Fundamental Needs in Wearable Computing: Specificities for Young People

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Abstract

Infants, children and adolescents have specific needs reflected by their growth, activities and use of technology. We present their cognitive, emotional, physical, physiological, sensory, and social characteristics. Based on impacts on fundamental needs, we discuss dedicated systems exploiting wearable computers and the proper design of such systems. Our most significant contribution is to provide the first overview of young people's specific needs in wearable computing.

1. Introduction

To properly support everyday life or immersion in virtual worlds, wearable computers must fit human diversity. Disabilities are sometimes considered but culture, gender, and age are frequently overlooked. Here, we examine the case of young people because of their increasing access to mobile technologies (e.g. cellular phones), of the potential for familial services, and of design complexity induced by growth.

Due to phylogenic and ontogenic influences, young people continuously change from cognitive, emotional, physical, physiological, sensory and social points of view. Dedicated useful wearables were suggested by researchers [1] and science-fiction authors [2]. However challenges are great and negative impacts must be considered. The following sections clarify these issues and discuss the proper creation of dedicated wearables.

This work is part of a project that aims to identify the significant potential benefits of, and constraints on, ubiquitous systems dedicated to the general public. Considering healthy adults as reference, our complementary investigations focused so far on quality of life [3] and on wearable technologies for older adults [4].

Age-related specificities significantly influence (1) the nature of services useful to–or needed by–a given user, (2) appropriate designs, and (3) the potential for life-long use of wearables. Hereafter we highlight the characteristics of young people from birth up to adolescence. Then we describe the impact of growth on needs and on the definition of dedicated services. Finally, we discuss the design of such services based on wearables.

2. Characteristics vary greatly from birth to adolescence

Young people undergo important cognitive and bodily changes. According to Piaget, a renowned psychologist, development unfolds in stages that occur at different ages depending on domains and individuals, but appear universal rather than culture-dependent. Although lauded for his findings, Piaget failed to take into account social ecology. This aspect was investigated by Vygotsky, who studied the role of culture and interpersonal communication in child development. Together they showed that cognitive functions undergo the most complex and critical changes. Besides, physical characteristics of potential users are more often considered than their thought processes. We consequently chose to detail hereafter this aspect of development.

2.1. Cognitive development: the four stages

Human thought is constructed by interaction between innate elements and contacts with the world. Due to their current approximate understanding of reality, young people make systematic errors that accumulate and combine with each other. The widening gap between their model and reality pushes them to transform their model, and to advance through the *sensorimotor*, *preoperational*, *concrete operational*, and *formal operational stages* (see table 1 for details). During this progression, concept formation, egocentrism, and memory are of particular interest.

2.2. Cognitive development: concept formation

Children may use the same words as adults but only referents are shared, not meanings. During the formation of concepts, the meanings of words change:

> "[C]ertain thoughts cannot be communicated to children even if they are familiar with the necessary words. The adequately generalized concept that alone ensures full understanding may still be lacking." by Vygotsky [5, p8]

Forming concepts and understanding relations happens slowly. Although starting early, the required processes become available only at puberty [5, p106]. The formation of concepts is marked by three basic phases (themselves divided in stages): syncretic heaps, complexes and concepts. Adolescence is a transition period towards the use of true concepts, which coexist with– and do not supersede–complexes. Complexes can be confusing because they are groups based on *concrete factual* bonds rather than *abstract logical* bonds:

> "Complex formation is [...] responsible for the peculiar phenomenon that one word may in different situations have different or even opposite meanings as long as there is some associative link between them." by Vygotsky [5, p127]

Emerging from different roots, everyday and scientific concepts develop separately. Rooted in verbal definitions, scientific ones move towards phenomena whereas everyday concepts are rooted in experience and move towards generalization. Scientific concepts take shape earlier and faster than everyday concepts [5, p147] but, with time, they join at a level simultaneously elementary and concrete [5, pp192-193].

