Assistive technologies for people with disabilities

Part II: Current and emerging technologies

STUDY

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Assistive technologies for people with disabilities

Part II: Current and emerging technologies

Study

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Abstract

This report focuses on Assistive Technology (AT) for three specific conditions of disability: 1) blindness and visual impairment; 2) deafness and auditory impairment; 3) autism spectrum disorders (ASD). These three groups of disability affect different body organs and functions, and have very different impacts on human activities and social participation. Yet, they have also two important features in common: 1) they all affect (also) the sensory system, and 2) they are not (always) immediately apparent.

We have carried out a comprehensive inventory and analysis of ATs for these three groups of disability. The main outcomes of our research are:

1) ATs for blindness and visual impairment far outnumber other ATs.
2) The traditional dichotomy between low- and high-tech holds. Yet, it is evident that there is a vast area of medium-tech devices. Interestingly, technologies in this area tend to differ very little from mainstream technology. In the longer term, one could even imagine that the distinction between non-assistive and assistive technology will fade away.
3) Most ATs aim at restoring the autonomy of disabled persons. The trend towards autonomy can have an important impact upon human rights. Yet, there is also a risk that risk that autonomy could turn into isolation and social indifference.
4) There is an increasing trend towards convergence between AT and prosthetics. The border between AT and augmentation technology risks becomes blurred, posing a myriad of legal, ethical and social issues.

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Executive summary

This study focuses on assistive technologies (AT) for three specific conditions of disability: 1) blindness and visual impairment; 2) deafness and auditory impairment; 3) autism spectrum disorder (ASD). These three conditions share a potential invisibility, say, they can be difficult for others to recognise or acknowledge. People affected by hidden (or non-immediately apparent) disabilities run the "risk" to be misjudged or neglected. They could be even accused of faking or imagining their disability.

Definitions

Blindness is a a loss of *useful* sight (say, it is not necessary a 100%loss of sight to speak of blindness), in more rigorous terms it is condition in which 1) there is no perception of light, or 2) there is a light perception of less than 3/60 or a visual field of less than 10 degrees in the better eye with best correction. Seeing is likely to be the most important sense for humans. It is estimated that 50 per cent of the cerebral cortex is involved in visual functions, and visual dominance is a universal characteristic of human cultures.

Deafness is a condition in which an individual has very little or no hearing. Hearing impairment is the inability to hear as well as someone with normal hearing. The hearing threshold is the sound level below which a person's ear is unable to detect any sound. Thresholds between -10 and +20 decibels hearing level (dB HL) are considered in the normal range. Thresholds greater than 25 dB in both ears are defined as hearing impairment. Acoustic experience plays a key role in all human cultures; moreover, acoustic experience is connected to verbal language and to social interaction and communication. "Deaf Culture" is a concept that has been developing since the early 1970s. Members of the Deaf community represent themselves as an ethnic minority, using their own language and possessing their own cultural tradition and heritage. Accordingly, deaf people who identify themselves into the Deaf community reject any account of deafness and hearing loss in terms of disability or disease.

Autism spectrum disorder (ASD) is a lifelong developmental disability. The autistic spectrum ranges from so-called high-functioning autism (HFA), with an IQ of greater than 70, to the Asperger syndrome in which intelligence and verbal communication are usually preserved but non-verbal skills (such as capacity for communicating through eye contact and facial expression) are seriously impaired and the so-called childhood disintegrative disorder (CDD) in which children, after a period of fairly normal development, have a psychotic break down and rapidly sink into an almost dementing state. Most people on the autism spectrum report also sensory distortions – hypersensitivity or hyposensitivity, or both at different times – which could affect any of the senses. The so-called autism rights movement refuses to associate the notion of autism with disease and disability, suggesting that ASDs are only expression of "neurodiversity".

Technology

1. ATs for blindness and visual impairment

Current ATs for blindness and visual impairment include, 1) haptic aids, 2) travelling aids, 3) AT for accessible information and communication, 4) AT for daily living, 5) phone and tablet applications for blind and visually impaired people. **Haptic aids** are low-tech (e.g., white cane, traditional Braille system, embossed pictures, including tactile maps etc.) and high-tech, which includes 1) advanced Braille applications, 2) advanced canes, 3) haptic aids for computer usage and 4) matrices of point stimuli. **Travelling Aids** can be classified into 1) primary aids, which provide sufficient information for the blind or visually impaired traveller to move around independently; they can safely be used alone; 2) secondary aids, which do not provide by themselves sufficient information for a blind or visually impaired person to safely and independently get around; they must be used in conjunction with a primary aid; 3) embedded technologies, which make the environment easier to cross and navigate; and 4) mixed systems. **Technology for accessible information and communication** includes technologies for specific purposes, such as education, working and employment, leisure and recreation. They comprise accessibility tools for television, computer, Internet navigation and mobile phone communication. **Low vision aids** aim at maximizing the remaining sight. **Systems tailored to the needs of blind people** turn visual information into other sensory modalities. **ATs for daily living** include devices for 1) personal care, 2) time keeping, alarms, alerting, 3) food preparation and consumption, 4) environmental control and household appliances, 5) money, finance and shopping.

Emerging ATs include 1) devices that can interface with neurons in the retina or in the optic nerve ("bionic eyes"), artificial silicon retina (ASR), retinal prostheses; 2) Augmented reality (AR) spectacles; 3) Implantable miniature telescopes; 4) Telescopic contact lenses.

AT for blind and visual impaired people is driven by: 1) increasing wearability and portability (driven by miniaturisation, reductions in power needs and availability of new, more affordable and smaller power sources); 2) innovations in display technologies and new flexible user interfaces and input options (e.g. touch screens, gesture recognition, brain interfaces, haptic feedback); 3) consumer-level access to tools of development and creation (e.g. 3D printers, app development tools for blind people). The main challenges concern accessibility and economic affordability.

2. ATs for deaf and hearing impairment

ATs for deaf and hearing impaired people include three broad classes of devices: 1) hearing technology, 2) alerting devices and 3) communication technology. **Hearing technology** includes devices used to improve the level of sound available to a listener and is, therefore, not made for deaf people with a complete loss of their hearing ability. This technology includes devices for hearing aids, assistive listening devices, personal sound amplification products (PSAPs) and cochlear implants. Personal sound amplification products (PSAPs) are devices that increase sound levels and reduce background noise. The cochlear implant (CI) is a surgically-implanted sensor that converts sound inputs into electrical outputs that can be transmitted through the auditory nerve. Cochlear implants are recommended for deaf children with the immediate goal to allow them to acquire basic speaking and listening skills, being the wider objective to improve their social interactions, their school performance and, finally, their quality of life. The Deaf community has, however, raised the basic objection that cochlear implants are more for making life easier to "oral culture" people than for improving deaf people's life. Alerting systems are devices that are suited also for deaf people, because they do not usually require any residual hearing capacity. They use light or vibrations or a combination of them to alert users that a particular event is occurring. **Communication support technology**, also known as augmentative and alternative communication (AAC), includes various tools that overall aim at improving communication skills of the disabled person. They are usually classified under two main headings: 1) telecommunication services and 2) person-to-person interactions. Telecommunication services include mainly standard technologies, such as physical and virtual keyboards, touch screens, video calling, captioning for phone calls, text messaging and other social media and text-based technology (e.g. WhatsApp, FB Messenger, Snapchat etc.). There are also systems that use voice recognition software and are able to translate spoken words into sign language or text. AAC for person-to-person interactions includes picture boards, keyboards, touch screens, display panels, speech-generating devices and software. Some of these technologies address also born-deaf people and deaf people who run the risk of losing their speaking ability as well as deaf-blind people

Emerging ATs include 1) advanced cochlear implants; and 2) auditory brainstem implant (ABI), which is a hearing device that stimulates neurons directly at the human brainstem, bypassing the inner ear and acoustic nerve. This device is designed primarily for children with profound hearing loss at birth who cannot receive – because of various medical reasons – cochlear implants. Other emerging technologies for deaf and hearing impaired people are essentially applications of existing technologies (e.g., *Google glasses* equipped with sign language interpreters; systems to provide *real-time captioning;*

purpose-designed software for laptops and tablets; *several smartphone applications* to be used as personal hearing technology). The main promise of future AT for deaf and hearing impaired people is likely to be new software for translating sign language into spoken and written languages and vice versa. The main challenge to be met is likely to concern economic costs and affordability of hearing aids.

3. ATs for Autism Spectrum Disorder

ATs are increasingly used by individuals with ASD to overcome barriers and to train people with disabilities in specific skills, such as 1) communication skills, 2) social skills and 3) adaptive skills. **ATs to support communication** are augmentative and alternative communication (AAC) technologies. They are usually classified in "*unaided*" and "*aided*" systems. *Unaided systems* are those that do not require the use of anything other than one's own body to communicate. They include gestures, body language and sign language. *Aided systems* are those that require the use of an object other than the individuals' body to communicate. **ATs for social skills** are mostly devices for computer-assisted instruction (CAI). By using dedicated software, people with ASD may practice various social skills (e.g. attending to eye gaze, discriminating between facial expressions, recognising faces, identifying emotions, and so on) with human avatars. Some applications are similar to realistic video games, in which the disabled individual trains him-/herself in various different life contexts. Researchers are currently exploring also the possibility to develop smart glasses to provide real-time social cues, with the goal of maximising behavioural feedback, while minimising the distractions to the child. **ATs for adaptive and daily living skills** are mainly applications for computer-assisted instruction (CAI). There are various instructional programs designed to train people with ASD in basic functional life skills in a virtual environment or through modelling.

Emerging technologies chiefly include social robotics. Robotic agents could be programmed to interact with children by simulating typical spontaneous human interactions. The next generation social robots will probably also be able to represent emotional states, empathy and non-verbal communication. Although most children with ASD show interest in robots, there is no consensus among experts and therapists about their clinical utility. The most promising field of research and development in technology for ASD focuses on the sensory information disorder associated with ASDs. Future challenges could concern the need to rethink the current approach to ASD treatment and develop technologies aimed at decreasing and fine tuning sensory, cognitive and emotional stimuli rather than augmenting them.

Analysis

ATs can be either **low or high tech**. This distinction is based on R&D intensities. Low-tech devices are mostly mechanical and do not necessarily require a power source; they are very easy to operate and usually low cost. High-tech devices always require a power source, are more difficult to program and use and are usually more expensive. In the three disability areas, there is an overall balance between low- and high-tech solutions, very high-tech devices are quite rare, the tendency is to stay somewhere "in between".

ATs can be also categorised into technologies intended primarily to **enhance ability or improve accessibility**. This distinction comes from the ergonomics theory. Our study shows a common trend to privilege "accessibility" over "ability", which is more evident in the case of AT for blind and visually impaired people.

A further perspective that can be used to analyse ATs is through the two categories **augmentation and automation**, which come from the theory of manufacturing. Augmentation refers to strategies in which human labour and technology are combined to create effective and efficient outcomes. Automation refers to strategies in which technology takes over human labour and machines substitute humans. Our study shows that the trend is towards automation, which means that current and emerging ATs tend more and more to take over the work of human caregivers.

Finally, ATs can be also categorized according to the two models **integration and inclusion**, which describe two different mechanisms of social assimilation. Integration means a process of incorporation in which individual diversity is "metabolised" and cancelled. The goal of integration is uniformity. Inclusion means a process in which individual diversity is protected and preserved. The goal of inclusion is parity. In the last decades, most representatives of people with disabilities have advocated an approach to disability based on the notion of "disabled identity", which means considering disabilities as biological variations not to be treated but to be socially included. This is mirrored by a corresponding trend towards inclusive technology, which emerges from our study.

Conclusions

1) The traditional dichotomy between **low and high tech** holds. Yet, it is evident that there is a vast area of medium-tech devices, which tend to differ very little from mainstream technology. This is due to many factors, not least due to an approach that is increasingly based on universal design principles. There are no signs that this trend is going to reverse; on the contrary, it seems destined to enlarge and to involve more and more ATs. In the longer term, one could even imagine that the distinction between non-assistive and assistive technology might fade away.

2) People with disabilities suffer from a lack of **autonomy**. Most ATs aim to restore autonomy of the person with disabilities. This goal can be achieved either by improving the impaired or by modifying the context, or by doing both. Today societal emphasis on autonomy is not totally risk-free. There is the actual risk that autonomy could turn into isolation and social indifference. This risk should be properly addressed.

3) Some emerging technologies can hardly be distinguished from **prosthetics**. The border between AT and augmentation technology runs the risk of becoming increasingly blurred, posing a myriad of legal, ethical and social issues. It is not by chance that most disabled people's associations are extremely reluctant to accept "prosthetic AT" and question its legitimacy.

4) The **main gap** observed by our study concerns the disequilibrium between ATs for blind and visually impaired people, and all other ATs. ATs for blind and visually impaired people outnumber other ATs and cover a much wider set of functions. There are cultural reasons that could explain this gap; a further reason might regard the information revolution, which has till now privileged visual communication. Yet, technology advances are increasingly enriching online communication, which now includes sounds and in the next future will include more and more tactile sensations. In the longer term, maybe other sensory modalities will be conveyed electronically. These trends are likely to affect future ATs.

1. Introduction

The present study focuses on assistive technology (AT) for three specific conditions of disability: 1) blindness and visual impairment; 2) deafness and auditory impairment; 3) autism spectrum disorders (ASD). In section 2, we will provide an overview of the whole disability framework; in section 3, we will present each of the three groups; in section 4, we will describe the methodology of the study; in section 5, we will carry out a systematic inventory of the main categories of AT for each group, focusing on emerging technology, promises and challenges; in section 6, we will discuss the main technology trends seen from four different perspectives (the affected individual, technology providers, caregivers, society as a whole); finally, in section 7, we will elicit some preliminary conclusions.

2. Disability framework

2.1. Definition

Disability is defined by the World Health Organization (WHO), in its International Classification of Functioning Disability and Health (ICF) as an "*umbrella term for impairments, activity limitations and participation restrictions*" (WHO 2001, p. 213). Disability is considered by the WHO as the outcome of "*interactions between health conditions (diseases, disorders and injuries) and contextual factors. Among contextual factors are external environmental factors (for example, social attitudes, architectural characteristics, legal and social structures, as well as climate, terrain and so forth); and internal personal factors, which include gender, age, coping styles, social background, education, profession, past and current experience, overall behaviour pattern, character and other factors that influence how disability is experienced by the individual*" (WHO 2002, p. 10). This comprehensive definition is the current benchmark.

The WHO model of disability is also designated as the **biopsychosocial model**. The key concept of this model is that a disability emerges from the tension between individual (in)capacity and contextual needs. Disability should not be considered as a black and white condition; rather, it is a continuum between two poles: the individual and its surrounding. For this reason, a specific condition can or cannot be considered a disability, depending on the environmental and societal challenges that a given individual, with its personal characteristics, has to meet.[1] Other conceptual models have been proposed in the past, among them the medical[2] (Stiker 2000) and the social[3] models (Abberley 1987, Imrie 1997) are the most important ones. They have been historically important, yet they both lacked – although in opposite senses – a holistic perspective.

People with disabilities are defined by the United Nations Convention on the Rights of Persons with Disabilities (UNCRPD as "*those who have long-term physical, mental, intellectual, or sensory impairments which in interaction with various barriers may hinder their full and effective participation in society on an equal basis with others*" (United Nations 2007, art. 1). This definition has been endorsed by the European Union and its Member States, which – in order to apply the UNCRPD – have adopted the European Disability Strategy 2010-2020[4]. A glossary of the other relevant terms is included in the annexes (10.1).

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[1] E.g., in a dark room, a blind person would not be disabled, while a sighted person would be.

[2] The medical model was the traditional model of disability, based on the conception of disability as a disease-like condition, to be treated within a medical context and, possibly, cured.

[3] The social model was developed by critical social scientists in reaction to the medical model. According to this model, disability is a social label used to stigmatise and exclude differently abled persons. Disability would be chiefly an issue of social exclusion.

[4] COM (2010) 636 final, Brussels, 15.11.2010.

2.2. Classifications

In the disability field, classifications are extremely important since they usually support and drive social policies. It is, however, important to remind that – as it often happens with classifications – they cannot capture all nuances of the disability phenomenon, also because multiple and fluctuating impairments are increasing and are prevalent today (WHO and World Bank 2011).

2.2.1. Disability

The WHO International Classification of Functioning, Disability and Health (ICF) is the classification currently adopted at international level. The ICF classifies disabilities through a multiaxial system[5] which considers two main axes – functioning and activity – and includes several other factors within a third level of "participation". Finally, a fourth level, "environmental factors", includes all background factors that may significantly impact on disabled people's life and social inclusion. The ICF aims to avoid linguistic stigma related to the notion of disability. Negative terms such as "impairment", "handicap", "incapacity" are replaced by more neutral concepts such as "body structures/functions", "activity", "participation". Eventually, the ICF's philosophy is that the notion of disability indicates a set of conditions, one of which any person in his/her life can – and sooner or later will – experience . The ICF is very comprehensive but also rather complex.

