Noise-induced hearing loss in children: A 'less than silent' environmental danger

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A review of the problems of noise-induced hearing loss in children, especially related to recreational music and the use of personal entertainment devices. The pathophysiology of noise-induced hearing loss and its associated problems (eg, tinnitus) are discussed. The evidence for an increase in noise-induced hearing loss in children and young people is reviewed. Some practical advice (for clinicians, caregivers and children) on hearing loss prevention is provided.

Key Words: *Acoustic trauma; Hair cell damage; Noise-induced hearing loss; Recreational music*

La perte auditive due au bruit chez les enfants : Un risque environnemental loin d'être silencieux

L'auteur analyse les problèmes reliés à la perte auditive due au bruit chez les enfants, notamment en ce qui a trait à la musique récréative et à l'utilisation d'instruments de loisir personnel. Il expose la physiopathologie de la perte auditive due au bruit et des troubles connexes (p. ex., acouphènes). Il étudie les données probantes démontrant une augmentation de la perte auditive due au bruit chez les enfants et les adolescents. Il fournit des conseils pratiques (à l'intention des cliniciens, des personnes qui s'occupent des enfants et des enfants) en vue de prévenir la perte auditive.

Pollution experts and environmental toxicologists constantly warn the public about chemical and other airborne factors that can be a danger to their health, but one problem that is rarely mentioned in the context of environmental hazards is noise-induced hearing loss. It is time that the dangers of exposure to excessive and chronic noise are seriously taken into consideration, as well as the growing evidence that it can cause irreversible hearing loss. Historically, the focus on acoustic trauma problems has largely been related to adults (eg, hearing loss in soldiers from the battlefields of world wars; workers in noisy industrial factories; and in the elderly, for whom a lifetime of noise exposure can hasten the onset of presbyacusis [age-related hearing loss]). However, since the advent of amplified sound in the music and entertainment industries, and the growing popularity of portable music and gaming devices among the younger population, noise-induced hearing loss in children is a serious and growing concern.

The present article is written to provide health care professionals with more information about noise-induced hearing loss in children. It briefly describes the pathophysiology of hearing loss, and explains what structures of the inner ear are vulnerable and can be damaged by loud noise exposure. Also, it reviews the current literature that relates to noise-induced hearing loss in youth, and discusses the practical consequences of reduced hearing ability in children (eg, in relation to education and quality of life). Finally, the article suggests some educational tools and guidelines that can help inform professionals (clinicians, teachers and caregivers) and children about the risks of noise-induced hearing loss, and offers some practical advice on hearing loss prevention.

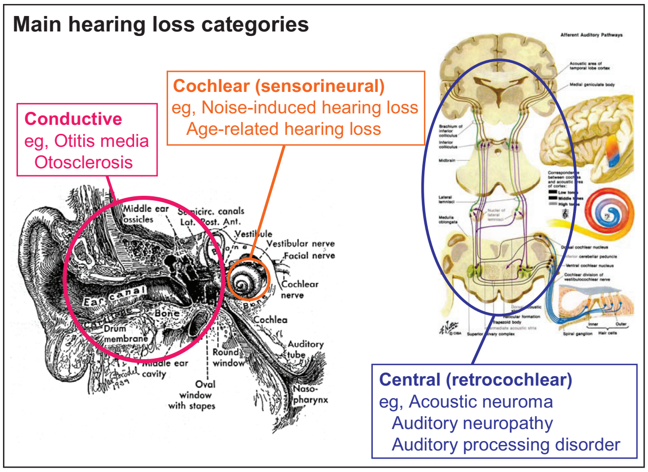

Figure 1) *A broad classification of the types of hearing loss. While noise-induced hearing loss is usually categorized as a cochlear or sensorineural hearing loss, it may also be combined with a conductive loss, and will also impact on central auditory processing*

WHAT IS NOISE-INDUCED HEARING LOSS?