Spontaneous concepts (arising from one's own mental efforts) and non-spontaneous concepts (critically guided by adults) constantly influence each other, and are assimilated with alterations. Spontaneous and non-spontaneous concepts are replaced *gradually* thanks to firm roots in the child's thinking, whereas suggested concepts disappear rapidly.

2.3. Cognitive development: egocentrism

Egocentrism implies a low or inexistent ability to distinguish between oneself and others, between what one knows and what others know. Egocentric speech is speech that happens when a child engages in an activity and shares her thoughts as a monologue. Its course reveals and shapes the child's thoughts.

Children believe their egocentric speech is listened and understood by surrounding people. It temporarily disappears when obviously not understood (e.g. in presence of deaf-mute or foreign children) and is depressed when alone [5, pp233-234]. However, it is stimulated by the disruption of an activity, difficulties and frustrations: the child talks to herself to understand and remember the situation, and to plan solutions [5, p30]. Egocentric speech is audible, not whispered, but is only understood in context because the speaker omits elements obvious to herself [5, p32, p247].

2.4. Cognitive development: memory

Although we forget our first 3-4 years (*childhood amnesia*) [6], behaviors are acquired daily during that period through the examination and imitation of

Table 1: Main characteristics of young people by stage (based on works by Piaget)

Stage	*Usual age*	*Main characteristics*	*End of...*
Sensorimotor	0-2 years	– Experience through senses, movements – Learning of object permanence	N.A.
Preoperational	2-7 years	– Acquisition of motor skills – Animism – Centration[1] – Classification of objects – Egocentrism[2] – Use of symbols and words	None
Concrete operational	7-11 years	– Decentring[3] – Logical thinking about concrete events	– Centration – Egocentrism
Formal operational	11+ years	– Abstract reasoning	None

[1] Centration: seeing problems from a single angle.
[2] Egocentrism: seeing things only from one's own point of view.
[3] Decentring: seeing problems from multiple angles simultaneously.

others' actions and facial expressions [6].

Age correlates with all aspects of remembering [7]: duration of retention, cues required, richness of reports, susceptibility to suggestive questions, availability of mnemonic techniques for storage and retrieval… Differences may come from 'age-related differences in the basic processes involved in the encoding, storage, retrieval, and reporting of information' [7], knowledge required to interpret events, linguistic skills, or former experiences. Knowledge influences what is encoded and how, with possible distortions [7]. Growing up, encoding accelerates, memories remain longer, and the scope of used retrieval cues broadens [6].

Young children do not understand the uniqueness of events: they retain *generic* temporal sequences but not event-*specific* information [8]. Before 4-5 years, kids may locate their position in a sequence of events but neither with respect to similar nor different sequences [8]. Events appear in a referential that is recurrent relative (e.g. winter, evening) rather than absolute (e.g. specific day or hour) [8]. As soon as they can speak, children provide good verbal accounts of *recurring* events; with support (e.g. maternal interaction) 2- and 3-year-olds do the same for *unique* events [7].

Children-parent interactions (notably verbal) guide the understanding of events and thus memorization. This influence decreases with the development of independent attention [7]. For 4-year-olds, mothers' use of *wh-* questions, associative talk (e.g. related former experiences), follow-in (i.e. using the content to continue discussions), and positive appraisal results in immediate long-term increases in remembering abilities [7].

2.5. Bodily development

From birth to adolescence, bodily development concerns physical growth, sensory-motor evolutions, and physiological adaptations. Infancy (up to 5 years) is marked by the fastest growth, especially during the 2-3 first years. During childhood, the body's shape, size, and proportions (e.g. limbs grow faster than the trunk) change. Adolescence occurs later for boys than girls but lasts longer (up to 20 years), and is characterized by important physical, sexual, behavioral, and psychological changes.

Growth can be assessed using references based on an international reference population, as done by the National Center for Health Statistics (NCHS) and World Health Organization (WHO). The NCHS provides gender-dependent charts for *weight for age* and *stature for age* from birth up to 20 years [9]. The WHO also provides *head circumference for age*, *arm circumference for age*, and *weight for height* up to 5 years [10]. *Ehrenberg law-like relationship* describes the relationship between weight and height among children aged 5-13 years [11]; it was adapted with recent data to 0-10 years (with a better match for boys than girls):

<log10(w) = 0.8h + 0.39>, with *w* for the weight in kilograms, and *h* for the height in meters [12].

