Improving Quality of Life from Birth to Old Age with Ubiquitous Computing and Virtual Reality

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Abstract

Virtual reality and ubiquitous computing can significantly improve the general public's quality of life worldwide from birth to old age because they allow monitoring, awareness and support in real and digital worlds thanks to sensors, actuators, remote connections, and dedicated knowledge bases. However, age influences their usefulness and appropriateness due to growth and decline as well as changes in activities and uses of technology. Based on the cognitive, physical, physiological, and sensory characteristics of young people and older adults, we discuss dedicated systems that exploit intelligent environments, wearable computers and virtual reality. Our most significant contribution is the analysis of the potential and limits of ubiquitous computing and virtual reality to improve quality of life, taking into account all age ranges.

1. Introduction

Virtual reality and ubiquitous computing can significantly improve the general public's quality of life worldwide from birth to old age through support for everyday life and immersion in virtual worlds. Specialists already succeeded in developing useful applications such as treatments for phobias and infantry information systems but failed to create useful applications for life-long use by the general public because focus was on young adults and well-funded specific services (e.g. health, military). Besides, researchers separately investigated ubiquity and virtuality due to specialization, with only limited exchanges in augmented reality and mixed reality fields. Hereafter, we cover these lacks by highlighting the complementarity and mutual benefits of virtual reality and ubiquitous computing, with a focus on life-long improvements of quality of life.

Virtual reality and ubiquitous computing are founded on different premises. *Virtual reality* is a computer-generated experience in which users feel in a different place or time, marked by a high degree of presence, and associated to multi-sensorial stimulations. Typical applications are rehabilitation, gaming, art, and training. *Ubiquitous computing* is linked to continuous contacts with computers that use sensors, actuators and networking. It covers *intelligent environments*, material environments like streets, offices and houses that react to people and events, and *wearable computers* (a.k.a. wearables), worn by users, embedded in e.g. earrings or clothes. Typical applications are health monitoring, context-awareness, and communication support. Both virtual reality and ubiquitous computing rely on leading edge technologies.

Virtual reality notably allows exposure to novel situations and ubiquitous computing support for everyday life, which may both improve quality of life. For the sake of simplicity, we will consider that quality of life is the level of objective satisfaction of human fundamental needs [14], and let readers consider our arguments in the light of their own definition. Although fundamental needs are universal, their expression varies based on personal experiences, physical and mental challenges, cultures, gender, and age. We focus first on age because it is usually neglected, because children increasingly access mobile technologies (e.g. cellular phones), elders become more numerous, and because growth and decline induce design complexities. Age influences (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 technologies. We will consider other influences in future studies.

We first outline age-related specificities in section 2, choosing healthy adults as reference. Then, we suggest and describe useful services based on virtual reality and ubiquitous computing in section 3. As a complement, we highlight design issues of resulting systems in section 4. Then we discuss technological complementarity and mutual benefits in section 5 and conclude on critical research needs.

2. Human characteristics vary widely with age

Young people (0 to 20 years) and older adults (60 years and more) undergo important cognitive and bodily changes. For infants, children and adolescents, most changes are predictable. Among older adults however, abilities decline with a high inter- and intra-individual variability. For example, although blindness becomes more common, some people keep excellent eyesight; decline may plateau then accelerate, etc. Thus the younger population is homogeneous whereas the older population is heterogeneous, with problems emerging from concurrent disabilities.

According to Piaget [20], due to their approximate understanding of reality, young people make systematic errors that accumulate and combine with each other. The widening gap between model and reality pushes them to transform their model and to advance through four stages (Table 1). During this progression, concept formation, egocentrism, and memory are of particular interest.

Table 1. Main characteristics of young people by stage (based on [20]).

Stages	Main characteristics
Sensorimotor (0-2 y.o.)	- Experience through senses, movements - Learning of object permanence
Preoperational (2-7 y.o.)	- Acquisition of motor skills - Animism, centration, egocentrism - Classification of objects, use symbols
Concrete operational (7-11 y.o.)	- Decentring - Logical thinking about concrete events
Formal operational (11+ y.o.)	- Abstract reasoning

Concept formation is marked by 3 phases: *syncretic heaps*, *complexes* and *concepts* [24]. Based on concrete factual bonds rather than abstract logical bonds, complexes can be very confusing; true concepts start to coexist with them during adolescence.

