HI by other known NSHI genes (Bosch et al., 2014; Gasmelseed et al., 2004; Javidnia et al., 2014; Lasisi et al., 2014; Lebeko et al., 2015).

From 1995, when the first HI gene was identified (Vona et al., 2015), many genes involved in congenital HI were identified across the World (Robson, 2006). Over 141 NSHI loci have been identified and published in peer-reviewed journals (Vona et al., 2015). The common and most frequently identified NSHI genes used in diagnosing genetic HI are *GJB2*, *GJB6*, *SLC26A4*, and *OTOF*. These genes code for transport, synaptic, cytoskeleton, and ion homeostatic gap junction proteins (Chan and Chang, 2014). The gap junction protein beta 2 and 6 or alpha 1 genes (*GJB2, GJB6, or GJA1*) code for a family of proteins (connexins), which, by oligomerization, forms transmembrane channels in vertebrates.

These channels are referred to as connexons that form gap junction channels directly between neighboring cells as intercellular communication pathways. A connexon is responsible for transporting potassium ions and some small molecules between cells. *GJB2*, *GJB6*, and *GJA1* sequences are highly conserved with their protein consisting of extracellular loops from a middle cytoplasmic loop and the N- and C-terminal cytoplasmic ends separated by four transmembrane domains (Chan and Chang, 2014).

Mutations in the *GJB2* and *GJB6* genes have been implicated as the major cause of NSHI, accounting for up to 50% of cases in the population of European and Asian descent. The most prevalent mutation in Europe and the Middle East was found to be 35delG (Gasparini et al., 2000; Norouzi et al., 2011). In Asia, 235delC and V37I were the most prevalent mutations in East and South East Asia, respectively, while W24X mutation was prevalent in India (Chan and Chang, 2014).

However, there is a little contribution of *GJB2* and *GJB6* genes among people of African descent. Indeed, the prevalence of *GJB2*- or *GJB6*-related NSHI in several sub-Saharan populations (e.g., Cameroon in Central Africa (Bosch et al., 2014), Kenya (Gasmelseed et al., 2004) and Uganda (Javidnia et al., 2014) in East Africa, Nigeria in West Africa (Lasisi et al., 2014), and in African population in South Africa (Bosch et al., 2014; Kabahuma et al., 2011) was zero, while *GJB2* C35delG (MAF 6.0%) is more common in Sudan and Kenya (Gasmelseed et al., 2004). Prevalence of *GJB2*- or GJB6-related NSHI is also rare among African-Americans (Morell et al., 1998; Shan et al., 2010).

Although different studies from Ghana reported on the burden, etiology, and genetics of HI, there is currently no extensive review in the subject area to report the public health burden of the condition. In this article, we have systematically reviewed published articles on HI in Ghana to determine the reported burden of the condition, etiological agents, and the different types of HI reported. Even though this report is a case study, it relevant to understand the public health burden and various genetic and environmental causes of HI in Ghana.

Methods

A literature search was conducted by the authors from December 2016 to March 2017, covering the literature from 1973 to 2017. We used the PubMed (National Library of Medicine), Medline, and Google scholar. Key words included the individual use or a combination of the following: ''hearing loss'' OR ''hearing impairment'' OR ''deafness'' AND ''Ghana,'' were used to search for publications in PubMed to obtain a comprehensive, but broad, review of the literature on the study of HI in Ghana. In addition, specific expert authors' names active in the field of HI were also used to complement the literature searches. Prior knowledge of research groups working on HI, in Africa and Ghana, further facilitated the identification and selection of research articles. Only available full-length articles, in English, were selected.

In cases where multiple studies reported a similar result, the most recent report with the most detailed studies was included. The main search was conducted by PhD students in Human Genetics and reviewed by a Medical/Human Geneticist with expertise in HI and a Molecular Geneticist, and an ear, nose, and throat (ENT) specialist.