As Figure 1 illustrates, there is a common categorization of the types of hearing loss, which distinguishes conductive loss, cochlear or sensorineural loss, and central hearing

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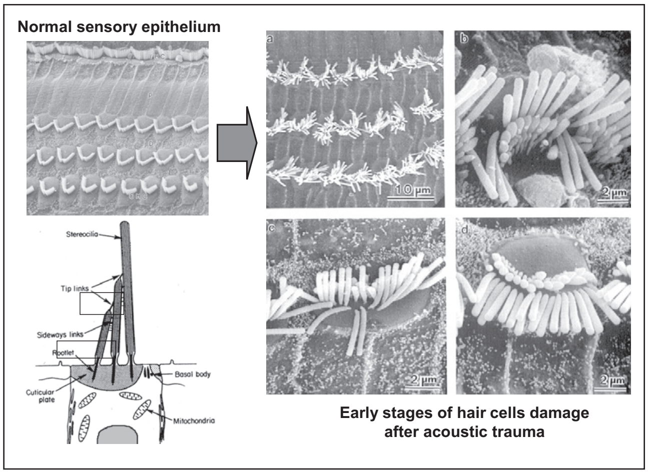

Figure 2) *Scanning electron images illustrating normal cochlear hair cells (left) and immediately after noise trauma (right). The lower left diagram shows the normal linkages between stereocilia that are disrupted or broken in noise-induced hearing loss*

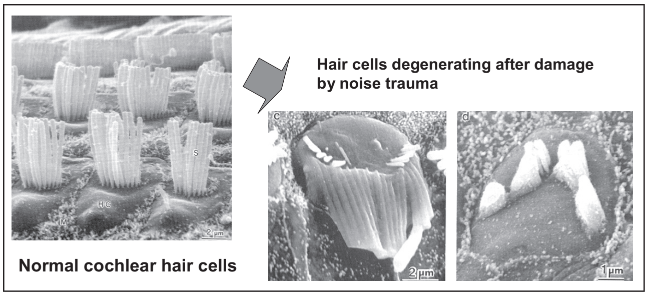

Figure 3) *The stereocilia of normal cochlear hair cells (left) compared with cells after acoustic trauma and in the process of complete degeneration (right). There is no natural regeneration of hair cells in the mammalian cochlea*

disorders. A conductive loss is anything that reduces the transmission of acoustic signals to the cochlea; this can simply be wax or other obstructions in the ear canal, or fluid build-up in the middle ear. Paediatricians will, of course, be familiar with conductive hearing loss that can accompany otitis media. In relation to noise exposure, it is possible to have intense acoustic trauma that damages the eardrum or the middle-ear ossicles, but this is rather unlikely in infants and children (unless they live in a war zone). For the most part, noise-induced hearing loss involves damage to delicate structures of the inner ear, particularly the hair cells, and is thus categorized as a cochlear or sensorineural hearing loss. The third category of hearing loss relates to a central auditory system disorder. A cochlear hearing loss cannot be absolutely separated from a central loss because any reduction or degradation of the peripheral auditory input will have an impact on central auditory function. Importantly, health care professionals dealing with infants should also recognize that in early life, the activity patterns that are present at the cochlear level are important for the development of the central auditory brain, and that cochlear disorders and even conductive loss may have significant impacts on the development of (central) mechanisms of hearing (1,2).

With regard to noise-induced hearing loss or acoustic trauma, Figures 2 and 3 show what can happen to the delicate hair cells of the cochlea after physical insult. The left panels of Figure 2 show normal hair cells, and a diagram (for one cell) showing how the stereocilia (hair) are organized. These stereocilia, when deflected by acoustic signals, cause an excitation (depolarization) of the hair cell that leads to neural activity in cochlear afferent neurons that make up the auditory (eighth cranial) nerve. For each cell, the stereocilia are neatly organized in a bundle. The individual 'hairs' are cross-linked, and when the whole bundle is displaced by sound signals, some of these links pull open membrane ion channels on the surface of the hair. Flow of ions (mainly potassium) through these membrane channels changes the hair cell receptor potential. These details are mentioned to emphasize that the micromechanical arrangements of stereocilia, their linkages and the membrane ion channels are delicate and can be damaged by acoustic overstimulation.

Some of the first obvious signs of acoustic overstimulation are illustrated in the right-hand images of Figure 2. Note how the stereocilia appear to lose their rigidity and become splayed. Clearly, when this happens, the linkages between the hairs are broken and can no longer mediate the opening and closing of membrane ion channels; the hair cells can no longer work as sensory receptors. Importantly, the cells cannot recover from this state, and soon after this degree of damage, the cell self-destructs, (apoptosis sets in; lysosomal activity 'eats up' the cells). The right-hand images of Figure 3 show how the stereocilia start to be 'digested' back into the cell; there is no recovery.