Based on the ICF, the Washington Group on Disability Statistics (WG) has developed a simplified matrix for census purposes. Disabilities are classified according to three main criteria: 1) Basic Activity Domains; 2) Body Function Domains; and 3) Complex Activity/Participation Domains. These three macro-categories are then further segmented (Table 1).

Table 1- Washington Group Matrix

DOMAIN	SUBDOMAIN	NOTE
BASIC ACTIVITY		
	Communication	
	Mobility	
	Hearing	
	Visual	
	Cognition/Remembering	
	Upper Body	
	Learning/Understanding	
BODY FUNCTIONS	Affect	*includes aspects of psychological functioning: anxiety and depression*
	Pain	
	Fatigue	
COMPLEX ACTIVITY & PARTICIPATION	Activities of Daily Living	*e.g. walking inside the home, standing from a chair, getting into and out of bed, eating, and dressing*
	Instrumental Activities of Daily Living	*e.g. doing chores around the house, preparing meals, and managing money*

[5] It is, however, important to emphasise that "ICF classifies functioning and disability, NOT the people, themselves […] it is not possible to assign people to a category within the ICF. ICF provides a framework for the description of human functioning and disability and for the documentation, organisation and analysis of this information" (WHO 2013).

	Getting Along with People	*involves interpersonal interactions and relationships (socialising and interacting with others) and includes dealing with family, friends, persons in authority*
	Major Life Activities	*include working inside or outside the home to earn an income and support the family or going to school and achieving educational goals*
	Participation in Society	*includes joining in community/family gatherings, religious/civic activities and leisure/social/sports events*

2.2.2. Impairment

"Impairment" is a concept often criticised by disabled activists for being inherently demeaning (Bickenbach et al. 1999), yet it is impossible to skip it entirely. Traditionally, impairments have been classified by using medical parameters, typically 1) their aetiology (i.e. their causes); 2) the moment of life in which they occurred; 3) the part of the body, the system or the function affected; 4) the severity of the impairment itself. The most comprehensive medical classification is probably that offered by Wood and Badley (1978).

Here, impairments are classified into 1) **inherited** (caused by genes and genetically transmitted) or 2) **acquired** (caused by environmental factors). Acquired impairments are further classified into 1) **congenital** (caused by insults affecting intra-uterine development and acquired during the embryonic or foetal periods); 2) **developmental** (caused by insults affecting extra-uterine development and acquired at birth or during early childhood); 3) **post-traumatic or post disease** (caused by illness or injury and acquired in adult life**)**; 4) **age-related** (related to ageing processes and acquired in later stages of life).

The **International Paralympic Committee** (2007) classifies impairments into 10 main categories, focusing on performances. The Paralympic Classification is interesting because it is one of the few classifications of impairments that are not fully in line with the ICF. The Paralympic Classification of Disabilities has been criticized by the International Organisations of Sports for the Disabled (IOSDs), which argues that this classification is too market-oriented, overemphasises competitive aspects, high performance disability sport, and hardly meets the needs of the Paralympic practice community (Howe and Jones 2006).

Table 2- International Paralympic classification of impairments

Impaired muscle power	Reduced force generated by muscles or muscle groups, such as muscles of one limb or the lower half of the body, as caused, for example, by spinal cord injuries, spina bifida or polio
Impaired passive range of movement	Range of movement in one or more joints is reduced permanently
Limb deficiency	Total or partial absence of bones or joints as a consequence of trauma (e.g. car accident), illness (e.g. bone cancer) or congenital limb deficiency (e.g. dysmelia)
Leg length difference	Bone shortening in one leg due to congenital deficiency or trauma
Short stature	Reduced standing height due to abnormal dimensions of bones of upper and lower limbs or trunk, for example due to achondroplasia or growth hormone dysfunction
Hypertonia	Abnormal increase in muscle tension and a reduced ability of a muscle to stretch, due to a neurological condition, such as cerebral palsy, brain injury or multiple sclerosis
Ataxia	Lack of co-ordination of muscle movements due to a neurological condition, such as cerebral palsy, brain injury or multiple sclerosis

Athetosis	Generally characterised by unbalanced, involuntary movements and a difficulty in maintaining a symmetrical posture, due to a neurological condition, such as cerebral palsy, brain injury or multiple sclerosis
Visual impairment	Visual is impacted by either an impairment of the eye structure, optical nerve or optical pathways, or the visual cortex
Intellectual impairment	A limitation in intellectual functioning and adaptive behaviour as expressed in conceptual, social and practical adaptive skills, which originates before the age of 18

Finally, it is worth mentioning that in its definition of people with disabilities (see 2.1), the United Nations **UNCRPD**[6] also implicitly proposes a classification of impairments into four categories, 1) **Physical**[7]; 2) **Sensory**[8]; 3) **Mental**[9]; 4) **Intellectual**[10].

2.2.3. ISO classification of assistive products

ISO 9999:2011 (2011) classifies assistive products and technologies (including software) for persons with disabilities according to their function. The classification consists of three hierarchical levels in line with the ICF classification.

AN abstract medical definition.

shows the highest (one-)level classification. It should be noted that the following items are specifically excluded from ISO 9999:2011: items used for the installation of assistive products; medicines; assistive products and instruments used exclusively by healthcare professionals; non-technical solutions, such as personal assistance, guide dogs or lip-reading; implanted devices; and financial support.

Table 3- ISO 9999 2011 – one-level classification

ISO Code	Description
	Classification
04	**Assistive Products for Personal Medical Treatment** Included are products intended to improve, monitor or maintain the medical condition of a person. Excluded are assistive products used exclusively by healthcare professionals.
05	**Assistive Products for Training in Skills** Included are, e.g. devices intended to improve a person's physical, mental and social abilities. Devices that have a function other than training but that may also be used for training, should be included in the class covering its principal function. Assistive products for vocational assessment and vocational training, see > 28 27.
06	**Orthoses and Prostheses** Orthoses are externally applied devices used to modify the structural and functional characteristics of the neuro-muscular and skeletal systems; prostheses are externally applied devices used to replace, wholly or in part, an absent or deficient body segment. Included are, e.g. body-powered and externally powered prostheses, which are not part of this International Standard.
09	**Assistive Products for Personal Care and Protection** Included are, e.g., assistive products for dressing and undressing, for body protection, for personal hygiene, for tracheostomy, ostomy and incontinence care and for sexual activities. Assistive products for eating and drinking, see > 15 09.

[6] People with disability are defined as "those who have long-term physical, mental, intellectual or sensory impairments".

[7] Motoric impairments.

[8] Vision, hearing, olfactory, etc.

[9] Pervasive developmental disorders, depressive disorders, psychotic disorders, etc.

[10] Learning disorders, cognitive disorders, etc.

ISO Code	Description
	Classification
12	**Assistive Products for Personal Mobility** Orthoses and prostheses, see > 06. Assistive products for carrying and transporting, see > 24 36. Assistive products for transporting objects in the workplace, see > 28 06.
15	**Assistive Products for Housekeeping** Included are, e.g., assistive products for eating and drinking.
18	**Furnishings and Adaptations to Homes and other Premises** Sets of castors, see > 24 36 06. Assistive products for environmental improvement, see > 27 03. Workplace furniture and furnishing elements, see > 28 03.
22	**Assistive Products for Communication and Information** Devices for helping a person to receive, send, produce and process information in different forms. Included are, e. g., devices for seeing, hearing, reading, writing, telephoning, signalling and alarming and information technology. Assistive products for office administration, information storage and management at work, see > 28 21.
24	**Assistive Products for Handling Objects and Devices** Assistive products for transporting objects in the workplace, see > 28 06. Assistive products for hoisting and repositioning objects in the workplace, see > 28 09.
27	**Assistive Products for Environmental Improvement and Assessment** Devices and equipment to enhance and measure the environment. Assistive products for employment and vocational training, see > 28.
28	**Assistive Products for Employment and Vocational Training** Devices which mainly fulfil the requirements of the work place and for vocational training. Included are, e.g., machines, devices, vehicles, tools, computer hardware and software, production and office equipment, furniture and facilities and materials for vocational assessment and vocational training. Excluded are products that are mainly used outside the work environment. Assistive products for training in skills, see > 05. Assistive products for personal mobility, see > 12. Furnishings and adaptations for homes and other premises, see > 18. Assistive products for communication and information, see > 22.
30	**Assistive Products for Recreation** Devices intended for games, hobbies, sports and other leisure activities.

3. Overview of the three groups of disability

We will start with a brief introduction to blindness and visual impairment, deafness and auditory impairment and autism spectrum disorders by providing for each of these group of conditions the most relevant definition, a description (based on ICF criteria) of the way in which they may affect people's life and some cultural considerations[11]. Finally, we will briefly discuss two significant aspects shared by these three groups of disability.

3.1. Blindness and visual impairment

3.1.1. Definitions

Blindness is a loss of *useful* sight, thus it is not needed a 100% loss of sight to speak of blindness, the WHO's definition is (2015a) a condition in which 1) there is no perception of light, or 2) there is a light perception of less than 3/60 or a visual field of less than 10 degrees in the better eye with best

[11] We will only mention cultural issues relevant to Western culture. A discussion of the main cultural aspects is out of the scope of this report.

correction.[12] While (1) is universally considered an absolute criterion to determine blindness, (2) varies according to national legislations, which establish legal criteria to determine those who are qualified for special assistance. **Visual impairment** is defined by the WHO (2015a) as the condition of moderate or severe visual impairment (low vision), even after treatment and/or refractive correction. Interestingly enough, the WHO (2015a) proposed to include in the definition of blindness and visual impairment also people with correctable conditions (e.g. by standard glasses, contact lenses, medicine or surgery) but who do not have actual access to corrective measures because of environmental (e.g. disadvantaged economic conditions, social norms and practices) or personal (e.g. psychological conditions, attitudes of immediate family members) factors. This is a good example of a comprehensive definition of disability which considers the actual context instead of an abstract medical definition.

3.1.2. Functions affected, activity limitations and participation restrictions

Blindness and visual impairment directly affect the sensory function of **seeing**. The related sensory experience is **watching**, which is defined as "*using the sense of seeing intentionally to experience visual stimuli*" (WHO 2001, d110).

By preventing or limiting watching, this group of disabilities implies a number of activity limitations and participation restrictions that relate to the severity of the impairment and to environmental and personal factors. As to the **severity of impairment**, we have outlined the main definition criteria in the previous chapter (i.e. no perception of light, moderate or severe visual impairment).

Participation may be restricted by the design and the construction of products and technologies for public infrastructures (WHO 2001, e150) and private use (WHO 2001, e155); products and technology for urban and rural areas, as they affect an individual's outdoor environment (WHO 2001, e160); products or objects of economic exchange such as money, goods, property and other valuables that an individual owns or of which he or she has rights of use as far as they imply visual skills to be used (WHO 2001, e165).

Personal factors that may **limit activities** are presence of multiple impairments affecting other functions and body structures (WHO 2001, b8); lack of social support and personal relationships, including family, friends, colleagues, caregivers, health professionals, public authorities (WHO 2001, e3); discriminatory individual and social attitudes, social norms, practices and ideologies (WHO 2001, e4). **Participation may be restricted** by impaired psychosocial or personality functions due to coping difficulties (WHO 2001, b122-b126); unsatisfactory or deficient services, systems and policies to meet the needs of affected individuals (WHO 2001, e5). Relevant **environmental factors** are summarised in Box 1, below.

Box 1- Environmental Factors in Blindness and Visual Impairment

Blindness and Visual Impairment **Environmental factors**
• access to equipment, products and technologies used by people in daily activities as far as they imply visual skills (WHO 2001, e115); • access to products and technology for personal indoor and outdoor mobility and transportation (e.g. driving a car) (WHO 2001, e120); • access to products and technology for communication as far as they imply visual communication (e.g. televisual and video equipment not adapted or specially designed) (WHO 2001, e125); • access to equipment, products, processes, methods and technology used for education (WHO 2001, e130), work activities (WHO 2001, e135), culture, recreation and sport (WHO 2001, e140).

12 These two conditions do not perfectly overlap and WHO is revising this definition.

3.1.3. Cultural considerations

In Western culture, a blind person has often been regarded as a tragic character (e.g. Oedipus), associated with poetic sensitivity (e.g. Homer, J.L. Borges) and even with clairvoyance (e.g. Tiresias, the legendary Greek prophet) (Paterson 2006). Classical Greek civilisation was deeply ambivalent towards blindness, which was simultaneously perceived as a means of punishment (or self-punishment) for horrible crimes (e.g. Oedipus), as a means of defeating monsters (e.g. Polyphemus), but also associated with the gifts of poetry, music (e.g. Demodocus, Odyssey's blind singer) and prophesy. In short, for the ancient Greeks, blindness was a "tremendous" event, in the double sense of something dreadful and marvellous (Buxton 2013). Blindness is one of the most frequently mentioned disabilities in the Bible (Avalos 2000). Also ancient Israel had an ambivalent approach to blindness: obstacles that could injure blind persons were prohibited by law (Lev. 9:14 and Deut. 27:18), but blind people were not allowed to serve in the temple (2Sam. 5:8 and Lev. 21: 18) and blind animals could not be offered to God (Mal. 1:8). However, healing the blind was one of the signs of the Messiah (Isa. 39:18, 35:5). This is mirrored in the Gospels, which record at least four of Jesus' miracles of healing blind persons (Mark 8:22-26, Matthew 9:28, Luke 18:35-43, John 9:7). The New Testament also largely uses the metaphor of "spiritual blindness" (notably in Paul's letters). Ironically enough, this metaphor was then used by French philosophers in the mid-18th century with an antireligious emphasis in order to differentiate their Age of Enlightenment from past ages of "blindness" and religious "obscurantism". The use of blindness in such a demeaning sense has probably negatively affected blind and visually impaired people (Schillmeier 2010).

3.2. Deafness and hearing impairment

3.2.1. Definitions

Deafness is currently defined by the WHO (WHO 2015b) as a condition in which an individual has very little or no hearing. **Hearing impairment** is defined by the WHO (WHO 2015b) as the inability to hear as well as someone with normal hearing. The hearing threshold is the sound level below which a person's ear is unable to detect any sound. Thresholds between -10 and +20 decibels hearing level (dB HL) are considered in the normal range. Thresholds greater than 25 dB in both ears are defined as hearing impairment, which may be (WHO 2016a)

- slight (26-40 dB better ear)
- moderate (41-69 dB better ear)
- severe (61-80 dB better ear)
- profound, including deafness (81 dB or greater, better ear)

It can affect one ear or both ears and can be due to various medical causes. From an anatomic-physiological point of view, it can originate from a dysfunction of the external or middle ear (conductive hearing loss), deterioration of the cochlea (sensory hearing loss), neurological conditions affecting either the auditory nerve, or nuclei, or the cortex (neurologic hearing loss). As previously mentioned, the auditory cortex tends to become atrophic when under-stimulated. As a consequence, uncorrected hearing losses of sensory nature (i.e. due to the organ of hearing) sooner or later also tend to cause a deterioration of the auditory cortex (i.e. lead to neurosensory hearing loss). This is particularly relevant because when a hearing loss becomes neurosensory, hearing aids become less effective. They may indeed improve the sensory function but they cannot substantially improve neurological atrophy. Hard of hearing (HOH) refers to people with hearing loss ranging from moderate to severe.

3.2.2. Functions affected, activity limitations and participation restrictions

The sensory modality impaired in deafness and auditory impairment is **hearing**, which includes functions relating to sensing the presence of sounds and discriminating the location, pitch, loudness and quality of sounds (WHO 2001, b320). The related sensory experience is **listening**, which is defined as "*using the sense of hearing intentionally to experience auditory stimuli, such as listening to a radio, music or a lecture*" (WHO 2001, d115). By limiting or preventing listening, deafness and auditory impairment imply quite a number of activity limitations and participation restrictions that relate to the **severity of the impairment** (see 3.2.1) and to environmental and personal factors.

Participation may be restricted by design, construction and building products and technology for public infrastructures (WHO 2001, e150) and private use (WHO 2001, e155); products and technology for urban and rural areas, as they affect an individual's outdoor environment (WHO 2001, e160).