Egocentrism implies a low ability to distinguish between oneself and others, between what one knows and what others know. It leads to *egocentric speech*, which happens when a child engages in an activity and shares her thoughts as a monologue. It is depresssed when alone or obviously not understood by others [24].

Young children do not understand the uniqueness of events: they retain *generic* temporal sequences but not *event*-specific information [16]. Age is correlated with all aspects of remembering, and encoding depends on knowledge [18]. Understanding, and thus memorization, is guided by children-parent interactions (e.g. *wh-* questions, follow-ins, associative talks, ositive appraisals) [18].

Objects influence human development, and computers may magnify this phenomenon because of their potential to expose virtual worlds, and exhibit seemingly intelligent behaviours. *Things* shape a child's mind during her activities [24]; 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 [23].

Until adolescence, bodily development concerns physical growth, sensory-motor evolutions, and physiological adaptations. Growth, notably influenced by nutrition, can be assessed with references proposed by the National Center for Health Statistics and the World Health Organization for people up to 20 years [1][3]. Although sensory systems are mostly complete at birth (e.g. vestibular system), some elements require years to fully develop (e.g. the visual system matures until puberty), and perceptual skills must be learnt. Finally, children's physiological condition differs from adults': children are more sensitive to heat and cold [15], sleep needs sharply increase during adolescence [6], etc.

For older adults, cognitive abilities decline unequally, control decreases, fatigue increases, perception and communication are hampered [11][13][17][26]. Intellect is globally maintained but memory, learning, and attention are impaired. Motor abilities decrease, and physiology is perturbed. Visual and aural abilities decline due to a degradation of our natural "sensors" and associated processes. Finally, speech turns less distinct.

Due to limited space, we only briefly evoked age-related specificities and encourage readers to consult our more detailed accounts: [7][9] for young people, and [8][9][10] for older adults.

3. What services to improve quality of life?

Young people and older adults undergo different changes, with specific consequences on health and daily life. However, virtual reality and ubiquitous computing afford complementary solutions for most issues, as summarized in Table 2. Existing notable systems include *Lifebelt* [5], *Mamagoose* [2], *Dog@watch* [25], *FearNot!* [12], and the *arctic suit* [21]. *Lifebelt* is a garment that monitors foetal 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. The *arctic suit* is a suit that produces heat on-demand, warming up the user in cold environments. *FearNot!* is a virtual environment to teach kids to deal with bullying at school.

Table 2. Comparison of services particularly useful to young people and older adults.

Needs	Intelligent environments	Wearable computers	Virtual Reality
Heat/cold stress (Physiology)	- Adaptation: warming up and cooling down places. - Alerts based on environment.	- Adaptation: temperature-changing clothes. - Alerts based on body.	No service.
Sleep (Physiology)	- Monitoring, advice based on environment.	- Monitoring, advice based on body & light.	No service.
Airborne allergens (Physiology)	- Monitoring, advice based on body & air. - Selective filtering.	- Monitoring, advice based on body & air.	No service.
Nutrition (Physiology)	- Personalization: e.g. menus in restaurants.	- Monitoring, advice based on RFID tags and cameras.	- Training: select foods.
Direct dangers (Safety)	- Monitoring, advice based on environment. - Alerts based on environment.	- Monitoring, advice based on private data. - Alertsbased on private data.	- Teaching: dangers.
Indirect dangers (Safety)	- Tests: growth/decline based on local actions. - Training: favor growth, limit decline thanks to context.	- Tests: growth/decline based on all actions. - Training: favor growth, limit decline thanks to context.	- Tests: growth/decline. - Training: favor growth, limit decline with simulations.
Remote contacts (Belonging)	- Contacts: episodic, limited in public and outdoors, simple clarification.	- Contacts: continuous, personalized clarification.	- Contacts: episodic high quality, personalized clarification.
Loneliness (Belonging)	- Support: episodic shared digital agents.	- Support: continuous personal digital agent.	- Support: episodic personal digital agent.
Mobility (Belonging)	No service.	- Exoskeletons.	No service.
Face-to-face communication (Belonging)	- Reminders: limited identity in some places. - Contacts: simple clarification.	- Reminders: full identity everywhere. - Contacts: personalized clarification.	No service.
Kids' Achievements (Esteem)	- Teaching: real situations, with environments data.	- Teaching: personalized in real situations.	- Training: diverse, few limits.
Elders' maintenance (Esteem)	- Training: strong privacy issues.	- Training: little privacy issues.	- Training: diverse, privacy respected.
Finding one's way (Self-actualization)	- Tests: real-world basis, quality contextual data.	- Tests: real-world basis, quality emotional data.	- Tests: diverse, with quality emotional data.