In addition to the direct mechanical trauma that loud sounds can cause to the hair cells, there are also secondary effects that can cause further damage. Just as with a brain injury (eg, stroke), there can be an initial restricted lesion, but cellular byproducts that are released (eg, oxidative free radicals or excessive amounts of neurotransmitter) can cause more extensive damage. It is also possible that prolonged acoustic overstimulation can lead to local vascular damage and cochlear hypoxia, which in turn can cause damage to hair cells (3).

Everyone is born with a fixed number of cochlear hair cells. In humans (and all other mammals), they do not regenerate, and so preventive care should be taken. In some vertebrates (eg, birds), similar hair cells do regenerate after damage. New hair cells develop from local supporting cells, which act like a type of stem cell. There is evidence that in vestibular sense organs, the hair cells are capable of regenerating from supporting cells, but in the cochlea, this does not happen. Presently, there are considerable research efforts to determine whether cochlear hair cells can be made to regenerate, either by providing suitable growth hormones or by finding a genetic switch to turn on the cell differentiation process (4-6). Presently, however, the fact remains that if we kill hair cells by noise exposure, they are lost forever.

TEMPORARY THRESHOLD SHIFT AND TINNITUS

Other than the loss of hearing sensitivity, there are two other common symptoms related to noise-induced hearing loss. One is temporary threshold shift (commonly referred to as TTS), the other is tinnitus or ringing in the ears. Regarding the former, after exposure to a period of loud sound, there can be a 'temporary' mild hearing loss (eg, after a long air flight or bus journey, or following a loud music concert). It is a period when everything sounds quieter (eg, your car might sound better, at least until the next day). People tend not to worry about such experiences, in part, because there appears to be a full recovery. However, it is widely believed that repeated episodes of TTS can result in permanent changes. It is likely that the noise exposure causing TTS alters the delicate micromechanics of the cochlea, including the linkages between hair cell stereocilia, and that the reversibility of such insults may not be 100%. People should avoid any noise exposure that leads to TTS.

There are a number of types of tinnitus, and not all result from cochlear damage. Often tinnitus is transient, and it is normal to occasionally hear a brief ringing in the ear, which dies away within a few seconds. However, when chronic tinnitus is experienced after exposure to loud sounds, it is not just a warning sign, but a clear manifestation of cochlear injury. Consider the ringing sound to be caused by hair cells and neurons actually in the process of dying. Such cells generate a neural injury discharge because the cell membrane breakdown causes repeated depolarization (excitation) and/or uncontrolled release of neurotransmitters. In the case of severe acoustic trauma, tinnitus can persist and becomes permanent. It has been suggested that the initial neural injury discharge sets up (synaptic) connections in a network of auditory neurons at a more central (cortical) brain level, and that these cells continue to fire spontaneously (perhaps because a local positive feedback circuit is established or because local inhibitory neuron activity is reduced). Chronic tinnitus can be as devastating on quality of life as hearing loss. Clearly, any recreational activity that induces tinnitus should be avoided.

NOISE-INDUCED HEARING LOSS IS A GROWING PROBLEM

In this section, some of the current literature on the noise-induced hearing loss in children and young adults is reviewed. This is not an exhaustive or systematic review, but a representative sample of studies that all point to the growing problem. In terms of general population studies, a report (7) from a large-scale American national health survey indicated that 12% to 15% of school-aged children have some hearing deficits attributable to noise exposure. In Canada, there are no large surveys that specifically address noise-induced hearing loss. Statistics Canada data indicate that 13% of children (up to 14 years of age) have some hearing disability, but it does not separate out specific etiology (8). WorkSafeBC (Workers Compensation Board of British Columbia), in a large survey (9) of young workers entering the workforce, report that over 20% have some early signs of hearing loss, but this includes all causes of hearing loss, not just noise-induced loss.