Personal factors that may **limit activities** are the presence of multiple impairments affecting other functions and body structures (WHO 2001, b8); lack of social support and personal relationships, including family, friends, colleagues, caregivers, health professionals, public authorities (WHO 2001, e3); discriminatory individual and social attitudes, social norms, practices and ideologies (WHO 2001, e4). **Participation may be restricted** by impaired psychosocial or personality functions due to coping difficulties (WHO 2001, b122-b126); unsatisfactory or deficient services, systems and policies to meet the needs of individuals affected by deafness and auditory impairment (WHO 2001, e5); the impairment of mental functions involved in discriminating sounds, tones, pitches and other acoustic stimuli (WHO 2001, b1560); and the impairment of expression and reception of spoken language (WHO 2001, b1681). Relevant **environmental factors** are summarised in Box 2, below.

Box 2- Environmental Factors in Deafness and Hearing Impairment

Deafness and Hearing Impairment **Environmental factors**
• access to equipment, products and technologies used by people in daily activities as far as they imply auditory skills (WHO 2001, e115); • access to products and technology for personal indoor and outdoor mobility and transportation (e.g. driving a car) (WHO 2001, e120); • access to products and technology for communication as far as they imply audio communication (WHO 2001, e125); • access to equipment, products, processes, methods and technology used for education (WHO 2001, e130), work activities (WHO 2001, e135), culture, recreation and sport (WHO 2001, e140).

3.2.3. Cultural considerations

Western culture preserves one of the most tragic testimonies of hearing loss: Beethoven's *Heiligenstadt Testament*. Yet, with few other exceptions, deaf people have often been portrayed as funny, cognitively diminished, less able and socially incompetent (Southall, Gagné and Jennings 2010). The bias against deaf people was already evident in Aristotle's short treatise "On Sense and the Sensible" in which the Greek philosopher wrote: "*seeing, regarded as a supply for the primary wants of life, and in its direct effects, is the superior sense; but for developing intelligence, and in its indirect consequences, hearing takes the precedence […] it is hearing that contributes most to the growth of intelligence. For rational discourse is a cause of instruction in virtue of its being audible […] of persons destitute from birth of either sense, the blind are more intelligent than the deaf and dumb*" (Aristotle 1931, 437a 10-13). In Western literature and theatre, deaf people were rarely represented and, when they were, they were frequently associated with preposterous characters, such as the stubborn person or the doddering old man (Grant 1987). This is also reflected in popular sayings (e.g. "*There is none as deaf as he who will not hear*"), which indirectly hints at an alleged "bad will" of the deaf person (Mackenzie and Smith 2009). "Deaf Culture" is a concept that has been developing since the early 1970s, starting with a paper manifesto arguing "*deaf people do not have to become like hearing people to be successful in life […] Deaf people can belong to the deaf world or to the hearing world or to both these worlds […] By the deaf world, I do not mean some imaginary world. I mean a real world, a living world, a world full of people who interact with each other. The deaf world has its own national organizations, its own small social clubs, its own churches. It has its own schools, and, most important, the deaf world has its own language that ties it together – sign language*" (Woodward 1973, 57). Members of the Deaf community represent themselves as an ethnic minority, using their own language and possessing their own cultural tradition and heritage (Lane, Pillard and Hedberg 2011). Accordingly, deaf people who identify themselves into the Deaf community reject any account of deafness and hearing loss in terms of disability or disease (Ladd 2003). It is important to emphasise that the Deaf community does not include all, and is not limited only to, deaf and hearing impaired persons. According to the World Federation of the Deaf, "*identification with the Deaf community is a personal choice and is usually made independent of the individual's hearing status, and the community is not automatically composed of all people who are Deaf or hard of hearing. The Deaf community may also include family members of Deaf people, sign language interpreters and people who work or socialize with Deaf people who identify with Deaf culture. A person is a member of the Deaf community if he or she self-identifies as a member of the Deaf community, and if other members accept that person as a member. Very often this acceptance is strongly linked to competence in a signed language*" (WFD 2016). Another important sign of the new climate surrounding deafness has been the world success of "*Seeing Voices: A Journey into the World of the Deaf*", a 1989 book by British neurologist and best-seller author Oliver Sacks.

3.3. Autism spectrum disorders

3.3.1. Definitions

Autism spectrum disorders (ASDs) are lifelong **developmental disabilities.** They are defined by the WHO (WHO 2016b) as a "*range of conditions characterized by some degree of impaired social behaviour, communication and language, and a narrow range of interests and activities that are both unique to the individual and carried out repetitively*". The fourth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM)[13] classified autism under the label of "pervasive developmental disorders" (PDDs), which included Autism, Atypical Autism, Asperger's Syndrome, Childhood Disintegrative Disorder and Rett's Syndrome (American Psychiatric Association 2000). In the fifth edition, this definition was substituted by the term "Autism Spectrum Disorders" (ASDs), which replaced all the previous subtypes with one central diagnosis (American Psychiatric Association 2013). The rationale for this change was the demonstration that the distinction among subtypes was inconsistent over time, difficult and controversial to apply, and hardly supported by any biological evidence (Vivanti et al. 2013). The expression "Autism Spectrum Disorders" is thus an umbrella term covering conditions previously classified as autism, atypical autism, childhood disintegrative disorder, and Asperger syndrome. Autism spectrum disorders are included in the broader category "neurodevelopmental disorders", which are a group of conditions with onset in the developmental period, variously affecting learning, executive functions, social skills or intelligence.[14]

ASDs start in childhood but tend to persist into adolescence and adulthood. In terms of disability, all people affected share important deficits in social skills and empathic capacities (which are likely to be the functions primarily affected in all ASDs), while they show very different levels of intellectual functioning and behaviour problems (Volkmar 2013). The autistic spectrum ranges from so-called **high-functioning autism (HFA)**, with an IQ of greater than 70, to the **Asperger syndrome** in which

[13] The DSM, edited by the American Psychiatric Association, is one of the world's two most commonly used manuals to classify mental disorders, the other one is the International Classification of Diseases (ICD-10), published by the World Health Organisation, which is not, however, specifically devoted to mental disorders.

[14] Neurodevelopmental disorders include 1) intellectual disability, 2) communication disorders, 3) autism spectrum disorder, 4) attention deficit hyperactivity disorder, 5) specific learning disorder and 6) motor disorders.

intelligence and verbal communication are usually preserved but non-verbal skills (such as capacity for communicating through eye contact and facial expression) are seriously impaired and the so-called **childhood disintegrative disorder (CDD)**, also known as *Heller's syndrome*, in which children, after a period of fairly normal development, have a psychotic break down and rapidly sink into an almost dementing state (Volkmar 2013). It is important to emphasise that the notion of "spectrum" implies that there is actually a continuum between all these conditions and it is possible to meet all imaginable states. This means that it is very difficult to categorise ASD-related disability, given that in principle one could include also people like Albert Einstein, Glen Gould, Henry Cavendish, Bela Bartok and many others, who have been supposed retrospectively to have suffered from either HFA or Asperger syndrome (James 2006)[15].

In recent years, evidence has been collected which suggests that ASDs are usually associated with a sensory disorder (Kern et al. 2007), notably difficulties receiving and responding to sensory information (Ayres and Robbins 2005). Information is correctly sensed and relevant inputs are properly transmitted to the brain, but the brain processes the information in an unusual way. For instance, most people on the autism spectrum report sensory distortions – hypersensitivity or hyposensitivity, or both at different times – which could affect any of the senses (Kientz and Dunn 1997). Objects may appear dark or lose some of their features; images may fragment; noise can be magnified, sounds and voices become distorted; smells can become too intense and overpowering; some food textures may become intolerable; pain threshold can be abnormally high and people may self-harm; the perception of proximity to other people can be altered and people can have difficulty judging personal space (Talay-Ongan and Wood 2000). Moreover, people on the autism spectrum may suffer from a peculiar sensory misperception, called synaesthesia (Cohen Kadosh and Terhune 2012). Synaesthesia is a condition where experiencing one sensation in one of the senses involuntarily triggers another sensation in another sense. A typical experience is seeing a given colour when listening to a particular sound. There are many forms of synaesthesia (Eagleman and Cytowic 2009); sometimes they concern only a couple of sensory modalities, other times they affect several senses. Synesthetic experiences may be triggered by a single sensory stimulus (e.g. a musical note, a specific odour), but they can also be associated with complex patterns. Moreover, they can be provoked by hallucinogenic drugs and may occur in case of stroke or sudden sensory loss (e.g. sudden loss of hearing or sight). However, synesthetic experiences are not necessarily an impairment, it can also happen that they may enhance memory or creativity.[16] People on the autism spectrum, who report synesthetic experiences, are often people with high-functioning autism.

3.3.2. Functions affected, activity limitations and participation restrictions

According to the ICF, functions affected in ASDs are general mental functions as they develop over the life span, which are required to understand and constructively integrate "*the mental functions that lead to the formation of the interpersonal skills needed to establish reciprocal social interactions, in terms of both meaning and purpose*" (WHO 2001, b122-139). An impairment of these functions may imply a number of activity limitations and participation restrictions that relate to the **severity of the impairment** (see 3.2.1) – which also determines the degree of social and language impairment and the range of interests of the disabled person – and to environmental and personal factors. **Environmental factors** that **limit activities** of people affected by ASD are so many and varied that listing them would be futile. The same holds true for factors that restrict **participation**, which ultimately coincide with the symptoms of ASD. Other **personal factors** that may **limit activities** are the presence of multiple impairments affecting other functions and body structures (WHO 2001, b8) and concurrent diseases (e.g. epilepsy, ADHD, mood

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15 Needless to say that there is little consensus in the psychiatric community about these retrospective diagnoses, yet they are important because they show unequivocally to what extent ASD is a disability sui generis.

16 The proportion of synesthetes among artists, notably musicians, is around twice as high as in the general population (Specht 2012).

disorders, schizophrenia); lack of social support and personal relationships, including family, friends, colleagues, caregivers, health professionals, public authorities (WHO 2001, e3); discriminatory individual and social attitudes, social norms, practices and ideologies (WHO 2001, e4). **Participation may also be restricted** by impaired psychosocial or personality functions due to coping difficulties (WHO 2001, b122-b126); unsatisfactory or deficient services, systems and policies to meet the needs of individuals affected by ASD (WHO 2001, e5).

3.3.3. Cultural considerations

The notion of "autism" is quite recent, dating back to Swiss psychiatrist Eugen Bleuler, who coined it in 1911 to refer to some symptoms of schizophrenia (Volkmar 2013). In the 1940s, American psychiatrists started to use this term to indicate children with emotional or social problems, and only in the 1960s the notion of autism was definitely distinct from the diagnosis of schizophrenia. Cultural considerations about autism thus largely coincide with wider societal implications of psychiatric conditions in childhood (Mordini 2002). In the last decades, ASDs have been in the limelight of public debate for various reasons. Autism was initially believed to be a disease primarily caused by parents' coldness (Kanner 1943). This perspective was taken up by and became mainstream thanks to Austrian-American child psychologist Bruno Bettelheim and his group at *Chicago's Sonia Shankman Orthogenic School*, who coined the expression "refrigerator mother" to mean a frigid, uncaring mother (Bettelheim 1967). Bettelheim made a parallel between concentration camp survivors and children with autism, and his theory put a heavy burden on families (Gray 1993; Farrugia 2009). Bettelheim's hypothesis was largely rejected by the scientific community (Ozonoff, Goodlin-Jones and Solomon 2005); yet autism etiology remains a battlefield for a number of controversial, poorly grounded – nonetheless popular – theories, like the *vaccine theory*[17] (Waterhouse 2008). The autistic community is currently rather powerful, yet it is split between two contrasting approaches (Grinker 2007). Some groups advocate for more scientific research, care and support in the community (Autism Europe 2015), but other groups, the so-called autism rights movement, refuse to associate the notion of autism with disease and disability (Dekker 2015). They suggest that ASDs are healthy ways of being and support autistic people to be proud of their "neurodiversity" (Silberman 2015). The autism rights movement rejects the notion of assistive technology for children and adults with ASD and ask only for tools to cope with non-autistic culture (Autistic Self Advocacy Network 2016). Just as the Deaf culture movement, the autism rights movement depicts itself as an ethnic minority (Nelson 2004). In May 2014, the Sixty-seventh World Health Assembly adopted a resolution entitled "*Comprehensive and coordinated efforts for the management of autism spectrum disorders (ASD)*". The resolution notes that "*individuals with autism spectrum disorders and their families face major challenges including social stigmatization, isolation and discrimination, and that children and families in need, especially in low-resource contexts, often have poor access to appropriate support and services*" and urges WHO to collaborate with Member States and partner agencies to strengthen national capacities to address ASD (WHO 2014).

[17] According to this theory, autism spectrum disorders are due to child vaccination. Notwithstanding its enduring popularity, this theory lacks any scientific evidence and rationale.

4. Common features shared by the three groups of disability

The three groups of disability (blindness and visual impairment, deafness and hearing impairment, and autism spectrum disorders) affect different body organs and functions and have very different impacts on human activities and social participation. Yet, they have also two important features in common: 1) they all affect the sensory system and 2) they are not (always) immediately apparent.

Box 3- The Sensory System

The Sensory System

The sensory system is the body's system of sense organs. Since ancient times, senses have been classified into five major *sensory modalities*: vision, hearing, taste, smell and touch. Each sense consists of submodalities which capture the various facets of the overall perception. Touch is a residual category that includes all other sensations, such as pain, temperature, pressure, texture, position and movement of the body's muscles and joints. Each of the senses possesses peripheral receptors, which are specialised cells that are sensitive only to a class of physical and chemical inputs. The lowest stimulus an organism can detect is called *sensory threshold*. Sensory thresholds change across time, contexts and individuals. They are deeply influenced by training, experience, fatigue, general physical conditions and cultural factors. It is well known that the perceptions of pain vary from society to society (Campbell and Edwards 2012), but it is less known that the same holds true for all sensory modalities (Classen 1997). For instance, populations that categorise colours differently from Euro-Americans are able to distinguish shades of green, blue and white that are almost indistinguishable to European people (Regier and Kay 2009); microtonal intervals, which are barely recognized by (non-musician) Europeans (Bailes, Dean and Broughton 2015), are very well perceived by Indonesian and Indian people (Perlman and Krumhansl 1996), whose traditional music includes 22 tones instead of 12, as in Western tuning. When the sensory threshold is reached, sensory receptors generate electro-chemical inputs that are transmitted through nerve impulses to specific brain regions where the internal sensory representation is produced. Sensations are not passive impressions generated by physical properties of "external" objects, and the brain does not simply record the world; sensations are rather complex constructions that depend on biological constraints, innate processes and acquired (cultural) rules. "*We receive electromagnetic waves of different frequencies but we perceive colors […] We receive pressure waves but we hear words and music […] Colors, sounds, smells and tastes are mental constructions created in the brain by sensory processing. They do not exist, as such, outside of the brain*" (Martin and Jessell 1995, 370).

Language and cultural training also contribute to the social relevance of each type of sensory loss, and even to adapt the biological capacity to compensate by cross-modal interactions (Majid and Levinson 2011). Cross-modal interactions are indeed an important feature of the sensory system. No sensory modality works completely isolated from other modalities, there is instead a continuous interaction between sensations at cerebral level (Welch and Warren 1986). In case of absence or deterioration of one sense, the brain tends to reorganise itself and compensate by using another sense (Soto-Faraco et al. 2004). This process, called *sensory substitution*, is fundamental to understand the rationale behind many assistive technologies (Bach-y-Rita 1972). A blind person may "see" by substituting vision with hearing, touching, smelling, tasting. Likewise, a deaf person may "hear" by substituting hearing with watching, perceiving bodily vibrations, smelling and so. Sensory substitution may evoke the original sense only in people who still keep any sensory capacity (e.g. visually or hearing impaired), while people who totally lack a sensory modality (e.g. blind and deaf persons) experience the sensation in terms of the substituting sense (e.g. a blind person perceives to see through touch, a deaf person perceives to hear through vibrations) (Poirier, De Volder and Scheiber 2007). Sensory substitution is one of the oldest strategies adopted to overcome sensory disabilities, and still today most assistive products are based on this principle. An emerging application of sensory substitution concerns the so-called "artificial" senses (e.g. bionic eyes, cochlear implants), which are systems that replace a sensory modality by using artificial peripheral receptors coupled to the brain via a human–machine interface (Bach-y-Rita and Kercel 2003). Research on sensory substitution is currently also focusing on the possibility to augment sensory capacity (e.g. nocturne vision) and to create new senses (e.g. magnetic perception) (Nagel et al. 2005).