A total of 5869 articles were identified. Successive elimination was performed on the basis of the article title and its relevance to the scope of the review (Fig. 1). The criteria below were used to screen the titles and abstracts of these articles and 18 were selected for the review.

Inclusion criteria

Original research articles that report on HI or deafness in Ghana.

Exclusion criteria

HI studies that are not from Ghana and studies that measured noise levels and used them to predict the risk of developing HI without measuring the degree of HI of any of the study participants.

Results

The burden of HI in Ghana

Many researchers have studied the prevalence of hearing loss among the Ghanaian population at different geographical location in the country (Fig. 2). Although majority of these studies were not population based and/or did not have a nationwide coverage, they gave an idea of the burden of HI in Ghana. In January, 1999, a prevalence study was carried out in a Ghanaian village called Adamarobe that was known to have a number of HI citizens. The results of the study stated that a total of 45 deaf people were identified in 14 families based on their physical examination and family history (Amedofu et al., 1999). Otoscopy and audiometric evaluation from the study also revealed that only 7 out of 30 people who enrolled in the study had total loss of hearing while the remaining 23 had a residual hearing at the low and middle frequencies. The incidence of hearing impairment in this village was calculated as 23.7 per 1000 when a better ear hearing level of >25 dB was used (Amedofu et al., 1999).

A report from Komfo Anokye Teaching hospital (KATH) stated that there is an overall increase in the number of patients (from 3.7% to 15.5%) with hearing loss who visited the hospital between 1999 and 2004 (Amedofu et al., 2006). According to the researchers, the increased number of hearing impaired patients was due to awareness about the Hearing Assessment Center in Kumasi (Amedofu et al., 2006). Awuah and his coworkers in the year 2006 screened 268 patients suffering from different forms of ENT disease, who visited the KATH. They enrolled 188 patients of whom 51 were diagnosed of acute otitis media (AOM). The prevalence of HI

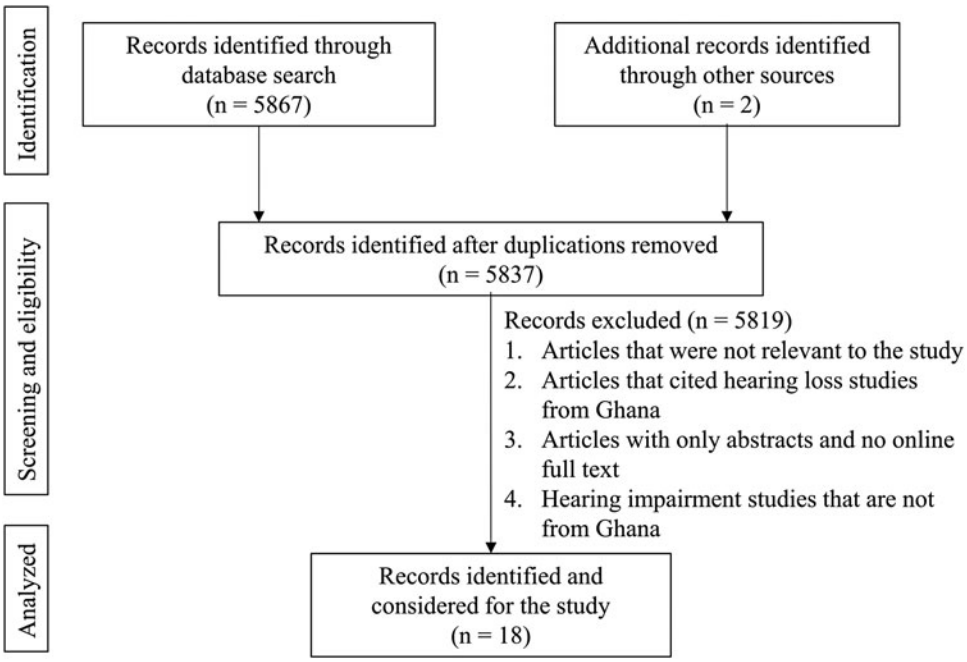

FIG. 1. Flow diagram for article selection.