There are not many Canadian statistics, but there are plenty of data from other countries. In a Scandinavian study (10), a hearing test on 538 teenage boys revealed a hearing loss (greater than 15 decibels [dB]) in 15%. The characteristics of the loss indicated that the majority were related to noise exposure. Similarly, a German review (11) of clinical data estimated that one in 10 adolescents had some degree of noise-induced hearing loss from 'leisure time noise'. In a recent Chinese study (12) of 120 young users of 'personal listening devices', impaired hearing (loss greater than 25 dB) was found in 14% of subjects. A French audiometric survey (13) of 1364 young subjects found evidence of hearing problems in 12% of the general population, and in a subgroup that often attended rock concerts or used 'personal cassette players' (more than 7 h per week), 66% had hearing loss. A similar finding was reported in a smaller group (n=24) of German teenagers (14). Many studies (15) describe the increase in the use of personal entertainment devices and attendance of concerts where amplified sounds are enough to cause noise-induced hearing loss.

Recognizing that there is a real problem, many studies have focused on some of the specific causes, such as very loud signals from some cordless telephones (16), the types of headphones or earphones used in personal entertainment devices (17), and the actual levels of sound that are generated by earphone transducers (18). In addition, there are numerous other reports on other possible sources of noise trauma for children, including very noisy toys, cap guns and fireworks. Other research has assessed the risks of noise-induced hearing loss at specific entertainment venues, such as rock concerts (19) and 'urban music clubs' (20). There is even a published report (21) with the title "Can hockey playoffs harm your hearing?", from a Canadian research team of course. All of these reports and studies confirm that there is a potential problem with noise-induced hearing loss at certain entertainment events. In noise-induced hearing loss from very high-level sound exposures, tinnitus is often reported. For example, in a Swedish study (22) of 55 boys (eight to 20 years of age) who were seeking help for tinnitus, the majority were found to have been exposed to excessive noise, mostly from recreational music. One study (23) suggested that after short-term exposure to (over-) amplified music, tinnitus may be more of a problem than any other hearing deficit.

To balance the evidence, some researchers have concluded from their data that there is no clear link between recreational noise exposure and hearing loss. For example, one research group (24) concluded that most young users of personal listening devices were at low risk for noise-induced hearing loss. However, these authors cautiously admitted that their study group did not include certain high-risk populations with greater noise exposures, and go on to strongly recommend educational sessions about

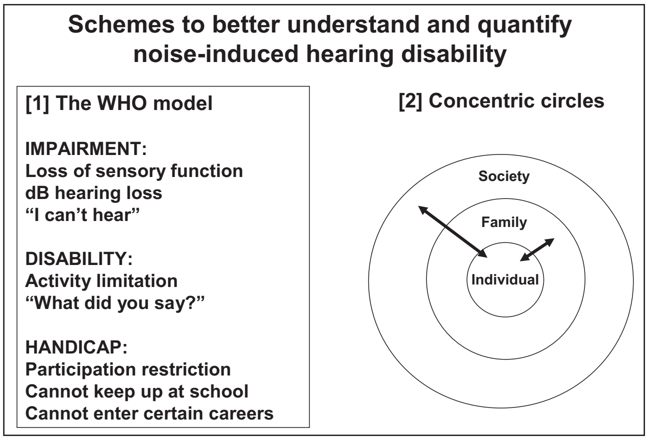

Figure 4) *The consequences of hearing loss should be considered in broader terms than just the clinical measures of hearing threshold loss. dB Decibel; WHO World Health Organization*

the dangers of noise exposure. An extensive Australian survey (25) also concluded that there was "no widespread hearing loss caused by recreational noise", but the authors did warn that "if recreational patterns remain the same", teenagers will be at high risk for noise-induced hearing loss by their mid-20s. Indeed, there is a strongly held view (which this author also holds) that noise exposure effects are cumulative. Thus, over the short term, the effects of noise overstimulation may not be obvious, but the accumulated effects of damaging episodes will eventually lead to significant hearing deficits. An important point here concerns the redundancy of hair cells in the cochlea. There are many more sensory elements than needed, so considerable cell loss can occur before there are clinical signs of a problem. However, with repeated insults, the fixed complement of hair cells eventually runs out. This is one reason why noise-induced damage in early years may not immediately manifest, but may become a problem later in life.

To summarize, on a cautious note, a recent general review (26) of the issue of noise-induced hearing loss in relation to school-aged children concluded that it is a major cause of hearing loss (in the United States), and that hearing impairment among children and teenagers is increasing mostly due to 'voluntary exposure' to loud noise (ie, using personal entertainment devices or attending amplified sound concerts).