4.1.1. The sensory system in blindness and visual impairment, deafness and hearing impairment, and autism spectrum disorders

It is a truism to say that blindness and visual impairment and deafness and hearing impairment affect sensory information. Seeing is likely to be the most important sense for humans. It is estimated that 50 per cent of the cerebral cortex is involved in visual functions, and visual dominance is a universal characteristic of human cultures (San Roque et al. 2015). Hearing ranks in second place among senses (San Roque et al. 2015). Acoustic experience plays a key role in all human cultures; moreover, acoustic experience is connected to verbal language and to social interaction and communication (Gerber 2007).[18] As previously mentioned, research is currently suggesting that also ASDs involve a sensorial impairment, which, however, does not affect the way in which sensory information is captured and turned into nervous signals. Rather, it involves the way in which information is processed by the central nervous system. It is difficult to say whether the sensory processing disorder in autism is primarily part of the autistic syndrome or just associated with it (Talay-Ongan and Wood 2000). More recently, a fascinating theory is gaining momentum that looks at autism and sensory processing disorder quite differently. The *Intense World Theory*, proposed in 2007 by Markram and colleagues (Markram, Rinaldi and Markram 2007) on the basis of a number of neurobiological studies, suggests that the autistic child could primarily suffer from *hyper-perception, hyper-attention*, *hyper-memory and hyper-emotionality*. It would experience an extreme painfully intense world to which he reacts by developing "*a hyper-preference and overly selective state, which becomes more extreme with each new experience and may be particularly accelerated by emotionally charged experiences and trauma. This may lead to […] an involuntarily and systematic decoupling of the autist from what becomes a painfully intense world. The autistic is proposed to become trapped in a limited, but highly secure internal world with minimal extremes and surprises […] The degree of hyper-functionality in different brain regions could vary in each child depending on genetic personality traits, on unique epigenetic conditions, and unique sequence of postnatal experiences*" (Markram and Markram 2010, 2). This theory could explain most autistic symptoms, including sensory sensitivity, withdrawal, repetitive behaviour, idiosyncrasies and even exceptional talents. Interestingly enough, according to this theory, ASDs would probably be the sole disability due to "augmented" ability rather than to deficit and impairment. The consequences of this theory on autism treatment could be also significant.

4.1.2. Blindness and visual impairment, deafness and hearing impairment, and autism spectrum disorders as invisible disability

Blindness and visual impairment, deafness and hearing impairment, and autism spectrum disorders are disabilities that are not (always) immediately apparent. When compared to the other hidden disabilities, blindness and visual impairment are often considered much easier to recognise, which is only partly true. People tend to think that being blind means seeing nothing at all and tend to misjudge conditions of severe visual impairment that are functionally very close to blindness (Brookes, Broady and Calvert 2008). Moreover, some visually impaired people prefer to pass as sighted to avoid any disability-related stigma. They refuse to use obvious signs such as a white cane, a guide dog or other devices that could mark them as visually impaired (Noriega 2015). They therefore run the risk to be considered rude, for instance when they do not acknowledge other people, or to be suspected of being under the influence of drugs or alcohol, or just clumsy, when they move (Noriega 2015).

[18] Marshall McLuhan argued that non-literate societies were governed by spoken words and sound, while literate societies experienced words visually and thus were dominated by sight (McLuhan 1999).

Deafness and hearing impairment are more invisible disabilities. Their significant impact on communication and interaction with others sometimes goes unrecognised, even by healthcare practitioners (Mackenzie and Smith 2009). Behaviours associated with these conditions may not be apparent, and adult people with hearing loss are often perceived as just being slow. As a consequence, deaf and hearing impaired persons may try to hide their problem in order to avoid intolerance and ridicule (Dewane 2010). They tend to deny the disability, and this may further impair their quality of life, delaying them from seeking help. At the end, they risk a solitary self-confinement.

Also, ASDs are mostly hidden disabilities, meaning it is very difficult to tell whether a person is affected by ASD from his or her external appearance. People on the autism spectrum do not show any universally visible sign of their condition. There is no mobility aid, assistive technology, guide animal or specific language that can be used to recognise these people, who usually pass as non-disabled or are misjudged as they were primarily affected by a psychotic condition or by intellectual disability.

Box 4- Visible and Invisible Disability

Visible and Invisible Disability

The distinction between visible and invisible disabilities dates back to the early 1970s (Stodden and Roberts 2014, 676). According to the Invisible Disabilities Association (IDA) "*the term invisible disabilities refers to symptoms such as debilitating pain, fatigue, dizziness, cognitive dysfunctions, brain injuries, learning differences and mental health disorders, as well as hearing and vision impairments. These are not always obvious to the onlooker, but can sometimes or always limit daily activities, range from mild challenges to severe limitations and vary from person to person*" (Invisible Disabilities Association 2016). Invisible disabilities are often neurological in nature (this is the reason why they are not immediately apparent). An invisible disability can be difficult for others to recognise or acknowledge. Others may not understand the cause of the problem if they cannot see evidence of it in a visible way. As a consequence, people affected by hidden disabilities – though they largely differ as per biological conditions – share the "risk" to be misjudged or neglected by their social environment. People suffering from hidden disabilities could be even accused of faking or imagining their disability (Brookes, Broady and Calvert 2008; Matthews 2009; Bodey 2010). It is estimated that 10 per cent of people in the US have a condition that could be considered an invisible disability (Centers for Disease Control and Prevention 2015). There is no data available on hidden disability in the EU, but it is likely that prevalence is similar to the US. Hidden disability was recently addressed by the European Commission and the European Disability Forum on the occasion of the 2015 *International Day of Persons with Disabilities*. The Invisible Disabilities Association (IDA), established in 1996, is the world organisation of people affected by hidden disabilities.

5. Methodology

The methodology adopted is based on desk research.

5.1. Grey literature and technology database

Papers, conference presentations, reports and technical documents, official documents (white papers, EC Communications etc.), policy briefs and other types of grey literature were identified through general internet searches, scientific literature review as well as targeted searches on websites such as **DG Employment, Social Affairs & Inclusion** and the **European Agency for Special Needs and Inclusive Education**. Academic theses were located from the **ProQuest Database of Dissertations & Theses Global** database and the **Networked Digital Library of Theses and Dissertations**. Finally, we have also searched the **EASTIN database**[19], which is the European search engine on assistive technology. EASTIN offers a comprehensive pan-European searchable database including 1) AT products, 2) cases, 3) regulations, 4) companies and 5) projects.

5.2. Scientific papers and Wikipedia corpus

We extensively searched **academic databases** (*EBSCO ALL*, *IEEE*, *Web of Science*) by using Google and specialised search engines for modulated searching. Moreover, we searched the Wikipedia **Corpus**[20], which allows exploring and mining 4.4 million Wikipedia articles and entries, opportunely filtered in order to create and search personalised "virtual corpora".

5.3. Search criteria

Search criteria can be found in the Annexes in more detail. Our search focused on English language documents published between January 2000 and March 2016. Although there was no geographic restriction placed on the literature search, we paid particular attention to papers and documents coming from the EU area.

5.4. The analytical grid

In order to analyse findings (chapters 6 and 7), we developed a grid specifically tailored to the needs of this study. On the basis of the literature review, we identified four main perspectives from which disability can be observed by the main groups of players and actors. Within each perspective, we also identified a polar couple to describe the tension between opposite approaches. Like poles, these couples are the extreme of a continuum along which one could find actual technological solutions.

1. *Technological point of view* – this is chiefly (although not only) the point of view of engineers, technology providers and investors. According to a technology perspective, ATs can be either low or high tech. This distinction is based on R&D intensities (OECD 2011). Low-tech devices are mostly mechanical and do not necessarily require a power source; they are very easy to operate and usually low cost. High-tech devices always require a power source, are more difficult to program and use and are usually more expensive. Eurostat (2016) provides a more detailed classification into 1) low, 2) medium-low, 3) medium-high and 4) high tech manufacturing.
2. *Individual impairment point of view* – this is chiefly (although not only) the point of view that matters to disabled persons. According to this perspective, technologies can be categorised into technologies intended to increase abilities and technologies intended to increase accessibility. Of course, no

[19] European Assistive Technology Information Network, http://www.eastin.eu/en-GB/searches/products/index.

[20] http://corpus.byu.edu/wiki/.

distinction is completely black or white and in this case there are many grey areas. Yet, this distinction – which comes from the ergonomics theory (Bhattacharya and McGlothlin 2012) – is helpful because it focuses on one of the main sources of misunderstanding and controversies that surround disability. In a nutshell, the question is: what is the best strategy to deal with disability? Is it to try to "fix" impairments by using technologies for augmenting individual abilities? Or is it to use technologies for modifying the interface between individuals and the environment with the aim to help the disabled to maximise their actual potential? The answer critically depends on the way in which one conceptualises disabilities: those who tend to consider disabilities chiefly in terms of impairment will also tend to support technologies that increase abilities; those who tend to consider disabilities in terms of social exclusion will also tend to support technologies that increase accessibility.

3. *Caregivers' point of view* – caregivers and families are obviously interested in how technologies impact on them, on their tasks and responsibilities. The couple "augmentation" and "automation" describes well the tension within this perspective. We took this couple from the theory of manufacturing (Davenport and Kirby 2015), where scholars distinguish between two different approaches to production innovation: 1) augmentation, in which human labour and technology are combined to create effective and efficient outcomes; 2) automation, in which technology takes over human labour and smart machines substitute humans. Some ATs are designed to be combined with and to improve the quality of human assistance, while other ATs tend to take over the work of object to caregivers and to make human assistance redundant. This polarity is thus highly meaningful from a socio-economic point of view, involves family life and can have significant impacts also on the labour market.
4. *Wider societal point of view* – this is typically the policy makers' perspective, but it is also highly relevant to disabled people and civil society organisations. In this case, the tension concerns the way in which ATs may facilitate the social assimilation of disabled individuals. To describe this tension, we have used the polarity integration–inclusion, which comes from education theory (Frederickson and Cline 2002). Integration means a process of incorporation in which individual diversity is "metabolised" and cancelled. The goal of integration is uniformity. Inclusion means a process in which individual diversity is protected and preserved. The goal of inclusion is parity. In the last decades, most representatives of disabled people have advocated an approach to disability based on the notion of "disabled identity", which means considering disabilities as biological variations not to be treated – cured or cared – but to be accepted (Imrie 1997). Today, most disabled people's associations object to integration and promote inclusion as the sole decent objective to pursue (International Disability Alliance 2016).

Table 4- Analytical grid for assistive technology

ASSISTIVE TECHNOLOGY ANALYTICAL GRID												
AT analysed:												
TECHNOLOGY	**Low**											**High**
IMPAIRED INDIVIDUAL	**Ability**											**Accessibility**
CAREGIVERS	**Augmentation**											**Automation**
SOCIETY	**Integration**											**Inclusion**

6. Assistive technology

In the following chapters, we will carry out an inventory of existing assistive technologies in each of the three disability areas. We will then provide an overview of emerging technologies and future promises and challenges in each of these areas.

6.1. AT for blindness and visual impairment

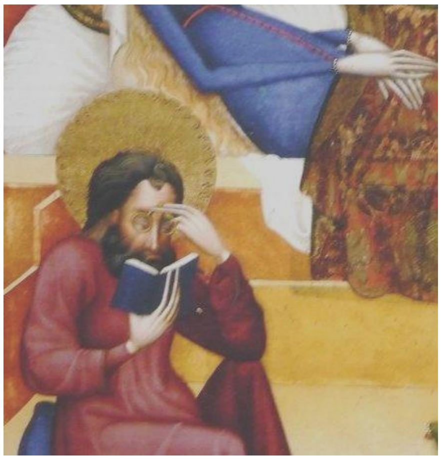

Figure 1: Medieval Spectacles (1400-30) (source: Wikimedia Commons

Visual correction devices, together with mobility aids, are among the oldest assistive technologies. The history of lenses dates back to approx. 4 500 years ago. However, the first wearable eyeglasses were probably invented during the XIII century in Italy (Rosenthal 1996) (Figure 1). Since then, different types of lenses – from traditional eyeglasses to contact lenses – have been used to correct refractive defects[21] in vision. Visual impairments due to retinal and neurological causes have not yet been effectively addressed.

Existing ATs for blindness and visual impairment could be roughly divided as follows: 1) haptic aids, 2) travelling aids, 3) AT for accessible information and communication, 4) AT for daily living (Hersh 2008). A fifth – emerging – category should be also mentioned: 5) phone and tablet applications for blind and visually impaired people.

6.1.1. Haptic aids

Haptics means "pertaining to the sense of touch", "tactile", which is a complex sensorial modality, actually including many subcategories.

Box 5- Tactile Sensation

Tactile Sensation

Tactile sensation includes information generated and transmitted by at least thirteen types of receptors, comprising four mechanoreceptors (which provide information about skin deformation) and four proprioceptive receptors (which provide information about muscle length, muscle force and joint angle) (Johnson 2002). Mechanic and proprioceptive receptors play a pivotal role in haptic aids, while other tactile information (e.g. thermic sensations) is less important (Jansson 2008).

The term, coined by scientists at the end of XIX century, derives from the Ancient Greek verb *haptein*, which means "to touch" (Harper 2015). Another term for **haptic aids** is *active touch*. The term "haptic" is today preferred to "tactile". It covers systems that also use kinaesthetic information, generated by sensors in muscles, tendons and joints (see BOX 3). Blind and visually impaired people have always used tactile sensations as a substitute for vision, and they have probably always used canes to avoid obstacles. However, the two most well-known and widely used tactile aids – the Braille writing system

[21] Refraction is the change of direction of a ray of light passing through one medium to another. Light rays entering the eye are refracted as they pass through the cornea and the lens. The light is then focused on the retina, which is a neurosensorial structure. The retina converts the light into nervous outputs that are sent through the optic nerve to the brain. Refractive errors occur when the shape of the eye prevents light from focusing directly on the retina, causing blurred vision.

and the white cane – have been introduced fairly recently, with the Braille system[22] dating back to the Napoleonic wars and the white cane[23] to the early 1900s.

Haptic low-tech aids include the white cane, the traditional Braille system and embossed pictures (including tactile maps).

Technologically advanced applications include 1) advanced Braille applications, 2) advanced canes, 3) haptic aids for computer usage and 4) matrices of point stimuli.

Figure 2: Braille Notetaker (source: Florida School for the Deaf and the Blind in St. Augustine, Florida – Video Library)

Advanced Braille applications are technological applications aimed at simplifying the use of Braille. They include 1) software for Braille training, 2) Braille embossers (also known as Braille printers) which transfer computer-generated text into embossed Braille output, 3) Braille translation programs, which convert text scanned in or generated via standard word processing programs into Braille, 4) Braille computer interfaces, such as Braille monitors and keyboards (Figure 2). In total, the EASTIN database of assistive products[24] lists 302 products based on Braille applications.

Advanced canes (also known as technology canes or smart canes) have been developed over the last decades. Cane technology has chiefly focused on improving lightness and length of canes, consequently most progress has been made in relation to the material used (e.g. graphite-reinforced plastic, fibre-reinforced plastic etc.). However, technologists today also explore the possibility to create electronic canes that better detect and identify obstacles (Ong, Zhang and Nee 2013). This technology is ultimately based on traditional cane principles coupled with additional technology to detect obstacles and transmit information to the cane bearer (Hersh and Johnson 2008d). Technologies explored to detect obstacles include laser and ultrasounds (also known as Batcane). Technologies to transmit information include both audio and tactile interfaces as well as a combination of the two. The tactile interface is usually made of vibrating buttons or pins. The audio interface usually comprises tones of different pitch conveyed through a single earphone. Information includes basic details on obstacles, but can also become very sophisticated, using a combination of haptic and auditory signals to suggest a spatial map of the surroundings (Hoyle and Waters 2008). The EASTIN database of assistive products lists 243 products, including three laser canes and one ultrasound cane, under the heading "Tactile sticks or white canes" (ISO Code 12.39.03).

Haptic aids for computer use include 1) tactile computer mouse and touchpad, 2) haptic graphical user interface, 3) haptic display. The EASTIN database of assistive products lists 134 products under the heading "Tactile computer displays" (ISO Code 22.39.05). At present, there is no other specific category for haptic aids for computer use.

Matrices of point stimuli is a major enabling technology for new haptic applications. Haptic applications typically convey their signals to the user's body surface. By using several static and/or vibrating pins, it is possible to create a matrix of point stimuli. By dynamically activating some of these pins, it is then possible to form different patterns which may provide details that are usually only

[22] To demonstrate the significance of the context in the notion of disability, it is worth reminding that Braille was originally a tactile military code to be used by soldiers to communicate silently at night and without light, that is to say, a condition in which a sighted person becomes virtually blind (Roth and Fee 2011).

[23] There are various types of canes: 1) the long cane, designed as a mobility tool, 2) a shorter cane for guiding, detecting steps and body protection, 3) an identification cane, used to alert others as to the bearer's visual impairment, 4) a support cane for physical support (Lions Clubs International 2016).

[24] http://www.eastin.eu/en/searches/products/index, accessed April 2016.

captured by sighted people, such as written texts, tactile pictures (including diagrams and maps) and so on. Devices provided with a matrix of point stimuli can be fed, for instance, by a wearable camera, becoming tactile-visual substitution systems (Jansson 2008).