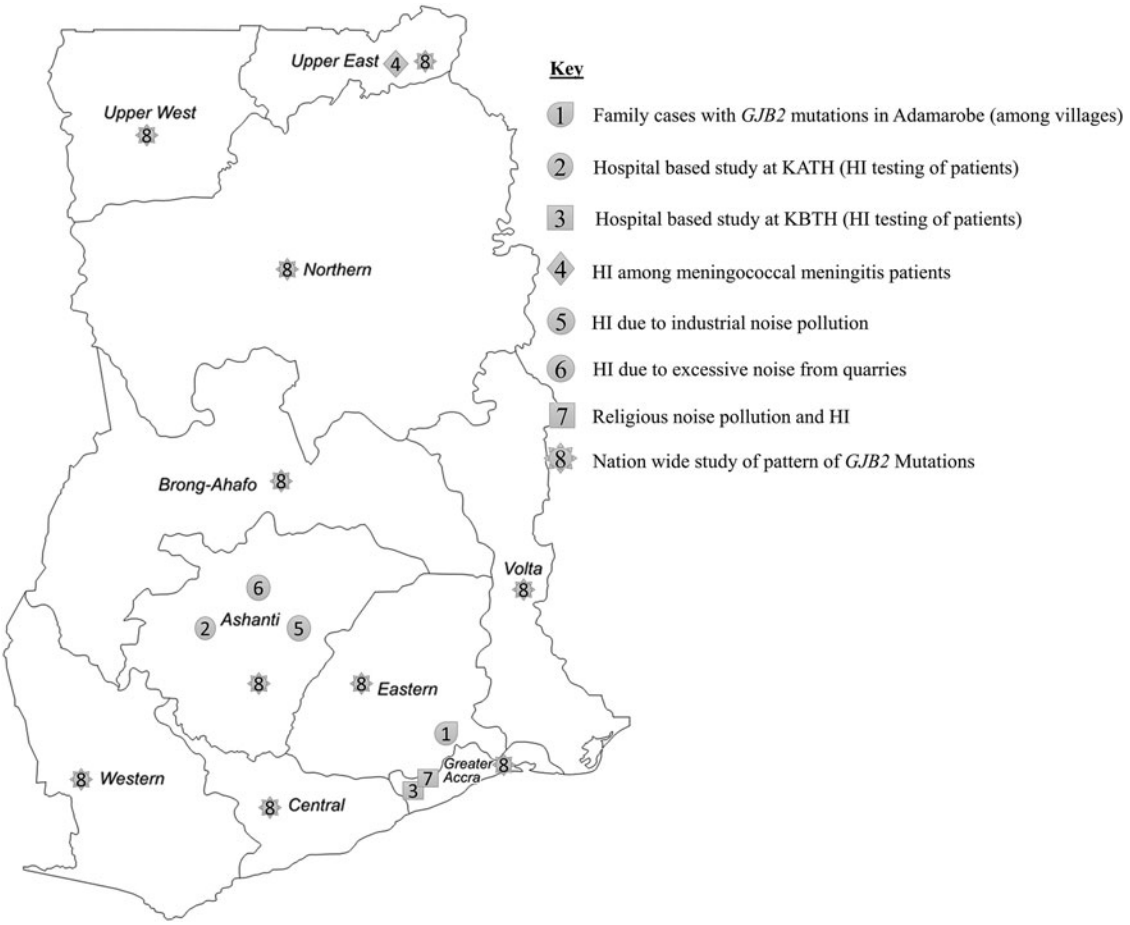

FIG. 2. Geographical representation of the major studies on hearing impairment from Ghana.

among the AOM patients was calculated as 91.3%; thus 37 out of the 51 patients were further diagnosed of HI (Awuah et al., 2012). In Accra, there was a similar study where 66.3% (474 out of 715) patients who visited the Korle-Bu Teaching Hospital (KBTH) in the year 2013 were screened and diagnosed of HI (Nyako, 2013).