WHAT ARE THE FULL CONSEQUENCES OF HEARING LOSS IN CHILDREN?

For most health care professionals, hearing loss is largely described by the results of clinical tests, such as the audiogram or speech threshold measures. The general categories of loss range from mild, to moderate, to severe, to profound (each has a specific audiometric definition). In infants, hearing can be assessed objectively using auditory evoked potentials or otoacoustic emissions. Typically, a deficit will be described as a hearing threshold loss in dB. It is important to point out that such basic measures, while useful, do not always reflect a hearing problem. It is common to have a child with normal hearing thresholds, but with significant problems in understanding speech. In other words, the ability to understand complex sounds can be reduced before pure tone audiometric thresholds are apparent. Clinicians should recommend a comprehensive hearing evaluation, including speech discrimination tests.

Beyond clinical test results, there are broader ways of looking at hearing disability. The World Health Organization has a scheme for assessing and describing hearing problems (Figure 4, left panel). This model distinguishes impairment, disability and handicap. Impairment is the actual loss of sensory function quantified by the clinical tests mentioned above. Disability is the 'activity limitation' of an individual that results from the impairment (eg, a patient might not understand what you say, and needs to ask you to repeat words). Handicap is a measure of 'participation restriction' (ie, activities that a child may not be able to do because of the hearing problem). This might include making friends, keeping up at school or being excluded from training for a certain career. Another 'holistic' approach to measuring a hearing disability is illustrated in Figure 4 (right panel). Here, one can separately consider the core as one-on-one interactions of a subject with a mother, a sibling, a teacher, etc. In the wider circle, there is broader communication and interaction with family and friends. Finally, there is the impact of the subject's hearing impairment on society (including economic issues, educational achievement, employability and quality of life).

For a child with noise-induced hearing loss, the degree of deficit is likely to be mild or moderate, as opposed to severe or profound. However, such a loss might still be a barrier to effective communication, especially in noisy environments such as the school classroom. It should also be recognized that mild-to-moderate hearing losses may not be immediately apparent to a child (in the same way that many older persons do not recognize that they have age-related hearing loss). Parents and clinicians should be vigilant; it is worth repeating that measures of speech discrimination will more accurately reveal a hearing problem than simple audiogram or hearing screening tests. In a very young child, hearing problems can delay language development, and if information is being missed at school, educational achievements can be reduced. For adolescents, communication difficulties can lead to social isolation; there have been reports of suicide resulting from such situations. If hearing aid use is warranted, the adolescent may also have problems with the cosmetic appearance of the device or the stigma attached. The child may decide to not use the aid, or choose to retreat to a small group or become socially isolated. In any case, it can be assumed that there will be quality of life implications.

In public advocacy and education campaigns by The Hearing Foundation of Canada (THFC) (27), one strategy for promoting hearing loss prevention in children is to say "save your hearing for the music" (Figure 5). In other words, if you love listening to your music now, you will lose that pleasure if you damage your hearing. The quality of life impact may also be felt at a later age when job opportunities are restricted because of the hearing problem itself or a reduced educational attainment. The impact may also be an economic one.

PRACTICAL ADVICE ABOUT NOISE-INDUCED HEARING LOSS

The noise in our environment is no longer all 'natural', and there are numerous sources of amplified sounds that can damage hearing. In (western-based) industries, business and the military, there are legislations or guidelines and safety factors relating to noise exposure. In the areas of public entertainment (night clubs, rock concerts and sports stadiums) and personal entertainment devices (MP3s or CD players, and electronic games), regulations are not in place, and even if they were, it would be difficult to achieve compliance. However, there are some public awareness campaigns on the dangers of noise exposure, and there are a few educational programs in schools that teach children that hearing loss can result from listening to loud sounds (by analogy, just as many people were told at school not to look directly at the sun!). THFC (27) has introduced a successful program into many schools called 'Sound Sense' (28), where age-appropriate materials provide children with the facts and encourage prevention. This foundation, and others, attempt to spread the message about prevention via Web-based information portals and advertisements. Another instructional Web site is named 'Dangerous Decibels', and is a joint project between the Oregon Museum of Science & Industry (USA) and the Oregon Hearing Research Center (USA) (29).