3.1. Physiological needs

Youth and old age influence the ability to maintain homeostasis, notably in regard to body temperature. In young people it mainly appears in a limited tolerance to heat and cold stress. In elders, such dysfunctions induce cardiovascular problems, diabetes, and dementia. Ubiquitous computers may monitor the body and environment, send alerts, and warm up or cool down the body. For older adults they may also monitor lifestyles and provide early detection of behavioral or physiological changes.

Sleep needs vary much until adulthood, and problems such as sleep apnea become more common in older adults. Ubiquitous computers may monitor sleep patterns and habits (e.g. light exposition that causes drifts of the biological clock) to provide proper advice or inform medical doctors. During sleep, intelligent environments may monitor body movements with cameras, and sleep apnea (marked by loud snoring) with microphones. Wearables can use accelerometers for movements, microphones for apnea, and specific sensors to monitor brain waves.

Finally ubiquitous computers may monitor the presence of allergens and pollution to limit negative influences on health and growth, and follow food intakes to propose personalized guidance aligning nutrition to growth needs. Virtual reality may be used to learn how to make appropriate menus at home or in restaurants, based on known allergies, preferences, and health concerns.

3.2. Safety needs

Infants explore the environment and interact with objects, unaware of dangers such as falling, drowning or getting burnt. For older adults, falls are a critical risk [4][19]; they are great even for seemingly minor accidents:

> "[Elders'] skin will just tear, it's like tissue paper. It loses elasticity as you get older, the slightest knock can tear it", ambulance crew [4].

With appropriate sensors (e.g. accelerometers, cameras) and personalized information, ubiquitous computers can detect dangers, and alert family members or emergency staff. Virtual reality may not monitor and alert about risks in everyday life but may expose users to various situations (especially unusual or problematic ones such as bullying [12]), to teach the existence of dangers and experiment behaviors.

Besides, virtual reality and ubiquitous environments may be used respectively in everyday life and in virtual worlds to assess users' evolution, and favor growth or slow down decline through e.g. exposure to vocabulary, multimodal stimulations, games, or help to do usual tasks.

3.3. Belonging needs

During infancy, the most important contacts are with parents; other contacts are motivated years later, and social life remains limited due to egocentrism, which decreases the usefulness of ubiquitous computers before 7-8 years. However ubiquity and virtual reality can maintain remote familial contacts at any age, especially during stressful separations. Intelligent environments provide limited links in public due to privacy issues and outdoors due to lack of equipment. Wearables offer permanent continuous links whereas virtual reality provides episodic contacts but potentially offer higher quality presence thanks to e.g. 3D telepresence. Besides, anthropomorphic agents based on such technologies may compensate a lack of social contacts.

Although still a significant need, elders' contacts due to reduced mobility, energy, memory, and communication abilities. Only wearables such as HAL exoskeletons [22] increase mobility but intelligent environments, wearables and virtual reality may all reduce the need itself with enhanced remote communication. Finally, intelligent environments and wearables may remind faces and names at appropriate moments thanks to cameras and RFIDs, or by clarifying discussions (e.g. noise filtering, transposition to lower frequencies, and display of speech on screens). For remote communication, virtual reality has the advantage to offer more numerous and better quality communication channels, potentially supported by tools such as noise filters, voice transposition, and transcription into visual text or touch displays.