Nutrition influences much development. Due to better living conditions (nutrition, health), height, weight, and developmental tempo increased gradually since 1850. Ignoring obesity issues (rising worldwide), this trend stabilized in Northern Europe but continues elsewhere [13]. Length and weight at birth are stable [13]; increases in height occur during the two first years of life, mainly through an increase in leg length [13]. Menarcheal age settled at 13 years [13]; highlighting inter-country differences, the age of puberty settled in Dutch boys but not yet in American boys [13].

Although human sensory systems are mostly complete at birth, several elements require years to fully develop, and perceptual skills must be learnt. For instance, the vestibular system (otolith, etc.) is fully formed at birth but the lateral geniculate nucleus (used to process visual information) develops during the first year [14], the myelination of the visual pathway completes around 2 years [14], the macula matures after 4 years [14], and the visual cortex matures until puberty [14]. The development of motor abilities is conditioned by changes in perception as well as physical condition (e.g. muscles). Infants have poor motor skills, and development varies much between individuals. For example, children start sitting without support between 4 and 9 months, crawl on hands and knees between 5 and 13 months, and walk alone between 8 and 18 months [10].

Finally, children's physiological condition differs from that of adults. Sleep patterns and the reaction to heat and cold stress are worthy of attention. Sleep patterns become regular during infancy but needs sharply increase during adolescence: 'Adolescents are even more impaired by sleep loss than are the rest of us' [15, p116]. Exposure to heat stress raises more core temperature in children than in adolescents and adults [16, p659]. Besides, children need more time to acclimatize to heat [16, p659]. Compared to adults, children's ratio of body surface area to body mass facilitates heat exchange with environments, which implies high heat loss in the cold or in water.

2.6. Emotional and social development

Emotional and social development depends heavily on relationships with parents and on the environment. Babies establish strong emotional links with the mother, social touch is necessary to the development of mental life [17], and the young accordingly value specific sensorial contacts [17]. However many theories are incomplete and e.g. the processes involved in the awareness and regulation of feelings are unclear.

2.7. A few words on activities and technology

Objects influence human development, and computers may magnify this phenomenon because of their potential to expose virtual worlds, and exhibit seemingly intelligent behaviors. *Things* shape a child's mind during her activities [5, pp39-40]; for example if a pencil breaks while drawing a car, the child may end up drawing a broken car. Robots, toys, and computers are commonly considered as alive and intelligent; children express animism towards these objects [18].

3. Services can satisfy specific needs

Due to these characteristics, fundamental needs are expressed in specific ways. We discuss below their potential gratification with wearables (figure 1). Notable systems include *Lifebelt* [19], *Mamagoose* [20] and *Dog@watch* [21]. *Lifebelt* is a garment that monitors fetal and maternal vital signs during pregnancy. *Mamagoose* is a pajama designed to prevent the sudden infant death syndrome. *Dog@watch* is a wrist-worn wearable that contains a location system, a wireless communication system, and an alarm.

3.1. Physiological needs

Youth influences the ability to maintain homeostasis, notably in regard to body temperature. Respiration, sleep, and nutrition also raise issues.

Incomplete adaptation to heat and cold limits physical activities and potentially endangers a child's life. With various sensors, wearables may monitor the wind, humidity, the environment's and body's temperature, the amount of sweat (eliminating excessive heat), shivering (used to fight against cold), and physical activity. Proper advice may be automatically given to children, and alerts sent to a nearby or related adult. Clothes may also warm up or cool down the body on demand.

Wearables may monitor the presence of allergens and pollution to limit negative influence on health and growth. Because pollution is associated to a rise in asthma and immuno-depression, and because problems occurring during youth are magnified with age, young people can greatly benefit from such detections.