The articles reviewed reported the similar pattern of HI across age groups where younger patients had mild form of HI and the older patients had moderate-to-severe HI (Amedofu et al., 2006; Nyako, 2013). The data suggested that HI worsened with increasing age in the Ghanaian population, which is consistent with other studies across the globe (Stevens et al., 2013). The age group of 60 years and older visiting KBTH in the year 2013 were reported to have the highest prevalence of HI (Nyako, 2013).

Types of hearing loss identified in Ghana

HI in Ghana was categorized by most researchers as conductive, sensorineural, or mixed. Conductive audiometry test was performed for 23 people from Adamarobe, a village in Ghana; 17 out of the 23 had hearing loss in the better ear. Three (3) people had moderate sensorineural hearing loss, while 14 had mild sensorineural hearing loss (Amedofu et al., 1999). The bone conductive audiometry test to distinguish between the different types of HI in recent studies has shown that more Ghanaians reported to the hospital with sensorineural HI that the other types of HI (Amedofu et al., 2006; Nyako, 2013). Bilateral HI was predominant among patients with hearing problem; however, some patients report with unilateral HI (Nyako, 2013). The most common audiometric configuration of HI was mild HI for both ears (Amedofu et al., 2006; Nyako, 2013).

Induced HI in Ghana

Factors such as noise, meningococcal meningitis, presbycusis, mumps, and Meniere's disease were identified as the major cause of sensorineural HI (Amedofu et al., 2006). A major sequela of meningococcal meningitis is HI. After a 2-year epidemic in northern Ghana, 696 patients who survived the condition were screened for HI. A reduced hearing was reported in 6% of the patients with 1.6% having severe and profound HI in their worse ear (Hodgson et al., 2001).

The recent of studies in the field of HI in Ghana tried to identify malaria and sickle cell disease as possible causes of HI in children. The results of a cross-sectional study to determine the role of sickle cell disease in causing HI had only a patient out of 35 sickle cell children who failed an otoacoustic emission test. The results therefore suggest that early HI does not frequently occur in sickle cell disease (Kegele

et al., 2015). Severe malaria was suggested to influence the function of the inner ear in children; however, the loss of hearing caused by malaria is reversed after treatment. Out of 144 children who had severe malaria, 58 (40.3%) failed the otoacoustic emission test, suggesting the development of HI (Schmutzhard et al., 2015). Sickle cell disease is not a likely cause of HI or delay in speech in children.

Noise exposure is another major cause of nongenetic HI in Ghana. The noise generated at gold mines, quarries, mills, and other noisy industrial area is mostly far above the normal levels and predisposing workers to the risk of acquiring HI. Research has proven that the risk of developing HI increases with noise exposure time (Amedofu, 2002). In a surface mining company in 2012, 23% (59 out of 252 workers) were diagnosed of HI (Amedofu, 2002). In a similar study, 818 sawmill, corn mill, and printing press workers were examined for HI. The results of this study showed that 23%, 20%, and 7.9% of corn mill, sawmill, and printing press workers, respectively, had evidence of HI. The level and duration of noise produced by the various occupations correlated significantly with the development of HI (Boateng and Amedofu, 2004). The contribution of excessive noise from quarries in the Ashanti region of Ghana to the development of HI was evaluated in between April to June 2012.

There was empirical evidence that excessive noise generated by the quarries caused 56% (224/400) of the workers to develop a hearing problem. The degree of hearing loss correlated positively with the duration of work (Boateng and Amedofu, 2004). Steel/metal workers and communities saturated with a lot of religious noise in Ghana were reported to be at higher risk of developing HI (Zakpala et al., 2014). Zakpala et al. after careful examination of noise generated in Ghana stated that the night-time noises generated by religious bodies were far higher than the recommended levels by the Environmental Protection Agency of Ghana. Empirical evidence was provided from the quarries (Gyamfi et al., 2016) and market mills (Kitcher et al., 2014) that Ghanaians working in these sites are exposed to noise that exceeds tolerable threshold; hence, the workers from these sites developed noise-induced HI, especially among the elderly and long-serving workers.