6.1.2. Travelling aids

One of the main challenges that blind and visually impaired people face is travelling through different environments, including unknown environments. Travelling challenges include 1) mobility, 2) navigation and 3) environmental access. **Mobility** concerns the identification of a safe path avoiding and negotiating obstacles and hazards. **Navigation** concerns wayfinding, that is to say, knowing the current location and establishing how to get from the current location to a destination. **Environmental access** concerns good design of the physical environment in order to minimise hazards for blind and visually impaired people and to provide them with contextual information.

A further important distinction concerns 1*) near space* and 2) *far space*. According to Hersh and Johnson (2008d, 170), "*Near-space is the space immediately around the person's body (or their body plus a short-range assistive device such as a long cane). This space can be explored by touch and thus it is often called the haptic-space. Far-space is distant geographical space, information about which is required for travel; hence it is also sometimes referred to as the locomotor space*". Following the distinction between near and far space, technologies that support mobility needs of blind and visually impaired people can be classified into 1) **primary aids**, which provide sufficient information for the blind or visually impaired traveller to move around independently; they can safely be used alone; 2) **secondary aids**, which do not provide by themselves sufficient information for a blind or visually impaired person to safely and independently get around; they must be used in conjunction with a primary aid; 3) **embedded technologies,** which make the environment easier to cross and navigate; and 4) **mixed systems**. In total, the EASTIN database list 42 products under the heading "Assistive products for electronic orientation" (ISO Code 12.39.06)

Figure 3: Project Tacit: Sonar For The Blind (source: Grathio Labs)

Primary aids: devices that are mainly used in near space. All primary aids share some features. They must be easy to carry, small, lightweight and, ideally, consist of a single unit. Moreover, given that they can be used outdoor and in many different situations, it is paramount that they are robust, able to withstand all weather conditions as well as knocks and falls. **Low- tech primary** aids include low-tech haptic aids, such as the white cane. **High-tech primary aids** include various *obstacle and object location detectors*, which scan the environment (Figure 3). They include devices such as hand-held ultrasonic torch, laser technologies and devices based on infrared and cameras (Karungaru, Terada and Fukumi 2011). Researchers are also studying the possibility of using kinetic sensors to provide the user with detailed information on the position and distance of an obstacle (Zöllner et al. 2011). Detectors are usually hand-held – although there are also devices that can be positioned at chest height through a loose strap. They usually use a tactile or an audio interface, or both (Hersh and Johnson 2008d). Refreshable Braille displays have also been tested, but the speed at which Braille is read is often to slow for the rate at which objects are encountered in the environment (Ross and Blasch 2000). Advanced haptic interfaces – providing kinaesthetic information such as vibrations – are also investigated (Berdinis and Kiske 2012).

Secondary aids: devices that are mainly used in far space for **orientation and navigation** (Bradley and Dunlop 2008). These devices usually provide two types of information. First, they provide *geo-location* *information* and assist in how to reach a given destination and find the best route to be followed. Once the user starts travelling, the integrated Global Positioning System (GPS) identifies the user's location and provides directions. Second, these devices may also provide *landmark information*. Landmark details serve a number of purposes: they allow validating positioning information, enabling a user to continue following a planned route even if satellite signals are temporarily unavailable; they also allow finding specific points along the route, such as an entrance, an obstacle and so on. Today, most secondary aids use GPS, combined with geographical information systems (GIS) (Ali and Sankar 2012). GPS accuracy is rapidly enhancing from the meter-level down to a few centimetres. Emerging technologies – mainly driven by the development of autonomous vehicles, improved aviation and naval navigation systems – may achieve centimetre-level positioning accuracy even on standard mobile phones and wearable devices (Chen, Zhao and Farrell 2015).

Figure 4: Braille Pedestrian Crossing (source Pixabay free photos)

Secondary aids include both **electronic travel devices (ETDs)** consisting of several hardware components specifically designed to assist the disabled person and assistive applications in **mobile phone technology**. ETDs are usually wearable devices including a small computer (provided with dedicated software for information processing, often with speech and voice recognition) coupled with GPS and GIS systems (Ball 2008). They may also include a Braille compass (a directional device using Braille characters). Early ETDs provided information mainly via speech audio outputs. Today, audio signals (non-speech) and haptic outputs are also commonly used (Ball 2008). Another approach, which is becoming increasingly important, is based on the development of assistive applications to be used in standard **mobile phone technology** (Doughty 2011). Smart mobile phones include components such as a multi-megapixel camera, high-quality directional microphone, tri-axial accelerometer, GPS receiver, digital voice recorder, touch-screen, electronic temperature chip, several vibration units, magnetic and electric field sensors as well as 4G, Wi-Fi and Bluetooth communications. Through low-cost downloadable applications, all these technologies can also be used for assistive purposes. There are many obvious advantages of such a strategy, inter alia the increased portability, lower costs and increased user acceptance. Moreover, by using different communication tools, mobile phones allow overcoming the main GPS limitation, which is the limited capacity for indoor operation. By using different types of signals (e.g. Wi-Fi hot spots, Bluetooth signals, cell phone signals) mobile phones may be used to triangulate the position of the user being indoors by creating an Indoor Positioning System (IPS) (Curran et al. 2011). Today, however, the interest in IPS is decreasing because of the advent of high-sensitivity GPS receivers, which work well also in most indoor environments (Horvath and Horvath 2014).

Embedded technologies: technologies that are embedded in the environment, aimed at making it accessible and user-friendly and overcoming the main barriers met by disabled persons. Most of them are **low-tech** and include 1) good lighting, 2) well-designed signage systems, including tactile and audio information and alarms, 3) tactile paving and surfaces to warn of hazards and to direct people, and 4) colour contrasts, including colour-contrasting strips to make items easier to recognise. **High-tech** devices are electronic signal systems embedded in the environment which are activated by the presence of the disabled person (Hersh and Johnson 2008a). *Talking signs* are repeating, directionally selective voice messages transmitted by infrared light to a hand-held receiver. *Radio frequency identification (RFID)* tags are also used to broadcast signals to be transmitted to the user either as an audio signal over a headphone or by vibration (Chen et al. 2010). Similarly, *Bluetooth technology* is used to create signal systems and alarms (Hersh and Johnson 2008a).

Mixed systems: semi-autonomous systems that possess full autonomy for local navigation, enabling the visually impaired to avoid obstacles. Some of these systems (robotic guides and walkers) have already been tested (Ulrich and Borenstein 2001). Moreover, they could be used for pedestrian navigation, allowing path planning and localisation, also relying on signals broadcasted by embedded technologies.

6.1.3. AT for accessible information and communication

Technology for accessible information and communication includes technologies for specific purposes, such as education, working and employment, leisure and recreation. They comprise accessibility tools for television, computer, Internet navigation and mobile phone communication (Hersh and Johnson 2008b). A clear distinction should be drawn between low vision aids and systems tailored to the needs of blind people. **Low vision aids** aim at maximizing the remaining sight by 1) increasing the object size, e.g. larger print keyboard stickers, 2) decreasing the viewing distance, e.g. magnifiers of various types, spectacles etc., 3) video magnification, e.g. closed-circuit television (CCTV), computer operating systems provided with magnification accessibility features, 4) telescopic magnification, e.g. contact lens telescopes. These tools are applied to different devices, such as computers, screens, tablets and phones etc. **Systems tailored to the needs of blind people** turn visual information into other sensory modalities (Figure 5) (Maidenbaum, Abboud and Amedi 2014), they are based on *speech, text and Braille conversion technologies* (e.g. Braille printers, Braille keyboards, Braille text recognition software etc.), *text and screen readers* (including audio-books and alike), *voice recognition software* (e.g. voice command for mobile phones). Specific applications include 1) audio support software, 2) text-to-speech software, 3) portable reading devices, 4) Braille computer input and output hardware and software, 5) tactile images and screens, 6) audio operating systems for computers (Hersh and Johnson 2008b). They mostly use haptic or audio technologies, or a combination of both. Given their heterogeneity, it is not possible to identify a specific EASTIN category for these products.

Figure 5: ComTouch haptic interface for pc (source Tangible Media Group)

6.1.4. AT for daily living

A vast array of devices is designed to assist blind and visually impaired people in dealing with daily living activities (Figure 6). They include devices for 1) personal care, 2) time keeping, alarms, alerting, 3) food preparation and consumption, 4) environmental control and household appliances, 5) money, finance and shopping (Hersh and Johnson 2008c). They use various labelling systems (e.g. tactile, RFD, talking labels) and various talking readers (e.g. talking bar code readers, talking health monitoring devices such as blood pressure readers and glucose readers etc.). They also include tactile and vibrating clocks and alarms, talking kitchen tools, talking microwave ovens, talking washing machines and talking vacuum cleaners etc. Money, finance and shopping tools

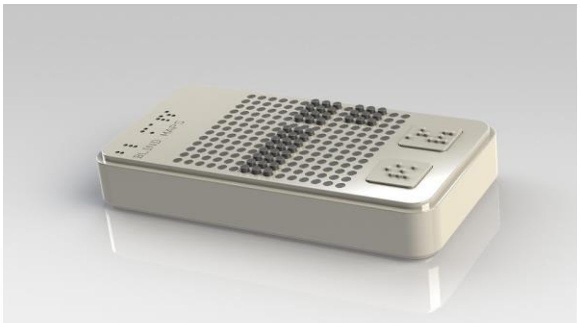

Figure 6: Blind Map (Source: Ars Electronica)

include talking wallets and purses, talking ATMs and so on. All these devices use technologies described above. The EASTIN database lists 1 622 products under the general heading "Assistive products for seeing" (ISO Code 22.03).

6.1.5. Phone and tablet applications for blind and visually impaired people

Finally, a short chapter will be devoted to phone and tablet applications for blind and visually impaired people. Theoretically, they could be classified into previous categories, but due to their number and increasing importance they deserve a separate chapter. They use existing phone or tablet technology (Ireland Citizens Information Board 2016). Just to mention a few, they include

- *magnification apps,* which use the phone camera as a magnifying glass;
- *colour detection apps*, which use the camera to identify and speak the name of the colour of an item;
- *money identification apps*, which use the camera to identify the value of a note;
- *object identification apps*, which use the camera to identify objects, also by reading labels and barcodes;
- *crowdsourcing apps*, which circulate photos taken by disabled persons among anonymous web volunteers who describe what they see;
- *light identification apps*, which convert light levels or motion into audio tones;
- *scan and read apps*, which turn images of text into plain text and read it;
- *screen reading apps*, which are standard screen readers;
- *voice recognition apps*, such as Siri on iOS;
- *location and GPS apps*, some of them specifically tailored to the needs of blind people;
- *reading apps*, for reading e-books;
- *Braille apps*, which teach Braille and allow typing Braille on the touchscreen;
- *security apps*, which connect blind users to sighted volunteers they can video chat with: the sighted person can tell the blind person what he sees when the blind user points his phone's camera at something.

6.1.6. Emerging technology

New technology approaches are under development, but it is not easy to predict which of them will finally emerge. Since the late 1990s, research has been in progress to create devices that can interface with neurons in the retina or in the optic nerve ("**bionic eyes**") (Stanford Ophthalmology 2016). They are based on micro light sensors, which can be implanted in the eye and send electrical signals to nerve cells. For instance, the **artificial silicon retina** (ASR) is a tiny computer chip to be implanted in a surgically created sub-retinal pocket (Chow, Bittner and Pardue 2010). The ASR is provided with five thousand micro solar cells that turn light into electrical signals. When the device is first switched on, patients see flashes of light, but in the course of a few weeks, the brain learns to convert these flashes into meaningful shapes. For now, the images are often black and white and very grainy (Krishnaveni, Lakkakula and Manasa 2012). **Retinal prostheses** are very close to bionic eyes (Second Sight 2016). The main difference is that the implanted device, interfaced with the optic nerve, is not able to sense light by itself but receives data signals from a miniature video camera mounted on special glasses.

Box 6- Sensations and Sensory Substitution

Sensations and Sensory Substitution
What do born blind or born deaf people sense when implanted with an artificial sensory organ, such as bionic eyes or cochlear implants? Do these people really see and hear or do they have different sensations that they translate into visual and acoustic terms because there are no other available and they have never experienced "true" vision or hearing (Bach-y-Rita and Kercel 2003)? The question is not a theoretical one at all, because – depending on the answer – neuroprostheses could be more or less justified. Do people who have never experienced a given sensory modality need to be implanted (with all risks, inconveniences and costs of such an intervention) if in any case they cannot experience vision or hearing (Fine and Boynton 2015)? Would it not make more sense to consider the lack of a given sensory modality as a variance of the human constitution that can be compensated by other senses and a friendly environment? This is the position taken by the Deaf culture movement, which strongly rejects cochlear implants.

6.1.6.1 The World Blind Union highlights universal design as technological priority

Augmented reality (AR) spectacles are supposed to help visually impaired people (eSight 2016). By using micro cameras and tiny ultra-powerful computers, they can magnify images, filter colours and provide object and facial recognition assistance and auditory help. **Implantable miniature telescopes**, which project a magnified image onto the retina, have been proposed for people with partial vision due to age-related macular degeneration (AMD) (Chan 2013). People with AMD lose central vision, while retaining some degree of peripheral vision, which is hardly suited for reading texts, recognising faces and so on. The miniature telescope is implanted only in one eye – the better of the two. The other eye continues to provide peripheral vision to help with balance and orientation. With the same aim, researchers are also investigating **telescopic contact lenses**, which would allow avoiding implantation surgery (Servick 2015).

6.1.7. Promises and challenges

AT for blind people is currently driven by some general technology trends, such as:

- increasing wearability and portability (driven by miniaturisation, reductions in power needs and availability of new, more affordable and smaller power sources);
- innovations in display technologies and new flexible user interfaces and input options (e.g. touch screens, gesture recognition, brain interfaces, haptic feedback);
- consumer-level access to tools of development and creation (e.g. 3D printers, app development tools for blind people).

These trends seem to lead towards technologies that incorporate the needs of disabled persons in mainstream production. The World Blind Union highlights universal design as technological priority and lists the following goals for the next years: "*to use mobile phones or computers and access websites on the internet, the use of automated bank machines and direct payment machines in stores, or the ability to read the screens in airports, bus terminals, or government kiosks in order to access important information, as well as the ability to vote with a secret ballot (like others) and have their vote be counted and still be private*" (WBU 2016). Technologically speaking, all these goals are in progress or have been achieved, chiefly thanks to the commitments of technologists and industries, which have understood that their interests could fruitfully meet with disable persons' interests. The main challenges thus seem to concern accessibility and economic affordability, notably at global scale. Addressing accessibility and economic affordability means to promote public private partnerships, with the aim to lower production costs and keep prices retail prices under control. This results can be achieved only through a mix of well-coordinated public and industrial policies.

Among "sensory substitution" technologies, first successful experiments with the most futuristic technology – i.e. bionic eyes – have received huge media coverage, but this technology does not seem to be a priority for the blind community. Technology developments based on **substitution across sensory systems**, such as auditory or tactile-vision substitutions (e.g., new advanced haptic technologies, are still raising more positive expectations than experimental high-tech brain-human interfaces. Likewise, it is likely that significant results may be achieved by using new computer vision algorithms, which will be able to recognise objects, faces and even a person's mood, with the additional advantage that both sensory substitution across sensory systems and new computer vision algorithms are suitable also for visually impaired people, who would not benefit from neuroimplants. The main players is this sector are likely to be academia and high tech industry; public authorities have the important responsibility for updating normative barriers (which have been often designed for different, obsolete, technological contexts and are consequently unfit to regulate today high tech research) and to simplify bureaucratic procedures, notably in the area of privacy and data protection.

Among "environment" technologies, the most promising development is the **Internet of Things** (IoT).[25] The creation of large networks of objects which collect and send data, store information and make use of real-time processing and cognitive computing to interact with blind and visually impaired people could have a tremendous impact on disabled people's life, not only making their environment more friendly but providing them with almost an "electronic eye", which exploits the mutual visibility between objects in the IoT. There are, however, also some challenges in this positive scenario. The IoT should be protected against attacks, notably denial-of-service attacks, and privacy issues must be addressed. Plunged into the Internet of Things, interconnected through their sensory substitution systems, disabled people would risk becoming victims of cyberattacks, giving up their privacy and being continuously monitored. It is thus important to address these challenges already in the design phase by applying default strategies for security and privacy protection. If correctly used, "environment" technologies based on the IoT could even have a positive impact on privacy, such as the possibility to detect security cameras or other surveillance technologies nearby and inform a disabled person about them (Ahmed et al. 2015). Governance of IoT is huge issue, which has been discussed in a number of studies (Weber, 2103). It should involve all the main stakeholders, notably research, industry, policy makers, and users.