Figure 5 is an informative poster distributed by THFC (27), and provides a guide to the levels of sounds that are a potential risk. This 'Sound Sense' poster is targeted toward children and young people. Note that in the table of various levels of sound examples, there is also an indication of how long an exposure to that sound can be considered safe. This is an important concept with regard to noise-induced hearing loss. It is not just the sound intensity, but also the duration of the exposure that determines its potential to cause cochlear damage.

In recent years, the manufacturers and distributors of personal entertainment devices have been providing (in packages) warnings and practical advice relating to the risks of noise-induced hearing loss. This is good corporate responsibility, as opposed to just being a hedge against possible litigation. In any case, such instructions, if attended to, can help prevent noise-induced hearing loss. One such warning suggests setting the device output to 'below 85 dB' (dB sound pressure level). Unfortunately, not everyone has access to a dB sound level meter, so it is not clear how one can practically make such an adjustment.

Many parents (and children) have concerns about the levels of sound exposure from personal entertainment devices, and the risks of hearing loss. One common problem is a tendency to turn up the device volume to overcome surrounding noise, which itself can be substantial. One should

Figure 5) *Sound Sense poster from The Hearing Foundation of Canada, targeting young people with the slogan "Save your hearing for the music". Reproduced from references 27 and 28*

adjust the device output in a quiet environment, to a level that is comfortable, and then try to avoid increasing the volume even in noisy settings. Our general auditory experience can tell us what is comfortable and what is too loud; perhaps parents should help younger children find that level. Some other useful advice is to get a child into the habit of checking if others nearby can also hear the music. If so, it may be set too loud; although this depends on the type of earphone in use (see below). Mention was made above of the notion that it is not just the intensity of noise that is a problem, but also the duration of exposure. In this regard, for a young person who is constantly listening to music, it is advisable to take periodic 15 min to 20 min breaks to allow the inner ear to 'recover'.

Another issue relates to the type of earphone or headphone used. The least risky in terms of the potential to do damage are the loose-fitting earbuds that do not insert tightly into the ear canal. They are typically small transducers and do not output acoustic energy directly into the confined space of the ear canal. On the other hand, the listener is not insulated from the environmental noise and, thus, there is often a tendency to increase the volume accordingly. Perhaps for the 'careless' child, this type of earphone is best. If the child is more responsible, then he or she should use a type of earphone that blocks outside noise, and can, thus, present the ear with a better quality sound and obviate the need to increase volume to compete with environmental noise. These can be earbuds that fit snugly right into the ear canal, or a larger headphone that fits against or around the ear. The downside for these transducers is that they can actually produce very intense signals, either because sound energy is transmitted into a closed space or because of the size of the transducer diaphragm, in the case of large headphones. For the serious music lover, active noise-reduction earphones are a nice luxury, but they may not be very practical for children, and may isolate an individual too much from the outside world!

Other potential noise dangers for children include powered garden and domestic equipment, such as mowers and leaf blowers, as well as the recreational use of firearms. In relation to the latter, there is a voluminous amount of literature on ballistic or 'impact noise', much of which is in relation to the military. Impact noise from a gun is of short duration but at a very high intensity, and poses a real danger to hair cells. Any use of guns for skeet or target shooting, or hunting must be done with hearing protectors; responsible gun clubs and firing ranges understand this. There is a wide range of hearing protector types ranging from simple earplugs and earmuff (circumaural) protectors, to fancy noise-activated sound attenuators (mainly for military and industrial use). Good quality earplugs made of expanding foam can provide a sound attenuation of 25 dB to 30 dB. Earmuff hearing protectors also provide approximately 30 dB of attenuation. If one considers that a gunshot impulse noise (at close range) will be over 160 dB, a 30 dB reduction by earplugs or earmuffs will still result in a sound exposure of 130 dB. The cautious youth or guardian might consider a 60 dB protection by wearing both earplugs and earmuff protectors.

The present article described the hair cell destruction that can result from acoustic trauma, and the fact that there is no recovery of such hair cells. In this sense, there is really no treatment for noise-induced hearing loss other than hearing aids, but these cannot fully restore normal hearing. This being the case, considerable attention should be paid to hearing loss prevention.

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