The false perception of sound in the absence of acoustic stimulation in the environment is known as tinnitus. Tinnitus is associated with age, exposure to noise, ototoxicity, tumor, and damage to the acoustic portion of the eighth cranial nerve. The prevalence of tinnitus in Ghana was estimated to be 19.3% among patients visiting the KATH (Awuah, 2012). Majority of the patients studied by Awuah had normal hearing; however, patients with mild sensorineural hearing loss had more tinnitus than the other degrees of hearing loss. Similar observations were made by researchers in Britain (Davis, 1989), United States (Henry et al., 2005; Shargorodsky et al., 2010), Sweden (Widén and Erlandsson, 2004), and other parts of the world.

Genetics of HI in Ghana

Genetic defects are responsible for more than 50% of all prelingual, sensorineural HI (Schade et al., 2003). Hearing is mainly affected by the inner ear sensory hair cells, and gene mutations in these cells can result in improper functioning of the cells, which may lead to HI at birth or later in life. The common mutations were found on chromosome 13q11 in the *GJB2* gene that encodes connexin 26 (CX26). CX26 plays an important role in the formation of gap junctions for intercellular exchange of electrolytes. Globally, different types of mutations in *GJB2* gene have been identified as the cause of inherited prelingual HI with 35delG as the most common mutation of about 2.5% carrier frequency (Schade et al., 2003). These mutations can be inherited in an AD, AR, X-linked recessive, or mitochondrial inheritance manner.

In Ghana, the first study to associate HI to genes was in the year 1998, where Brobby et al. (1998) examined several families in a village in the Eastern region of Ghana that had high prevalence of HI. The study screened and sequenced the coding region of connexon 26 gene of 21 deaf subjects from 11 families. In the connexon 26 gene, R143W mutation (T was replaced with C) was found at codon 143. A nationwide study was conducted in 2001 to identify *GJB2* mutations responsible for HI in Ghana. Among 365 unrelated individuals examined, 121 mutated chromosomes were identified, with 110 of them carrying the previously reported R143W mutation. The other *GJB2* mutations identified were L79P, V178A, R184Q, A197S, I203K, and L214P (Hamelmann et al., 2001). In total, only 63 out of 365 unrelated individuals, with evidence for profound congenital sensorineural HI, had mutations in *GJB2* gene. In 2003, Schade et al. associated two other mutations in the *GJB2* gene, 35delG and W24X, to cases of HI in Ghana.

Discussion

HI research in Ghana has received little attention from 1998 till now, with only a few publications. There is no extensive review from Ghana on the subject of hearing loss; therefore, this article appears to be the first to extensively review the burden of hearing HI in Ghana. The article reflects the current status of research in the subject area and the reported prevalence of the disease.

Analysis of the results suggested an inconsistent report of the burden of HI in Ghana (Table 1), which does not correspond with the alarmingly high increase of the disease burden globally (Vos et al., 2015). The inconsistency of the disease burden observed may be due to the hospital-seeking behavior of patients. In 2012, Awuah reported a high disease burden that was explained by the increased awareness and education on hearing loss after the establishment of the Kumasi hearing assessment center. The studies examined reported the disease to be prevalent in people working in noisy environment compared to their respective control groups. The industry-based studies were mostly screening for the disease among the high-risk populations and subsequently giving high prevalence of HI that fluctuates from industry to industry.