6.2. AT for deafness and hearing impairment

AT for deaf and hearing impaired people include three broad classes of devices: 1) hearing technology, 2) alerting devices and 3) communication technology.

6.2.1. Hearing technology

Hearing technology includes devices used to improve the level of sound available to a listener and is, therefore, not made for deaf people with a complete loss of their hearing ability. This technology includes devices for hearing aids, assistive listening devices, personal sound amplification products (PSAPs) and cochlear implants (Hersh and Johnson 2003).

Figure 7: Collapsible Victorian ear trumpet (source: Wikimedia Commons)

Hearing aids are sound-amplifying devices intended to compensate for impaired hearing (EHIMA 2015). Hearing aids have a long history (, much like lenses and eyeglasses, but their impact on disabled people's life differs substantially from that of vision aiding technologies. Ear trumpets date back to the

[25] The "Internet of Things" (IoT) refers to everyday objects that are networked and connected to the Internet.

17th century and the first electrical hearing aid was invented at the end of the 19th century (Washington University School of Medicine 2012). Hearing aids have been associated with the stigma evoked by deafness and, thus, people often feel ashamed of using them. Moreover, hearing aids were, and are, on average less effective than visual aids. In refractive disorders, the retina as well as the optic nerve is undamaged, meaning that the generation and transmission of visual inputs are still possible. Most cases of hearing loss are mixed, meaning there is also a damage of the neurosensory tissue, preventing – at least in part – the generation of nervous outputs. Hearing technology can amplify, filter and variously adjust sounds but it cannot generate nervous signals and cannot overcome a deficit of the brain auditory cortex itself. As we have mentioned in chapter 3.2.1, the auditory cortex shows a tendency to become atrophic when it does not receive regular stimulation. Because of the stigma related to deafness and the high cost of hearing aids, most people tend to procrastinate using hearing aids. So, when they eventually start using the aids, it is often too late to avoid that the original sensory deficit gets less manageable because of the progressive auditory cortex deficit, which poses an unsurmountable challenge to hearing aids. This explains the level of dissatisfaction that many people with hearing loss have with even the most technically advanced hearing aids. Early hearing aids used analogue signals which processed sound in a linear fashion; today they are very rarely used. Current hearing aids use **digital signals** which allow them to be programmed at different frequencies. Digitalisation also provides special processing capabilities that help improve speech recognition, noise reduction and overall performance. They may vary in size and features, including *behind-the-ear (BTE)*, *in-the-ear (ITE)* and *in-the-canal (ITC)* devices. A peculiar type of hearing aid, which is considered almost a prosthesis, is the **bone-anchored hearing aid** (BAHA), which is a surgically-implanted device, suited for conductive hearing loss because it allows bypassing external and middle ear anatomical malformations.

Assistive listening devices (ALD) can be used by individuals or large groups of people. They amplify the sounds and are particularly helpful when there is a significant background noise (NAD 2016). By using different types of energy (see below), ALDs transmit signals to a miniature wireless receiver (tele-coil, also known as t-coil), which turns back signals into sounds. Originally, ALD receivers were headsets; today, t-coils are often installed inside hearing aids or a cochlear implant. There are several types of ALDs: some are designed for large environments, such as conference halls, airports, theatres etc., others are to be used in small settings and for one-on-one conversations. They could use different technologies, including *hearing loop systems* (which create electromagnetic fields to amplify sounds), *frequency-modulated (FM) systems* (which use radio signals) and *infrared systems* (which use infrared light).

Figure 8:Infant with cochlear implant (source Wikimedia Commons)

Personal sound amplification products (PSAPs) are devices that increase sound levels and reduce background noise. They include a vast array of items, such as amplification systems, stethoscopes, TV/telephone amplification etc. Usually, they use earphones or headphones or have a neck loop for hearing aid users to listen through their hearing aids. They can also have directional microphones that can be angled towards sound sources (NAD 2016). The **cochlear implant** (CI) is a surgically-implanted sensor that converts sound inputs into electrical outputs that can be transmitted through the auditory nerve. It could be considered as an artificial cochlea, "*the cochlear implant does not result in "restored" or "cured" hearing. It does, however, allow for the perception of the sensation of sound*" (American Speech-Language-Hearing Association 2016). The cochlear implant, which remains controversial, is suggested for adults who have recently lost their hearing (in any case, after having learned speech and language) and for children older than 1 year and younger than 5 years who have profound hearing loss in both ears (American Speech-Language-Hearing Association 2016). There are several systems available and the technology – although still in development – cannot be considered any longer experimental (unlike bionic eyes). All current cochlear implants have external and internal components (Figure 8). The external component usually includes a miniaturised microphone, a speech processor, a battery and a transmitter. Sounds are captured by the microphone and send to the speech processor, which is a tiny computer that digitises sounds and sends them to a transmitter, which transmits signals to a receiver implanted under the skin. The receiver captures the signals and sends them to electrodes surgically inserted in the cochlea. The electrodes stimulate the auditory nerve. Researchers are now in progress to develop new low-power signal-processing chips connected to a **wirelessly rechargeable cochlear implant** with no external hardware (Hardesty 2014). Research on **next generation sound processors** – which can filter out noise and help people to focus on specific sounds – also seems promising (Technavio 2016).

The EASTIN database lists 300 products under the heading "Assistive products for hearing" (ISO Code 22.06.27), which include hearing aids, personal amplifiers and ALD.

Box 7- The Cochlear Implant Controversy

The Cochlear Implant Controversy

Cochlear implants were introduced in the 1980s and they raised quite soon two fundamental questions. The first question concerns their effectiveness. What purpose are cochlear implants for? These devices are often recommended for deaf children with the immediate goal to allow them to acquire basic speaking and listening skills, being the wider objective to improve their social interactions, their school performance and, finally, their quality of life. Undoubtedly, children who first did not hear at all may hear sounds after the implant, but it is unclear how many implanted children become also able to use oral language (Peixotoa et al. 2013). The ability of using a spoken language depends on a number of variables, and can be fluctuating. As a matter of fact, all implanted children are recommended also to learn or not to abandon sign language and, at the end, they use both languages plus lip reading. Furthermore, it is very difficult to assess whether cochlear implants truly improve social interactions, school performance and quality of life, as such an assessment depends on too many variables, including the level of basic assistance provided to deaf children (Percy-Smith et al. 2008). This leads to the second fundamental question. Given that cochlear implants are often performed on deaf children, who are twofold unable to consent (because they are minor and because they are impaired in their communication skills), is it ever ethical to submit them to a surgical intervention – which presents some significant complication risks (U.S. FDA 2016) – without any proven benefit in terms of quality of life? A cochlear implant is for life and one will depend forever on batteries, on a given manufacturer and so on. Consequently, the Deaf community has raised the basic objection that cochlear implants are more for making life easier to "oral culture" people than for improving deaf people's life (Blume 2009). A further highly controversial issue concerns the deaf parents' moral right to wish a child as deaf as them, an issue that was first raised after a deaf lesbian couple's deliberate attempt at finding a deaf donor to increase their chances of having a deaf baby (Bauman 2005). If deafness has to be considered a cultural condition rather than a disability, then this wish is perfectly legitimate. Following this line of thought, the quarrel has reached the point that people defending cochlear implants have been accused to plan the "genocide" of the Deaf culture (Friedner and Helmreich 2012). Statistical and demographic data about the size of the two groups, pro and against cochlear implants, are not available. It is likely that activists of both sides are a minority, as it often happens, while the majority of deaf people probably shares the mid-position represented by the World Federation of the Deaf in its 2011 Congress Resolution (WFD 2011), which did not ban cochlear implants but recommended that "*information on sign language development for children with cochlear implants be provided to parents, and that WFD create a position paper on cochlear implants*" (unfortunately, as per today, the WFD has not yet produced this paper). However, hyperpolarised positions are less and less frequent in literature and in the media, Deaf community activists tend to be less radical and cochlear implant supporters, including technologists and cochlear implant producers, show more will to understand the Deaf community's point of view (Cooper-White 2015).

6.2.2. Alarm and alerting systems

Figure 9: Video Relay Service to communicate with a hearing person via a video language interpreter (source Wikimedia Commons)

Alerting or alarm systems are devices that are suited also for deaf people, because they do not usually require any residual hearing capacity (Lucker and Hersh 2003). They use light or vibrations or a combination of them to alert users that a particular event is occurring. They include 1) clocks and wake-up alarm systems, 2) household device alerts, 3) doorbell and telephone alerts. They may use remote receivers placed around the house or portable pagers. There are also devices designed for baby monitoring, which are able to recognise different types of baby cries and alert the disabled parent accordingly. The EASTIN database lists 173 products as indicators "with visual signals" **(**ISO Code 22.27.03).

6.2.3. Communication support technology

Communication support technology, also known as **augmentative and alternative communication (AAC)**, includes various tools that overall aim at improving communication skills of the disabled person. They are usually classified under two main headings: 1) telecommunication services and 2) person-to-person interactions (NSW Government 2016). **Telecommunication services** (Figure 9) include mainly standard technologies, such as physical and virtual keyboards, touch screens, video calling, captioning for phone calls, text messaging and other social media and text-based technology (e.g. WhatsApp, FB Messenger, Snapchat etc.). There are also systems that use voice recognition software and are able to translate spoken words into sign language or text. **AAC for person-to-person interactions** includes picture boards, keyboards, touch screens, display panels, speech-generating devices and software. Some of these technologies address also born-deaf people and deaf people who run the risk of losing their speaking ability as well as deaf-blind people. Overall, these devices use technologies that are described in the present report and do not present any additional points of interest. The EASTIN database lists 223 products under the heading "Assistive products for alternative and augmentative communication" (ISO Code 05.06).

Box 8- Dual Sensory Impairment

Dual Sensory Impairment

Deaf-blindness is a unique and separate disability from deafness or blindness. It is important to emphasize that this is not necessarily a condition in which a person is completely deaf and blind. That might be the case, but absolute deafness and blindness occurring together is actually very rare. In most cases, people experience some level of both hearing and vision disability to an extent that it disrupts their ability to learn and communicate. It is typically due to congenital medical conditions, and it affects children. However, with population ageing, the number of senior people suffering from dual sensory impairment is increasing. Age-related, combined, vision and hearing loss is going to become a serious problem in the next future. Assistive technology for these people may rely only on haptic technology, because both vision and hearing are lost (Senses Australia 2016). They include 1) *Braille communicators*, which are devices for Braille writing (Braille note-taker) integrated with a Braille phone, 2) *communicators for deaf-blind and sighted persons*, in which communication appears both on the deaf-blind person's refreshable Braille display and visually on the screen of the sighted person, 3) *telephone devices for the deaf* (referred to as TDD or TTY), which usually use refreshable Braille displays. However, most haptic devices previously described (0) are also suited for this group of disabled people. *Smart Glasses*, using maps and GPS to create a live real time 'radar' showing where the wearer is at all times and where they are in proximity to roads and other hazards, are also in progress.

6.2.4. Emerging technology

New and advanced **cochlear implants** are in progress (Gaylor et al. 2013). Moreover, another prosthetic technology is emerging, the **auditory brainstem implant** (ABI), which is a hearing device that stimulates neurons directly at the human brainstem, bypassing the inner ear and acoustic nerve (Monsanto et al. 2014). This device is designed primarily for children with profound hearing loss at birth who cannot receive – because of various medical reasons – cochlear implants. Normal hearing is not restored but children may improve their conditions, and this could partly prevent deficits in communication skills secondary to their challenges. **Other emerging technologies** for deaf and hearing impaired people are essentially applications of existing technologies (NC-DHHS 2016), such as

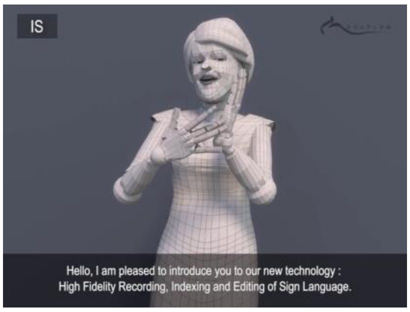

Figure 10: Sign Language Avatar (source: MocapLab)

- *Google glasses* equipped with sign language interpreters (Figure 10); they exploit a number of apps (e.g., Hand Talk, Mimix3D, ASL Translator, ProDeaf Translator, etc.) already available on the market, which display an on-screen avatar who translates the words heard into sign language; the system projects the interpreter on the screen of the glasses;
- various systems to provide *real-time captioning,* for instance, an app developed at Georgia Tech, working with a smartphone. The person with whom the glass wearer is speaking simply talks into the phone and the transcribed text automatically appears within the glass.
- purpose-designed software for laptops and tablets;[26]
- *several smartphone applications*

Actually, research on technology for deaf and hearing impaired people largely coincides with research on mainstream technology. This is not surprising because the information and communication revolution has been largely based on visual communication; consequently, deaf and hearing impaired people have been only marginally disadvantaged by technology advances, while, since the beginning, they have had the opportunity to use the huge potentialities of novel information technologies. This has allowed the Deaf community to become technology savvy. Deaf and hearing impaired people have thus actively contributed to mainstream technology (WFD 2014). They have been among the first adopters of video chat technologies and services such as Skype, Google Hangout and FaceTime. The sam holds true for Instant Messaging (IM) (WFD 2014). Also text-to-speech and speech recognition software has been promoted – and first used – by deaf people to communicate with others without the need for sign language or lip reading (WFD 2014). Finally, the Deaf community has espoused and successfully advocated the *Design for All* approach[27], which is now the benchmark.

[26] E.g. the video-based sign language interpreting and text-based operator service introduced in Hungary by the Hungarian Association of the Deaf and Hard of Hearing (https://www.skontakt.hu/english/).

[27] "Design for All is based on the recognition of the fact that it is often easier and more cost-effective to design a product from the ground up, so that anyone can use it, rather than building in accessibility features for specific target groups after the fact" (WFD 2014, 1).

6.2.5. Promises and challenges

Next developments of AT for deaf and hearing impaired people will probably still concern technologies for **sensory substitution across sensory systems**, such as vibratory and visual-auditory substitutions. Many applications are in progress in this field, and the apparent goal is to create direct perceptual experiences closer and closer to the equivalent experience of hearing. In principle, one could even imagine a technology for sensory substitution that is able to make a deaf person go through a musical experience translated into another sensory modality. As illustrated in the case of AT for blind and visually impaired people, sensory substitution technology will probably be coupled with the **new generations of computer vision algorithms** and **speech-to-text and text-to-speech software**. Needless to say that technology **standardisation** and full interoperability among devices and platforms are prerequisites. The development of the **Internet of Things** is expected to contribute to create a friendlier environment for disabled people.

6.2.5.1 Standardisation and full interoperability among devices and platforms are paramount

However, the main promise of future AT for deaf and hearing impaired people is likely to be new **software for translating sign language into spoken and written languages and vice versa**. This would not be a complete novelty, but current technology is far from being satisfactory. Sign language critically depends on facial expression to communicate thoughts. This makes it particularly difficult to use sign language software in suboptimal conditions and in real life contexts (e.g. for recording and translating conferences, interacting with automatic devices in crowded and badly illuminated areas and so on).

Besides a **more objective discussion on cochlear implants** and other neuroimplants, the main challenge to be met is likely to concern **economic costs and affordability of hearing aids**. Deafness and hearing loss are important disabilities in low income countries, where people can hardly afford to purchase expensive digital hearing aids. In industrialised countries, the aging of the population is likely to increase age-related hearing impairment. New generation hearing aids are very expensive and are usually not fully reimbursed either by public social insurances or by private health insurances. Moreover, hearing aids need routine maintenance and must be periodically replaced. This implies extra costs that are often too high to be met by retired elderly people.

6.3. AT for autism spectrum disorders

ATs are increasingly used by individuals with ASD (Lang et al. 2014), primarily to overcome barriers and to train disabled people in specific skills, such as 1) communication skills, 2) social skills and 3) various adaptive skills relevant to daily life (Nevers 2013). Searching the term "autism" in the EASTIN database, 540 products are identified.

Table 5- Assistive products for ASD

ISO Code	Description	Number of products
22.21.09	Products to support communication	480
22.33.12	Products for computer-assisted instruction	30
28.27.12	Assistive products for training in programming and informatics	30

6.3.1. AT for communication

Figure 11: GoTalk 20+ (source: Wikimedia Commons)

Communication skills are variously impaired in people with ASD: some only suffer from poor non-verbal empathic communication skills; others are affected by more severe forms of discourse perseveration, verbal stereotypies, echolalia, idiosyncratic reactions; others are totally unable to articulate an understandable language. Assistive technologies used to support communication are **augmentative and alternative communication (AAC)** technologies (Mueller 2013a) previously discussed (Figure 11). They are usually classified in "*unaided*" and "*aided*" systems. *Unaided systems* are those that do not require the use of anything other than one's own body to communicate.