Sleep needs vary much until adulthood. Wearables can monitor sleep patterns and habits (e.g. light exposition that causes drifts of the biological clock) to provide proper advice or to inform medical doctors. Due to a simultaneous change in sleep needs and acquisition of autonomy, adolescents often lack sleep; one advantage of the proposed service is that adolescents may consider it valid on the contrary to advice from their parents, and thus accept it more easily.

To favor growth and avoid various problems such as diabetes, wearables may follow food intake (with e.g. QR codes) and propose personalized guidance aligning nutrition to growth needs. Logs may also help medical doctors identify or reconsider the source of problems during check-ups.

Finally, wearables may automatically assess growth through appropriate health indicators such as weight, height, and limb size. For instance, weight can be monitored daily using pressure sensors embedded in shoes.

3.2. Safety needs

Infants explore the environment and interact with objects, unaware of dangers such as falling, drowning or getting burnt. Wearables may detect dangers (with e.g. temperature sensors) and request children to act accordingly [22], or alert nearby adults. For the detection, smart tags can be placed on known dangerous objects (e.g. irons, cleaning products). Accelerometers help detect collisions or falls in rivers to alert family members or emergency staff. Such reactions are appropriate because children are fragile and are unlikely to master skills like swimming.

In addition to informing medical doctors about a child's condition, a wearable may also favor the proper development of motor skills and perception, for example through dedicated games. It may also expose the kid to (1) words related to her environment, and to (2) multimodal stimulations.

Finally, parents' fears led to the creation of devices dedicated to protection from crime; in Japan for instance, small buttons activate alarms and cellular phones provide the GPS position to parents. More safety-related abilities may be added but it is unclear whether it would improve safety or just provide a sense of safety. On the negative side, monitored children may avoid activities practiced for centuries (e.g. playing around in a field), with detrimental effects on their mental development, and with little or no benefits from a safety point of view.

3.3. Belonging needs

During infancy, the most important human contacts are with the parents; other contacts are motivated years later. It is unclear whether wearables providing tactile stimulations could convey a feeling of presence to infants, soothing.

Social life remains limited due to *egocentrism*, which decreases wearables' usefulness before 7-8 years. However, they can maintain remote familial contacts at any age, especially during stressful separations. Cellular phones provide voice and text; wearables could add information (e.g. activities, emotions) and help manage contacts based on availability or time differences between countries.

Besides, wearables featuring anthropomorphic agents may compensate for a lack of social contacts (due to personality, environment or genetic defects), speeding up development; however this hypothesis must be tested. Considering the importance of social contacts and the frequency of potentially reduced contacts (e.g. monoparental setting, parents both working), this possibility should be seriously investigated.

3.4. Esteem needs

For children, successful achievement of a variety of activities is critical. For that, wearables may provide knowledge required to understand events and to fix memories. Wearables may monitor the environment, and proactively or passively inform about unfolding events or present animals. Because children may continuously access their wearable, knowledge acquisition may accelerate. Besides, wearables can display animations alongside explanations, enabling children to learn skills by imitation.

3.5. A few words about childhood amnesia

Because of childhood amnesia, records of childhood may be highly valued. Wearables offer the possibility to record and acquire information about one's activities and reactions when very young. In this case, one would benefit from the system years later.

4. Dedicated design is necessary

To create systems for young people, we must consider safety, integration, variability, senses, world vision, and knowledge transmission (figure 2).

Figure 1: Sources of problems, consequences, and services useful to young people

4.1. Safety

Safety depends on a wearable's form factor as well as components' weight and location, based on the wearer's characteristics, and thus on her age. The shape and location of physical components embedded in accessories or clothes should be selected based on (1) potential problems related to heat tolerance, and (2) potential danger to ulterior growth in case of accident.

Mental safety should also be considered; for instance, systems should respect kid's mental development and sensibility to external influences. Besides, children may easily accept wearables due to animistic tendencies but the impact over years of wearables seemingly alive and intelligent is unknown. Thus, the effect of wearables and digital companions should be prudently but rapidly investigated.