In Ghana, majority of studies reported the burden of the disease in the two major cities (Accra and Kumasi) (Table 1), hence the difficulty in calculating the national prevalence of the disease. The studies from Kumasi and Accra suggested that more women report to the hospitals and hearing facility with HI than men; however, only a few of the studies examined reported the burden of the condition based on gender. In addition to the little report on gender, the results from the study sites cannot be extrapolated to determine the national prevalence of HI based on gender. It

TABLE 1. REPORTS ON THE BURDEN OF HEARING IMPAIRMENT IN GHANA

Reference	*Year of study*	*Study participants*	*Study site*	*Total number of study participants* (N)	*Participants living with HI* (n)
Awuah (2012)	1995 to 1998	Patients attending Kumasi Hearing Assessment Centre	Ashanti region	2207	1987 (90.0%)
Amedofu et al. (1999)	1999	Villagers in Adamarobe	Eastern region		Incidence of 23.7/1000
Brobby et al. (1998)	1998	Families with HI in Adamarobe	Eastern region	29	Genetics studies
Amedofu et al. (2006)	1999 to 2004	Patients attending KATH	Ashanti region	6428	5734 (89.9)
Hamelmann et al. (2001)	2001	Unrelated individuals	All 10 regions	365	Genetics studies
Amedofu (2002)	2002	Workers in a surface gold mining company	Ashanti region	252	59 (23.4%)
Boateng and Amedofu (2004)	2004	Industrial workers	Ashanti region	818	416 (50.8)
Awuah et al. (2012)	2005 to 2006	Patients attending KATH	Ashanti region	268	51 (19.0%)
Nyako (2013)	2012	Patients attending KBTH	Greater Accra region	715	621 (86.9%)
Gyamfi et al. (2016)	2012	Quarry Workers	Ashanti region	400	240 (60.0%)
Kitcher et al. (2014)	2014	Market mill worker	Greater Accra region	204	32 (0.13%)
Kegele et al. (2015)	2015	Children with sickle cell disease	Ashanti region	35	1 (0.03%)

HI, hearing impairment; KATH, Komfo Anokye Teaching hospital; KBTH, Korle-Bu Teaching Hospital.

is therefore important to assess the burden of the disease across all regions in Ghana to determine the true reflection of the disease burden, so as to accurately examine the public health impact of the disease and also take informed decision in terms of national policies.

Mutations in *GJB2*, *GJB6*, and *GJA1* are not the major causes of NSHI among Africans and people of African descents (Lebeko et al., 2015; Wonkam, 2015); however, the studies to identify the HI genes in Ghana were only focused on *GJB2* mutations. Although the study by Hamelmann et al. in 2001 associated *GJB2* mutations to HI in Ghana, only 63 out of 365 unrelated individuals with evidence for profound congenital sensorineural HI had mutations in their *GJB2* gene. This suggests that, *GJB2* mutations cannot explain fully, the genetic etiology of HI in Ghana, hence, the need to identify other HI genes in Ghanaian patients. In addition, the most promising approach to discover novel HI genes in Africa is through the ''OMICS'' approach, which includes whole (exome)-genome analysis using the next-generation sequencing (NGS) platforms (Lebeko et al., 2015), which is globally replacing the older techniques.

The recent approaches to human genomics are targeted at ''personalized medicine,'' ''precision medicine,'' and ''stratified medicine'' (Cardon and Harris, 2016; De Andrés et al., 2016). In order for Ghana and Africa as a whole to be part of the advances in the field of genomics of HI, research should be focused on the identification of the major causes, novel genes, and the molecular mechanisms of HI pathogenesis, with the aim of developing novel diagnostics and therapeutics for the disease.

Future Directions

The most effective way to control and manage the increasing global burden of HI is to develop effective diagnosis, treatment, and preventive measures. It was estimated that over 50% of all HI cases can be prevented. The following have been identified as future focus to effectively manage the disease in Ghana:

1. Identification of major causes of HI in Ghana: in Ghana, occupational noise and noise pollution were reported as major causes of HI among adults (Boateng and Amedofu, 2004; Gyamfi et al., 2016; Kitcher et al., 2014), and fever, presbycusis, meningitis, and Meniere's diseases were identified at all ages (Amedofu et al., 2006). The major etiology of HI among Ghanaian children is not well established and therefore, more studies must focus on identifying the major causes of HI among the different occupation, sex, and age categories.
2. Understanding of the mechanism of pathogenesis of the disease: to effectively treat and prevent the disease, the molecular mechanisms underlining its pathogenicity must be elucidated. Over 50% of prelingual NSHI is caused by genetic factors (Wonkam et al., 2013). However, the genetics of HI has not been well studied in Ghana, hence the gap in understanding the contributions of hearing mutant genes in HI. It is also not clear how environmental factors and diseases such as measles cause HI. It is therefore important for future

research to focus on elucidating the mechanisms of pathogenicity of HI in Ghana.
3. Developing effective diagnostics and treatment remedies for HI: future research needs to be focused on developing point-of-care diagnostics for screening newborn babies and rural dwellers for HI. In the field of research to develop global health diagnostics and therapeutics in developing countries, the multi-OMICS technologies, as described in a recent study (Fang et al., 2016), are useful in the early detection, effective treatment, and management of the disease.

Caveats of this Review and Analysis

The study could not estimate the national prevalence of HI in Ghana because of limited number of publications on the subject. The studies from Ghana were mostly hospital based or industry based with little population data that did not reflect the national burden of the disease.

Conclusions

The burden of HI in Ghana was typically studied around the central (Kumasi) and coastal belts (Accra) of the country. A number of these studies were hospital based, where patients who visited the hospital were screened for HI, and the others were industry based to determine the role of noise pollution on acquiring HI. There was only a single nationwide study to identify mutations in the *GJB2* gene that are responsible for HI. Across the country, the HI cases recorded can be grouped into two main categories as inherited and acquired HI. The acquired HI is more prevalent in adults than children and female than male. Even though the prevalence of HI in Ghana is studied in different locations within the country, there is no nationwide study; hence the national prevalence of HI remains unknown.

Noise pollution, infectious diseases, and genetic factors were the major causes of HI identified in our study. All the major causes of HI identified could be prevented by (1) the use of the appropriate working apparels for those who work in noisy environments, (2) proper vaccination and treatment of childhood diseases, and (3) identifying HI genes to develop effective diagnostics for neonatal screening for deafness in Ghana. The studies on the genetics of hearing loss in Ghana focused only on *GJB2* mutations, hence the need to conduct massive NGS of the genome of HI patients to identify other HI gene mutations.

Long-Term Views

There are no extensive studies on the classification, burden, and the genetic etiology of HI in Ghana. HI research in the next 5 years should be aimed at the following:

1. A national study to determine the prevalence of HI in Ghana and classify the HI cases in Ghana.
2. Generating and analyzing whole exome genomic data of HI patients to generate a comprehensive list of HI genes and predominant HI gene mutations in Ghana.
3. Study the molecular mechanism of pathogenicity of the of HI gene mutations in Ghana.

Key Issues

1. Conductive HI occurs more frequently in children reporting with all kinds of otitis media; sensorineural and bilateral hearing loss were the common types of HI among Ghanaians.
2. Excessive noise and mutations in *GJB2* gene were identified as major causes of HI in Ghana.
3. Postlingual HI progressed with age and the degree of exposure to noise.

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Authors' Contributions

Conceived and designed the experiments: S.M.A. and A.W. Performed the literature search: S.M.A. and A.W. Analyzed the data: S.M.A., G.A., G.K.A., and A.W. Revised and approved the article: S.M.A., G.A., G.K.A., and A.W.

Author Disclosure Statement

The authors declare that no conflicting financial interests exist.

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Abbreviations Used

AD = autosomal dominant
AOM = acute otitis media
AR = autosomal recessive
CX26 = connexin 26
ENT = ear, nose, and throat
HI = hearing impairment
KATH = Komfo Anokye Teaching Hospital
KBTH = Korle-Bu Teaching Hospital
NGS = next-generation sequencing
NS = nonsyndromic hearing impairment