3.4. Esteem needs

For children, successful achievement of diverse activities is critical. Virtual reality is ideal to provide challenges to children without many real-world limitations such as distance, time, and equipment cost. However ubiquitous computers are more useful for everyday life because they may provide knowledge required to understand events and fix memories. Intelligent environments provide more numerous and more appropriate information about events but wearables provide information more appropriate to the user's specific abilities and knowledge.

For older adults, key concerns are to maintain or regain independence and freedom to take risks [4], and to avoid *looking* dependent or old [17]. Virtual reality is ideal to maintain or regain abilities in e.g. gradual ways, hopefully benefiting from virtual trainings in their everyday life. One advantage of virtual reality is that people can try things, assess their level and improve their abilities without being seen by other people. Ubiquitous computers can provide older adults with real world information that may reactivate memories and help complete tasks but bystanders may notice it, especially in public shared environments, leading older adults' to stop using the services.

3.5. Self-actualization needs

Finding one's way is a main aspect of self-actualization. Ubiquitous computers can maintain archives of events and help identify "best" activities on the long-term using e.g. emotional data acquired from physiological sensors or cameras. However efficiency would require important progress in affective computing and context-awareness. However virtual reality can already help try numerous activities with physiological and behavioral monitoring, helping identify things one can and wants to do.

4. What designs for appropriate use?

To create systems maintaining or improving quality of life for young people and older adults, we must consider safety, integration, variability, senses, world vision, knowledge transmission, acceptance, and memory (Figure 1).

Safety depends on the form of the equipment and on the weight/location of components, based on users' specificities and thus age. This is critical for wearables and immersive suits for virtual environments. Systems should limit unwanted changes in temperature, especially for children, as well as forces applied by e.g. room-scale or wearable SPIDARs due to children's growth (e.g. muscle development) and older adults' decline (e.g. weakness in limbs and joints). Mental safety should be enforced; for instance, elders' systems should respect self-esteem through decline,