Because the abilities of young people are limited, enabling location queries appears appropriate for emergencies, with the possibility to contact a nearby person rather than only acquaintances or emergency staff. Architectures allowing such a possibility are still lacking.

4.2. Integration and variability

Because young people change much, stable or shared designs should be favored, facilitating the use of new devices and their integration in everyday life. Permanent visual agents may be exploited, providing an anchor and an interface for help. To adapt the vocabulary used and the functions available, a system should learn which words the user knows.

Because needs may fluctuate, several activity levels are recommended, which is possible with multi-level interfaces, artificial intelligence, or adaptation to users' states. For instance, a system may avoid interrupting a child during activities marked by egocentric speech or a concentrated adolescent who shows signs of fatigue, and then provide requests or information during transitions between activities (e.g. moving to a different area, starting the use of a device). Profile data should be kept up-to-date to remain reliable.

Due to differing growth patterns (e.g. shorter height, earlier puberty, faster stabilization of bodily growth for females), gender should be considered. Similarly international differences influenced by culture, resources and nutrition should be taken into account.

4.3. Senses

Systems should take into account limitations and changes in young people's sensory systems.

Before adolescence, handwriting may be inefficient for input due to a lack of mastery. Egocentric speech renders speech recognition attractive to identify activities and problems but such speech may be malformed and meaningless for others; if exploited, speech recognition should be associated to a powerful context awareness system. Besides, egocentric speech disappears when a child is alone; it is unclear whether it would continue or resume in presence of life-like "intelligent" companions such as dog-shaped robots or as wearable-embedded digital companions.

Play, kid's main activity, involves more gestures, movements, and mimicry than words. Thus movement