They include gestures, body language and sign language. *Aided systems* are those that require the use of an object other than the individuals' body to communicate. Aided systems could be further classified into **low-tech** materials and **high-tech** devices. Low-tech materials are boards, cards, picture symbols, and so on. High-tech devices offer a similar functionality, but use electronic platforms. They include communication aids (usually hand held) which allow the user to create a variety of preformed messages simply by pressing a key. There are also more sophisticated tools, such as **speech-generating devices (SGD)** (Lang et al. 2014) that are connected to a touch screen (often of a tablet). The user writes messages on the screen, either using symbols or text, and the device speaks the message aloud. AT for communication in ASD usually also includes devices for **computer-assisted instruction (CAI)** (Mueller 2013b). These are computer applications for training people affected by ASD to practice certain communication skills in a virtual environment. They are not that different from software for training people in learning foreign languages or for teaching them to play a musical instrument.

6.3.2. AT for social skills

6.3.2.1 Children with autism show interest in robots, but there is no consensus among experts and therapists about their clinical utility

Deficits in social skills are a peculiar feature of ASD and are likely to be the most significant aspect. Typically, they include failure to develop peer relationships, lack of joint attention, deficits in the extent of social and/or emotional reciprocity, difficulties towards social relationships and emotions associated with them. Most ATs for social skills are devices for **computer-assisted instruction (CAI)** (Lang et al. 2014). By using dedicated software, people with ASD may practice various social skills (e.g. attending to eye gaze, discriminating between facial expressions, recognising faces, identifying emotions, and so) with human avatars. Some applications are similar to realistic **video games** (Shic 2013), in which the disabled individual trains him-/herself in various different life contexts. Other technologies include 1) **video-modelling** (Prelock 2013), which is a training based on watching a video and then imitating the modelled behaviour, 2) **script training** (Lang et al. 2014), in which the social interaction is scripted on a computer and the disabled individual is asked to play it. Researchers are currently exploring also the possibility to develop smart glasses to provide real-time social cues (Washington et al. 2016), with the goal of maximising behavioural feedback, while minimising the distractions to the child. Finally, researchers have also devoted efforts to investigating the possibility of using **robots and robot toys** with children with ASD (Diehl et al. 2014). Robotic agents could be programmed to interact with children by simulating typical spontaneous human interactions. Although most children with ASD show interest in robots, there is no consensus among experts and therapists about their clinical utility (Begum, Serna and Yanco 2016).

6.3.3. AT for adaptive and daily living skills

Adaptive and daily living skills are variously impaired in people with ASD. These skills are not impaired primarily; rather, they are impaired because of other deficits (Cassidy 2013). For instance, children who are unable to bond with others also have difficulty in developing the capacity for self-care (e.g. grooming, dressing), because they lack social motivation. This explains why persons with ASD often show a gap between intellectual capacity and very poor adaptive skills. ATs for adaptive and daily living skills are mainly applications for **computer-assisted instruction (CAI)** (Mueller 2013b). There are various instructional programs designed to train people with ASD in basic functional life skills in a virtual environment or through modelling.

6.3.4. Emerging technology

The next generation social robots will probably also be able to represent emotional states, empathy and non-verbal communication

Figure 12: Social Robot "Pepper" (source Wikimedia Commons)

Emerging technologies for ASD largely coincide with technologies previously discussed. The field of AT for ASD is quite recent and it is almost impossible to draw a clear-cut distinction between existing and emerging technologies (Silton 2014). However, the most important emerging area is probably represented by robotics, notably **social robotics** (Figure 12**)**. Robotics research over the past decade has suggested that most children on the autism spectrum are fascinated by humanoid robots and robot toys, and tend to interact with them more easily than with humans (Begum, Serna and Yanco 2016). Yet, although there is little doubt that ASD children like robots, there is no true evidence that robot-mediated interventions are of any utility in ASD. Caregivers and family members are rather sceptical about this possibility (Diehl et al. 2012). However, social robotics offers some interesting and advantageous features (Cabibihan et al. 2013). First, they could contribute to collecting data to formulate a correct diagnosis. There is growing evidence that it is possible to detect ASD earlier by studying eye contact in babies. Social robots can monitor eye contact more accurately than any human therapist and over longer periods of time. Social robots can also be used to train children to improve their social, sensory and cognitive skills as well as their motor control. Robots can be carefully programmed to repeat games again and again without ever becoming exhausted, and they may also record data to monitor the progress. Moreover, the next generation social robots will probably also be able to represent emotional states, empathy and non-verbal communication (Interdepartmental Research Center 2016). This could be very helpful in teaching children basic social skills.

Finally, other emerging ATs for ASD include the Apple Watch and other wearables devices (also provided with biometrics), Oculus Rift, Google Glass, Amazon Echo (Nelson 2014). Research is also focusing on digital avatars and video games specifically tailored to needs of ASD people (Nelson 2014).

6.3.5. Promises and challenges

Future assistive technologies for ASD will aim at decreasing and fine tuning sensory, cognitive and emotional stimuli rather than augmenting them

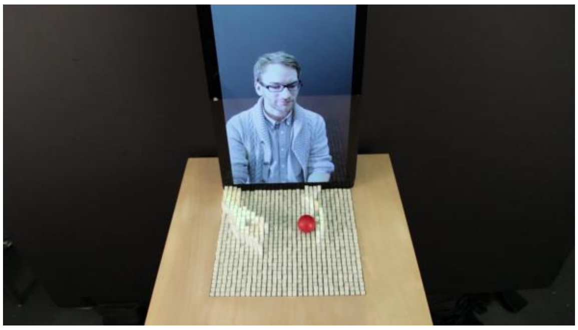

Figure 13: Dynamic Shape Display (source: inFORM)

The most promising field of research and development in technology for ASD focuses on the sensory information disorder associated with ASDs. As previously mentioned, evidence has been accumulated that people on the autism spectrum have difficulty modulating all the sensory inputs they receive. For now, it is impossible to say whether this disorder is just associated with ASD or whether it is causally related to the whole syndrome. Today, the mainstream approach to children on the autism spectrum is based on the assumption that they lack empathy, are emotionally distant and not paying much attention to their environment. Consequently, most current technologies for ASD aim to increase their attention and participation (Figure 13) . Also the approach to sensory processing disorder follows this perspective, being largely based on occupational therapy with the aim of retraining the senses. Technologies are mainly used to fine tune sensory information, mitigating it when people are over-sensitive and increasing it when they are under-sensitive (The National Autistic Society 2016). Technologies for increasing sensations are basically the same as those proposed for people with impaired sensory perception. Technologies for mitigating sensations include coloured filters to block the wavelengths of light to which an individual is hyper-sensitive, sound-blocking headphones to regulate the noise in the environment and similar technologies for filtering other sensory inputs. This approach is often integrated into the so-called "sensory diet", "*in which the child is slowly introduced to activities in a gentle, fun way, in order to get used to a range of sensations*" (Rodden 2016).

Yet, if the *Intense World Theory* (see chapter 3.3.1) is true, we probably have to rethink the standard strategy: sensory stimuli, cognitive and intellectual inputs, and emotions (including positive emotions) should be mitigated rather than increased. The goal should be to prevent the child from withdrawing into himself as an extreme defence against a world that threatens to invade and destroy him. This could be attempted by avoiding cognitive and emotional overflow and modulating sensory perceptions. Sensory modulation can result from filtering stimuli (according to the present approach) but also by contrasting them with other stimuli specifically tailored for this purpose, even taking advantage of autistic people's capacity for synesthesia. For instance, the social sensory surface (Ahlquist 2015) is an innovative project that aims to develop high-tech textiles which could be used to give autistic children pleasant and relaxing sensory stimuli that can help them to be less scared by their sensations. Special vests producing deep pressure in specific body points have also been proposed to calm autistic children and assist them in dealing with the sensory overflow (BioHug 2016). Moreover, a number of mobile applications are under development to prevent emotional overflow and regulate emotional stimuli by using vibrations and relaxing colours and music (Harpold 2016). Finally, it has also been proposed to produce "built environments" for autistic children. This strategy advocates the creation of ad hoc environments tailored to the needs of autistic children, made of various sensory spaces including reduced sensory areas (Research Autism 2016). In short, future challenges could concern the need to rethink the current approach to ASD treatment and develop technologies aimed at decreasing and fine tuning sensory, cognitive and emotional stimuli rather than augmenting them.

7. Technological trends analysis

In the previous sections, we described current trends in the field of AT within the three disability areas. In the following sections, we categorise them through the analytic grid described in Chapter 4.4.

7.1. Technology perspective: low-high tech

In this paper, we have made the distinction between low and high tech in operational rather than in absolute terms. For instance, when adopting a definition of high tech strictly based on R&D intensity, mobile applications should be considered high tech; yet, they are in fact medium-low tech because of their wide diffusion, learnability, ease of use and economic accessibility. The same holds true for devices provided with speech recognition and speaking capacities, which were definitely high tech fifteen years ago but are medium tech today. Looking at the three disability areas discussed, it seems apparent that there is an overall balance between low- and high-tech solutions, with probably a slight prevalence of medium-low tech solutions. Actually, very high-tech devices are rare (one could mention, e.g., bionic eyes, cochlear implants and robotics for autism); some devices can be classified as medium-high (e.g. ALDs, most advanced haptic aids, electronic travel devices, computer-assisted instruction); others are definitely medium-low (e.g. some haptic aids, most low vision aids, mobile applications for visually and hearing impaired people, video modelling for autism). This is also confirmed by the number and type of products listed in the EASTIN database. And also the systematic review of the scientific literature confirms that there is no trend towards low or high tech but that the tendency is to stay somewhere "in between".

7.2. Individual impairment perspective: ability – accessibility

Both poles, "ability" and "accessibility", are represented by a number of technologies previously discussed. Devices such as electronic travel aids and digital hearing aids incline more towards *ability*, because they focus more on bodily functions as a cause of individual impairment. Embedded technology for blind and visually impaired, ALDs for hearing impaired, visual alarms and alerting systems for deaf people, social simulators for ASD, incline more towards *accessibility*, because they primarily address the environment and barriers to disabled people's participation in social life. Overall, however, the three areas discussed in this study show a common trend to privilege "accessibility" over "ability", which is likely to be more evident in the case of AT for blind and visually impaired people. Both the search in the EASTIN database and the systematic review of the scientific literature confirm this analysis.

7.3. Caregivers perspective: augmentation – automation

The polar couple "augmentation" and "automation" focuses on social and contextual factors. Today, there is an apparent trend towards an increasing autonomy of the disabled individual, which means that ATs primarily tend to take over the work of human caregivers. This is apparent in the case of sensory disabilities, in which most ATs aim to make the disabled person fully autonomous, without the need of human assistance. In this case, as in the case of "prosthetic" ATs, automation might become very closer to human enhancement, being at the end the distinction between the two mostly a matter of perspective chosen (e.g., augmented-reality contact lenses, which provide extra capacities, including night vision, infrared and UV vision, etc.). This trend is also evident in the case of people with ASD, where technology tends to substitute humans for machines (e.g. social robots). Both the search in the EASTIN database and the systematic review of the scientific literature confirm this analysis.

7.4. Wider societal perspective: integration – inclusion

The trend that emerges from AT discussed in this paper seems to incline towards inclusion. With the significant exception of bionic eyes (Green 2015) and cochlear implants (Hyde and Power 2005), current ATs do not try to "hide" disability, i.e. to make the disabled person indistinguishable from normally-abled people; rather, they tend to make disability more socially manageable and to assimilate disabled persons without denying their disability. Both the search in the EASTIN database and the systematic review of the scientific literature confirm this analysis.

Table 6- Examples of application of the grid to three different ATs

ASSISTIVE TECHNOLOGY ANALYTICAL GRID												
AT analysed:	**SMART CANES**											
TECHNOLOGY	**Low**			■								**High**
IMPAIRED INDIVIDUAL	**Ability**		■									**Accessibility**
CAREGIVERS	**Augmentation**										■	**Automation**
SOCIETY	**Integration**										■	**Inclusion**

ASSISTIVE TECHNOLOGY ANALYTICAL GRID												
AT analysed:	**ALARM AND ALERTING SYSTEMS**											
TECHNOLOGY	**Low**	■										**High**
IMPAIRED INDIVIDUAL	**Ability**			■								**Accessibility**
CAREGIVERS	**Augmentation**									■		**Automation**
SOCIETY	**Integration**								■			**Inclusion**

ASSISTIVE TECHNOLOGY ANALYTICAL GRID												
AT analysed:	**COMPUTER ASSISTED INSTRUCTION (CAI)**											
TECHNOLOGY	**Low**									■		**High**
IMPAIRED INDIVIDUAL	**Ability**					■						**Accessibility**
CAREGIVERS	**Augmentation**	■										**Automation**
SOCIETY	**Integration**				■							**Inclusion**

8. Conclusions

It is not easy to draw any definite conclusion at this early stage of the project. The whole picture is extremely nuanced. While it is not possible to make conclusive statements, it certainly is possible to identify a major gap and a few tendencies, which are f summarised by two tables (Table 7 and Table 8).

Table 7- Where we might be in 2030

WHERE WE MIGHT BE IN 2030			
	TREND	**PROMISE**	**CHALLENGE**
Blindness and visual impairment	AT incorporated in mainstream technology	Internet of Things for visually disabled	Bionic eyes and augmented sight
Deafness and hearing impairment	Neuroprosthesis and brain-machine interfaces	Addressing deafness due to cerebral cortex damages	Devices more and more expensive
Autism spectrum disorders	Fine-tuning sensory perceptions, cognitive inputs, emotional reactions	Built environments for autistic children to reduce information overflow	Understanding the genesis of ASD

Table 8- Barriers and resistance to ATs

BARRIERS AND RESISTANCE TO ASSISTIVE TECHNOLOGY				
	TECHNOLOGY BARRIERS	**CULTURAL BARRIERS**	**ECONOMIC BARRIERS**	**REGULATORY BARRIERS**
Blindness and visual impairment	Navigation in urban areas	The “otherness” of the blind person	Resources to invest on technology for e-participation	Common European policies to support visually disabled persons
Deafness and hearing impairment	Addressing central brain, deafness	Deafness-related stigma	Outrageous costs of hearing aids	Legislation to protect and support hearing impaired older people
Autism spectrum disorders	Assistive technology tailored to ASD	Cultural biases against technology usage in ASD	Technology innovation under-funded	Lack of specific legislation on ASD in many European countries

The main gap concerns the evident disequilibrium between ATs for blind and visually impaired people, on the one hand, and ATs for deaf and hearing impaired people as well as for ASD, on the other hand. ATs for blind and visually impaired people outnumber other ATs and cover a much wider set of functions. This is confirmed by a simple comparison between data extracted from the EASTIN database: in total, 1 838 products are listed as ATs for blind and visually impaired people, 533 as ATs for deaf and hearing impaired people and 540 as ATs for ASD. Of course, figures should be normalised by considering the number of disabled people in Europe for each category and the overall economic dimension of the AT market. Yet, even from these rough figures it is evident that a gap exists. We have discussed some cultural reasons that could explain this gap, but a further reason is likely to be found in the nature of information revolution, which has initially privileged visual communication. This is also mirrored by the large attention devoted to visual processing disorders in autism, while little attention has been devoted to other kinds of sensory processing disorders, such as distortions of olfactory sensations, which can be even more disturbing for the individual affected.[28] Yet, technology advances are increasingly enriching online communication, which now includes sounds and in the next future will include also tactile sensations. In the longer term, maybe other sensory modalities will be conveyed

28 People suffering from persistent olfactory over-sensitivity and olfactory hallucinations may find it almost impossible to live in society.

electronically. There is an ongoing discussion among scholars about how technology advances may modify future sensory perception and sensory priorities (Howe 2006), whether, for instance, our civilisation is going to become "less visual" and "more acoustic" and "tactile" (Paterson 2006). These trends are also going to affect disabilities and ATs, but in what way will they be affected?

Three trend lines can be identified:

1. *Integration into mainstream technology*: The traditional dichotomy between low and high tech holds. Yet, it is evident that there is a vast area of medium-tech devices. Interestingly enough, technologies in this area tend to differ very little from mainstream technology. This trend emerges in all three disability fields. The most blatant example concerns smartphones and their applications, but it is also evident with GPS technology for blind and visually impaired, with video chat technologies for deaf and hearing impaired, and with video games and CAI for ASD. This trend is due to many factors, not least an approach to technology development that is increasingly based on universal design principles. There are no signs that this trend is going to reverse; on the contrary, it seems destined to enlarge and to involve more and more ATs. In the longer term, one could even imagine that the distinction between non-assistive and assistive technology will fade away.