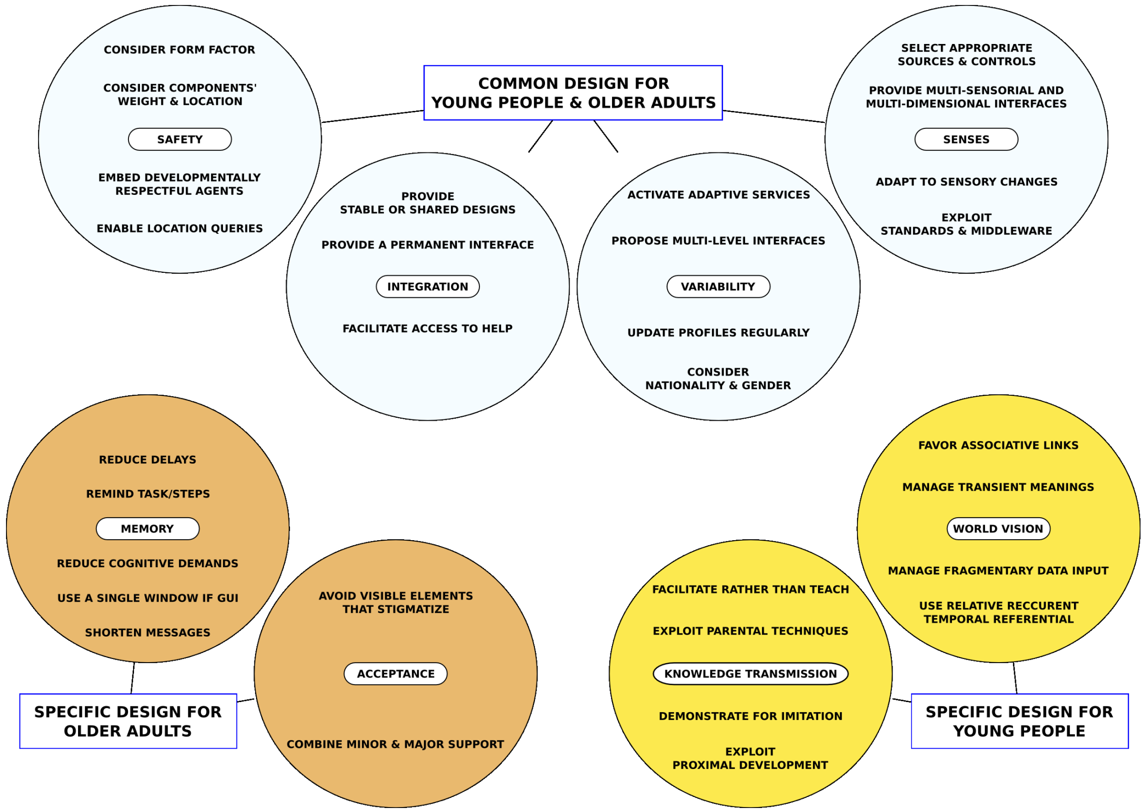

Figure 1. Critical design elements for young people and older adults in ubiquity and virtuality.

and children's systems should respect mental development. The impact of virtual companions should be prudently but rapidly investigated. Finally, because of children's and elders' limited abilities, enabling location queries in ubiquitous systems seems appropriate for emergencies, with the possibility to contact nearby people rather than only acquaintances or emergency staff. However architectures with such a feature are still lacking.

Because young people change much and elders difficultly acquire automated responses, stable or shared designs should be favored as well as intuitive metaphors and natural interactions in virtual environments. This facilitates the use of new devices and services, and their integration in everyday life. Permanent visual agents may provide an anchor and interface for help.

Because needs may fluctuate daily, we recommend several levels of activity based on multi-level interfaces, artificial intelligence, or adaptation to users' states. The aspect of virtual worlds may be adapted to the current ability to focus and notice information; for instance, cartoon-style rendering may replace photo-realistic rendering. A wearable may also avoid interrupting an elder with dementia to preserve her working memory, and then remind her of tasks during periods of lucidity. For both types of systems, profile data must be kept up-to-date to remain reliable.

Sensory requirements differ between young people and older adults. For older adults, good lighting and contrast are important, and semi-transparent glasses become inappropriate thus limiting uses of wearables and augmented reality. High frequencies may not be perceived, and synthetic voices are disliked, therefore voices in virtual environments should ideally be pre-recorded or provided by human operators. Reduced dexterity/precision prevents the use of sensitive and small controls. Providing information in multi-sensorial (e.g. visual and aural) and multi-dimensional (e.g. color and size) ways may counter varied effects of combined deficiencies; in virtual environments, photo-realistic rendering may thus not be ideal but multi-sensorial immersion appears most useful. Similarly, systems should take into account limits of, and changes in, children's sensory systems. The generation of virtual worlds for children should e.g. take into account that vision develops until adolescence. For real-world uses of ubiquitous systems, movement sensors may be most useful because children play much. However bodily changes hamper the evaluation of movements with wearables or immersive suits; systems must therefore be flexible and maintain functionality through hardware upgrades, for instance using standards and middleware. Egocentric speech renders speech recognition attractive to identify activities and problems but requires much knowledge about the kid and powerful context-awareness systems for everyday life uses; this is less an issue in virtual worlds because computers generate most of the context.

World vision is mainly an issue in youth. Children use their own current meanings for words and symbols; these transient meanings should be reassessed regularly, and related processes (speech processing, vocabulary in interfaces and of virtual agents, allowed actions in virtual environments) adapted to improve child-machine communication. Besides, centration and egocentrism lead to particularly fragmentary input of data. Because children have difficulties understanding relations and concepts, interfaces should stress associative links over abstract/logical links before puberty. 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 a higher importance of natural time and social events in virtual worlds, as well as unusual ways to explore temporal data provided by ubiquitous computers.