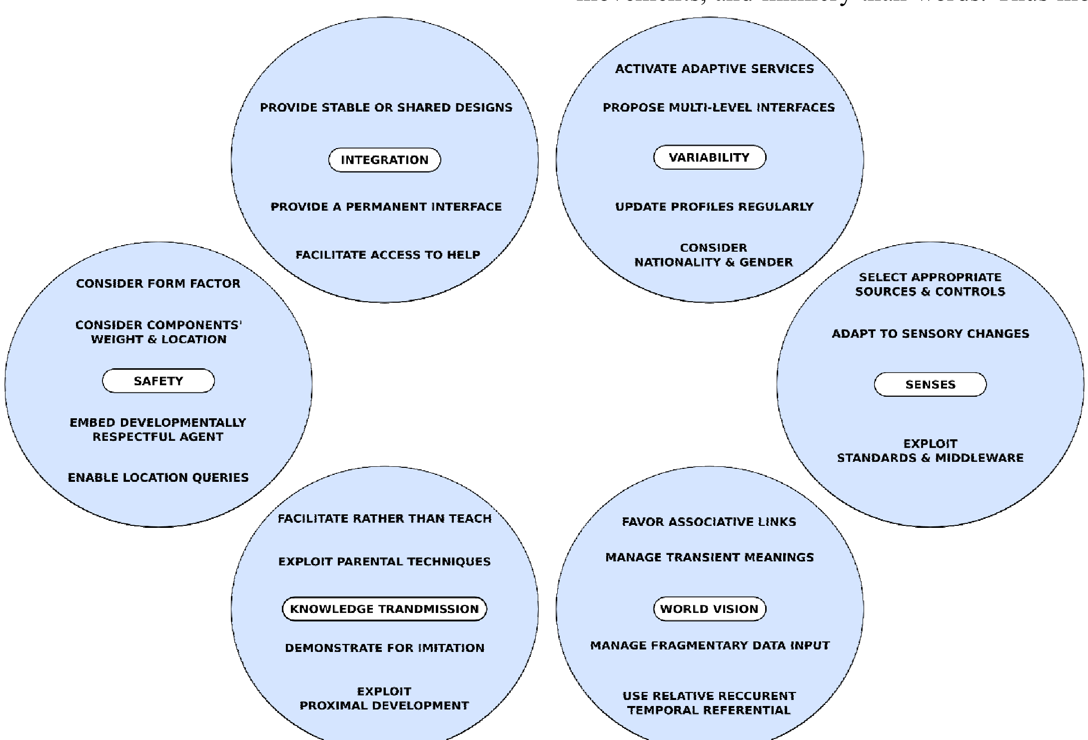

Figure 2: Design requirements for young people's wearable computers

sensors may be more useful than speech recognition. However, the quantity and nature of play hinders the separation of what kids believe and fantasy deliberately expressed. Besides, changes in abilities, shape, size, and proportions alter movements and hamper sensor-based evaluations of activities. Babies illustrate this problem perfectly: they grow rapidly during 3 years and simultaneously start to sit, crawl, walk, etc. To deal with important bodily changes, devices may be repeatedly replaced. Thus, systems must be flexible enough to avoid loss of stored data and maintain functionality even through important hardware changes. Solutions include the use of standards and middleware.

4.4. World vision

Children make systematic errors related to Piaget's stages. Because these errors are predictable, a wearable can adapt its output to improve communication with the child, and provide useful help, potentially enabling a child to learn and correct her model of reality faster.

Children use their own current meaning for words and symbols; these transient meanings should be reassessed regularly, and related processes (data labeling speech processing, vocabulary in interfaces) adapted accordingly to improve child-machine communication. Due to difficulties understanding relations and concepts, interfaces should stress associative links rather than abstract/logical links before puberty. Besides, concepts introduced should be based on the child's experience to facilitate understanding and retention. Presentation and manipulation of scientific knowledge may be sensibly higher level at any age than everyday knowledge.

Centration and *egocentrism* may lead to particularly fragmentary input of data in the preoperational stage; solutions depend on services considered.

Finally, management of temporal information by younger children requires recurrent relative referentials (e.g. winter, evening) rather than absolute ones (e.g. specific days and hours), which implies unusual ways to explore temporal data.

4.5. Knowledge transmission

Constructivism implies that learners are active in their acquisition/creation of knowledge, rather than passive recipients. Teaching systems should therefore act as facilitators rather than teachers; they may ask rather than tell, discuss rather than lecture, support rather than control, create a learning environment and follow children's interests rather than focus on curricula. Guidance to acquire knowledge and memorize can benefit from techniques used by parents, such as *wh*-questions, associative talks, follow-ins, and appraisals.

Because children learn new behaviors by watching and imitating, wearables may also provide animations of avatars to imitate in context. Contrariwise, attention should be paid to what services show; even avatars' facial expressions may be important.

Young people are not limited to what they can learn alone, but to what they can learn with assistance; systems should evaluate and exploit the extent of this *zone of proximal development* [5, p187]. To illustrate this concept, consider the acquisition of language: providing vocabulary just above a child's current level may benefit her more than complex words. Exposure to vocabulary below or within the kid's level has little potential benefits for learning words. Teaching systems should evaluate the extent of the proximal zone; however appropriate methods may not exist yet. Like parents, wearables could track the known vocabulary, but how would they evaluate the upper limit of the vocabulary group that the child may currently learn?

5. Perspectives

The specificities of infants, children and adolescents induce needs and priorities different from those of "standard" healthy adults. Besides affecting useful services, they impact the requirements for the proper design of wearable computers, notably regarding safety, integration, variability, senses, world vision, and knowledge transmission.

Taking into account former investigations about the specificities of older people, this study shows that age should be considered in detail to design wearable computers. Although universal access is promoted with such an approach, the main effect is to provide wearables with higher value and increased usefulness. Besides, the same method can be applied to design intelligent environments and robots, guided by needs rather than potentials.

The specificities of young people and their impact should be investigated in more depth, and the following questions must be answered by the research community: How may the continuous use of wearables influence children's development? Can wearables featuring anthropomorphic agents compensate for a lack of social contacts? What can wearables bring to physically and mentally challenged children? Can wearables efficiently exploit egocentric speech? How can wearables evaluate a child's zone of proximal development?

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