2. *Priority to autonomy*: People with disabilities suffer from a lack of autonomy. Most ATs aim to restore autonomy of the disabled person. This goal can be achieved either by improving the impaired functions (e.g. visual and hearing aids, AAC for ASD) or by modifying the context (e.g. RFID labels for blind and visually impaired, visual and vibrating alarms for deaf and hearing impaired, virtual reality for ASD), or by doing both (e.g. ETDs for blind and visually impaired, ALDs for deaf and hearing impaired, CAI for ASD). The trend towards autonomy is ethically significant and can have an important impact on human rights. Yet, it is not totally risk-free. If one considers the concurrent trend towards automation that we have identified, there is the actual risk that autonomy could turn into isolation and social indifference. This risk should be properly addressed. Being respectful of others' autonomy should not become an alibi to justify indifference and negligence, both at interpersonal and at societal levels.

3. *Convergence with prosthetics*: Some emerging technologies are technologies that can hardly be distinguished from prosthetics. This holds true for sensory disabilities (e.g. bionic eyes, cochlear implants) but also with respect to ASD (e.g. wearable devices). Convergence between AT and prosthetics could be a dangerous trend because it implies difficult and complex considerations about what constitutes the human nature. The border between AT and augmentation technology runs the risk of becoming increasingly blurred, posing a myriad of legal, ethical and social issues. It is not by chance that most disabled people's associations are extremely reluctant to accept "prosthetic AT" and question its legitimacy.

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10. Annexes

10.1. Glossary

DEFINITIONS ADOPTED IN THIS PAPER		
Term	**Source**	**Definition**
Disability	CPRD	*long-term physical, mental, intellectual, or sensory impairments which in interaction with various barriers may hinder their full and effective participation in society on an equal basis with others*
Health condition	ICF	*umbrella term for disease, disorder, injury, or trauma*
Body function	ICF	*physiological functions of body systems (including psychological functions)*
Body structure	ICF	*anatomical parts of the body such as organs, limbs, and their components*
Impairment	ICF	*problems in body function or structure, such as a significant deviation or loss*
Activity limitation	ICF	*difficulty encountered by an individual in executing a task or action*
Participation restriction	ICF	*problem experienced by an individual in involvement in life situations*
Environment	ICF	*the physical, social, and attitudinal environment in which people live and conduct their lives*
Personal factors	ICF	*contextual factors that relate to the individual, such as age, gender, social status, and life experiences*
Universal design	CPRD	*the design of products, environments, programmes and services to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design. "Universal design" shall not exclude assistive devices for particular groups of persons with disabilities where this is needed*
Assistive product	ISO 9999:2011	*any product (including devices, equipment, instruments and software) especially produced or generally available, used by or for persons with disability (1) for participation; (2) to protect, support, train, measure or substitute for body functions/structures and activities; or (3) to prevent impairments, activity limitations, or participation restrictions*

10.2. Hit count of AT-related terms

Hit count of assistive technology and governance of science, technology and innovation related terms in academic articles from the four academic databases independent of the terms "occupational therapy" or "occupational science.

Round 1

The autism one

Tech* AND (AUTISM OR ADHD OR autism spectrum disorder);

science* AND (AUTISM OR ADHD OR autism spectrum disorder);

inno* AND (AUTISM OR ADHD OR autism spectrum disorder);

assistive AND (AUTISM OR ADHD OR autism spectrum disorder);

device AND (AUTISM OR ADHD OR autism spectrum disorder);

"assistive device" AND (AUTISM OR ADHD OR autism spectrum disorder);

"assistive technology" AND (AUTISM OR ADHD OR autism spectrum disorder);

The visual one

Tech* AND (blind, Visually impaired, low Visual);

scienc* AND (blind, Visually impaired, low Visual);

inno* AND (blind, Visually impaired, low Visual);

assistive AND (blind, Visually impaired, low Visual);

device AND (blind, Visually impaired, low Visual);

"assistive device" AND ((blind, Visually impaired, low Visual);

"assistive technology" AND (blind, Visually impaired, low Visual);

The auditory one

Tech* AND (Deaf; hard of hearing; auditory impair*; hearing impair*);

scienc* AND Deaf; hard of hearing; auditory impair*; hearing impair*);;

inno* AND Deaf; hard of hearing; auditory impair*; hearing impair*);

assistive AND Deaf; hard of hearing; auditory impair*; hearing impair*);

device AND Deaf; hard of hearing; auditory impair*; hearing impair*);

"assistive device" AND Deaf; hard of hearing; auditory impair*; hearing impair*);

"assistive technology" AND Deaf; hard of hearing; auditory impair*; hearing impair*);

Round 2

The results of each search combination for example tech* AND deaf could then be searched for secondary keywords that allow us to look at certain things (others might have other words they find useful to get to these three sub areas, e.g. the future (future, emerging, potential and other synonyms looking forward); applications (application, product, usage, utility, … and other terms that could be seen to uncover an application and its utility); problem (risk, problem, issues, governance, regulation, and other terms that could be seen to uncover potential problems.

Web of science: first keyword- topic/second keyword -in text third keyword in text

EbSCO All all 70 databases first keyword- abstract/second keyword –abstract/ third keyword abstract (2000-2016; academic journals)

IEEE first keyword- metadata/second keyword –metadata/ third keyword-metadata

First keyword terms	second Keyword Search	Results from Academic Databases: *Web of Science*	Results from Academic Databases: *EBSCO ALL*	Results from Academic Databases: IEEE explore	Third keyword	Results from Academic Databases: *Web of Science*	EBSCEbsco allO	Ieee explore
Autism 41246/152593 732	Tech*	2042	6586	371	Future	299	300	27
					Emerging	140	95	19
					Potential	318	382	55
					Application	250	352	108
					Usage	16	7	6
					Utility	49	75	2
					Product	26	111	4
					Problem	198	179	44
					Risk	211	195	11
					Issues	159	253	22
					Governance	1	0	0
					regulation	42	23	1
					Trend*	41	59	3
	Scien*	1366	5995	246	Future	158		
					Emerging	82		
					Potential	168		
					Application	82		
					Usage	4		
					Utility	16		
					Product	30		
					Problem	134		
					Risk	163		
					Issues	155		
					Governance	3		
					regulation	24		
					Trend*	43		
	Innov*	183	774	27	Future	23		
					Emerging	4		
					Potential	7		
					Application	19		
					Usage	1		
					Utility	8		
					Product	7		
					Problem	20		
					Risk	19		
					Issues	19		
					Governance	0		
					regulation	5		
					Trend*	4		
	Device	311	944	73	Future	38		
					Emerging	12		
					Potential	28		
					Application	56		
					Usage	5		
					Utility	7		
					Product	3		
					Problem	43		
					Risk	15		

First keyword terms	**second Keyword Search**	**Results from Academic Databases: *Web of Science***	**Results from Academic Databases: *EBSCO ALL***	**Results from Academic Databases: IEEE explore**	**Third keyword**	**Results from Academic Databases: *Web of Science***	**EBSCEbsco allO**	**Ieee explore**
					Issues	0		
					Governance	0		
					regulation	2		
					Trend*	2		
	Assistive	127	165	68	Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive device	1	2	1	Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive technology	62	105	21	Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
ADHD 22603/ 60000/ 129	Tech*	587	509		Future	65		
					Emerging	29		
					Potential	118		
					Application	68		
					Usage	4		
					Utility	30		
					Product	12		
					Problem	102		
					Risk	78		

First keyword terms	second Keyword Search	Results from Academic Databases: *Web of Science*	Results from Academic Databases: *EBSCO ALL*	Results from Academic Databases: IEEE explore	Third keyword	Results from Academic Databases: *Web of Science*	EBSCEbsco allO	Ieee explore
					Issues	42		
					Governance	1		
					regulation	35		
					Trend*	18		
	Scien*	696	1657		Future	67		
					Emerging	33		
					Potential	92		
					Application	28		
					Usage	5		
					Utility	11		
					Product	11		
					Problem	92		
					Risk	127		
					Issues	64		
					Governance	2		
					regulation	29		
					Trend*	11		
	Innov*	75	258		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Device	90	208		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive	10	18		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			

First keyword terms	**second Keyword Search**	**Results from Academic Databases: *Web of Science***	**Results from Academic Databases: *EBSCO ALL***	**Results from Academic Databases: IEEE explore**	**Third keyword**	**Results from Academic Databases: *Web of Science***	**EBSCEbsco allO**	**Ieee explore**
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive device	0	1		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive technology	0	6		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
Autism spectrum disorder 8052 27158 178	Tech*	419	497		Future	55		
					Emerging	31		
					Potential	75		
					Application	49		
					Usage	4		
					Utility	12		
					Product	1		
					Problem	37		
					Risk	56		
					Issues	26		
					Governance	0		
					regulation	15		
					Trend*	7		
	Scien*	187	672		Future	35		
					Emerging	17		
					Potential	38		
					Application	7		
					Usage	0		
					Utility	6		
					Product	3		
					Problem	18		

First keyword terms	**second Keyword Search**	**Results from Academic Databases: *Web of Science***	**Results from Academic Databases: *EBSCO ALL***	**Results from Academic Databases: IEEE explore**	**Third keyword**	**Results from Academic Databases: *Web of Science***	**EBSCEbsco allO**	**Ieee explore**
					Risk	25		
					Issues	0		
					Governance	0		
					regulation			
	Innov*	50	140		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Device	78	184		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive	26	18		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive device	0	0		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			

First keyword terms	**second Keyword Search**	**Results from Academic Databases: *Web of Science***	**Results from Academic Databases: *EBSCO ALL***	**Results from Academic Databases: IEEE explore**	**Third keyword**	**Results from Academic Databases: *Web of Science***	**EBSCEbsco allO**	**Ieee explore**
					Issues			
					Governance			
					regulation			
	Assistive technology	7	8		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
Blind 312580 Blind people 1050 5900 426	Tech*	238	616		Future	18		
					Emerging	5		
					Potential	20		
					Application	52		
					Usage	2		
					Utility	3		
					Product	8		
					Problem	46		
					Risk	5		
					Issues	24		
					Governance	1		
					regulation	2		
					Trend*	5		
	Scien*	56	311		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Innov*	16	89		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			

First keyword terms	second Keyword Search	Results from Academic Databases: *Web of Science*	Results from Academic Databases: *EBSCO ALL*	Results from Academic Databases: IEEE explore	Third keyword	Results from Academic Databases: *Web of Science*	EBSCEbsco allO	Ieee explore
					Issues			
					Governance			
					regulation			
	Device	180	429		Future	8		
					Emerging	2		
					Potential	19		
					Application	43		
					Usage	4		
					Utility	1		
					Product	5		
					Problem	20		
					Risk	4		
					Issues	10		
					Governance	0		
					regulation	0		
					Trend*	2		
	Assistive	68	27		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive device	10	1		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive technology	31	9		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			

First keyword terms	**second Keyword Search**	**Results from Academic Databases: *Web of Science***	**Results from Academic Databases: *EBSCO ALL***	**Results from Academic Databases: IEEE explore**	**Third keyword**	**Results from Academic Databases: *Web of Science***	**EBSCEbsco allO**	**Ieee explore**
					Issues			
					Governance			
					regulation			
low Visual 3087 8673 110	Tech*	293	475		Future	26		
					Emerging	8		
					Potential	29		
					Application	36		
					Usage	10		
					Utility	3		
					Product	10		
					Problem	30		
					Risk	16		
					Issues	25		
					Governance	1		
					regulation	0		
					Trend*	4		
	Scien*	95	232		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Innov*	28	86		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Device	298	790		Future	19		
					Emerging	7		
					Potential	32		
					Application	25		
					Usage	12		
					Utility	9		
					Product	9		
					Problem	27		
					Risk	17		

First keyword terms	**second Keyword Search**	**Results from Academic Databases: *Web of Science***	**Results from Academic Databases: *EBSCO ALL***	**Results from Academic Databases: IEEE explore**	**Third keyword**	**Results from Academic Databases: *Web of Science***	**EBSCEbsco allO**	**Ieee explore**
					Issues	24		
					Governance	0		
					regulation	2		
					Trend*	2		
	Assistive	73	194		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive device	6	4		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive technology	28	94		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
Visual impair* 2200 5217 0	Tech*	133	283		Future	8		
					Emerging	6		
					Potential	15		
					Application	25		
					Usage	3		
					Utility	0		
					Product	10		
					Problem	19		
					Risk	10		

First keyword terms	second Keyword Search	Results from Academic Databases: ***Web of Science***	Results from Academic Databases: ***EBSCO ALL***	Results from Academic Databases: IEEE explore	Third keyword	Results from Academic Databases: ***Web of Science***	EBSCEbsco allO	Ieee explore
					Issues	15		
					Governance	0		
					regulation	2		
					Trend*	1		
	Scien*	49	151		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Innov*	10	30		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Device	75	201		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive	32	78		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			

First keyword terms	second Keyword Search	Results from Academic Databases: *Web of Science*	Results from Academic Databases: *EBSCO ALL*	Results from Academic Databases: IEEE explore	Third keyword	Results from Academic Databases: *Web of Science*	EBSCEbsco allO	Ieee explore
					Issues			
					Governance			
					regulation			
	Assistive device	1	2		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive technology	19	24		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
Deaf 15679 69226 841	Tech*	1113	2973		Future	77		
					Emerging	23		
					Potential	130		
					Application	125		
					Usage	12		
					Utility	22		
					Product	14		
					Problem	131		
					Risk	45		
					Issues	100		
					Governance	2		
					regulation	5		
					Trend*	18		
	Scien*	427	1374		Future	27		
					Emerging	6		
					Potential	41		
					Application	18		
					Usage	1		
					Utility	8		
					Product	10		
					Problem	43		
					Risk	8		

First keyword terms	**second Keyword Search**	**Results from Academic Databases: *Web of Science***	**Results from Academic Databases: *EBSCO ALL***	**Results from Academic Databases: IEEE explore**	**Third keyword**	**Results from Academic Databases: *Web of Science***	**EBSCEbsco allO**	**Ieee explore**
					Issues	29		
					Governance	1		
					regulation	7		
					Trend*			
	Innov*	87	421		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Device	601	1259		Future	25		
					Emerging	21		
					Potential	80		
					Application	51		
					Usage	9		
					Utility	11		
					Product	5		
					Problem	40		
					Risk	27		
					Issues	27		
					Governance	0		
					regulation	2		
					Trend*	22		
	Assistive	70	233		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive device	8	7		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			

First keyword terms	**second Keyword Search**	**Results from Academic Databases: *Web of Science***	**Results from Academic Databases: *EBSCO ALL***	**Results from Academic Databases: IEEE explore**	**Third keyword**	**Results from Academic Databases: *Web of Science***	**EBSCEbsco allO**	**Ieee explore**
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive technology	37	133		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
Hard of hearing 1751 7084 85	Tech*	219	677		Future	22		
					Emerging	4		
					Potential	16		
					Application	21		
					Usage	3		
					Utility	1		
					Product	5		
					Problem	34		
					Risk	7		
					Issues	24		
					Governance	0		
					regulation	1		
					Trend*	4		
	Scien*	48	245		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Innov*	23	105		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			

First keyword terms	**second Keyword Search**	**Results from Academic Databases: *Web of Science***	**Results from Academic Databases: *EBSCO ALL***	**Results from Academic Databases: IEEE explore**	**Third keyword**	**Results from Academic Databases: *Web of Science***	**EBSCEbsco allO**	**Ieee explore**
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Device	63	219		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive		132		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive device	4	5		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive technology	13	30		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			

First keyword terms	**second Keyword Search**	**Results from Academic Databases: *Web of Science***	**Results from Academic Databases: *EBSCO ALL***	**Results from Academic Databases: IEEE explore**	**Third keyword**	**Results from Academic Databases: *Web of Science***	**EBSCEbsco allO**	**Ieee explore**
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
Auditory impair* 259 493 0	Tech*	21	2		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Scien*	10	6		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Innov*	0	0		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Device	3	3		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			

First keyword terms	**second Keyword Search**	**Results from Academic Databases: *Web of Science***	**Results from Academic Databases: *EBSCO ALL***	**Results from Academic Databases: IEEE explore**	**Third keyword**	**Results from Academic Databases: *Web of Science***	**EBSCEbsco allO**	**Ieee explore**
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive	1	2		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive device	0	0		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance			
					regulation			
	Assistive technology	1	1		Future			
					Emerging			
					Potential			
					Application			
					Usage			
					Utility			
					Product			
					Problem			
					Risk			
					Issues			
					Governance regulation			

This report explores assistive technologies for three specific kinds of disability: blindness and visual impairment; deafness and auditory impairment; and autism spectrum disorders. These three disability groups affect different body organs and functions, and have very different impacts on human activities and social participation. The report describes the current state of the market before examining technical, social and other trends in the light of potential future developments in the sector.

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