Similarly, knowledge transmission is mainly an issue during youth. Because learners are active in their acquisition/creation of knowledge, systems should 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 for the acquisition of knowledge and memorization can benefit from techniques used by parents, such as *wh-* questions, associative talks, follow-ins, and appraisals. Because children also learn by imitation, animations of avatars to imitate may be provided in context; contrariwise attention should be paid to what is displayed. 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*. To adapt vocabulary used, functions available, and situations proposed, ubiquitous computers and virtual reality systems should ideally learn which words the user knows.

Older adults' acceptance of technologies depends on aesthetics and social perception. Because elders do not want to look old or dependent, visible elements should not be stigmatizing, and systems may be designed to avoid attracting attention to the need for specific help. This is usually not a problem in virtual environments because tasks may be done in private spaces and interfaces hidden from other people in shared environments. However, bystanders may see screens in intelligent environments or notice special parts of wearables. As a solution, minor functions may be added to major ones so that users can deny needing major support.

Because of memory issues, cognitive demands in older adults shall be reduced even at the detriment of other aspects such as photorealism in virtual environments. Besides, to compensate memory losses, delays should be avoided, textual and aural messages shortened or removed, and a single window used for a given task (e.g. preference screens). To support ongoing activities, systems may remind of ongoing tasks and previous steps taken, which is particularly challenging in immersive virtual environments.

5. Discussion

Virtual reality and ubiquitous computing are both well-suited to improve quality of life from birth to old age as shown by the diverse services they offer to satisfy human needs. However the characteristics of these technologies differ, which influences the services for which they are most useful and appropriate. We highlighted in section 3 that ubiquity best supports directly everyday life whereas virtuality best teaches and trains users for unusual or difficult situations. Thus, ubiquity and virtual reality are complementary and do not compete much except for financial resources required to acquire such systems in coming decades.

Ubiquity and virtuality provide little redundancy but may support each other if tightly integrated. Intelligent environments can inform virtual environments about local or worldwide events, thus facilitating the selection of useful training programs while raising awareness about related issues. For example, a house with cameras may notice snow, and inform a virtual program that would schedule a simulation for kids about risks of snow-based games (slippery ice, stones in snow balls, etc.) or a balance training program for an elder. Wearables may inform a virtual advisor about the user's bad nutrition, leading to diet-oriented simulations that raise awareness about problems and teach how to choose food. Contrariwise, virtual environments may compile data during games/trainings and inform the house about the family's sleepiness, latest preferences and moods to better select of e.g. lighting and music. Virtual systems may also inform wearables about latest individual abilities so they can focus their limited resources (e.g. energy) to important issues such as detecting cars on days when virtual environments noticed a lack of attention before leaving home.

To improve quality of life, technologies should be useful and appropriate to targeted users. For instance, age influences much functions and interfaces. As indicated in section 4, requirements are globally identical for intelligent environments, wearables and virtual systems. Solutions for a technology often apply to another, after adaptations to devices and knowledge bases. Unfortunately, most issues specific to children (see Figure 1) remain open because related research mainly concerned gaming and academic learning.

There is a critical need for research about children because (1) we lack knowledge, especially about long-term impacts of technologies on physical and mental growth, (2) children already use proto-services in Japan and South Korea, (3) this research requires years due to the existence of phases during growth, (4) this research is constrained by ethical issues and laws that will prevent varied and large-scale investigations, and (5) results may vary with cultural and linguistic backgrounds.

6. Perspectives

The specificities of young people and older adults induce needs and priorities different from those of "standard" adults. Besides affecting the nature of services that significantly improve quality of life, they impact requirements for proper design of ubiquitous and virtual technologies, notably regarding safety, integration, variability, senses, world vision, knowledge transmission, acceptance, and memory.

This study shows that age should be considered in detail when designing systems. Although universal access would be promoted with such an approach, the main effect would be to provide systems with higher value and increased usefulness, guided by needs rather than potentials.

The specificities of young people and older adults as well as their impact should be investigated in more depth, and the following questions must be answered by the research community: How may continuous use of ubiquitous and virtual systems influence growth and decline? Can systems featuring anthropomorphic agents compensate for a lack of social contacts? What can they bring to physically and mentally challenged children and older adults in their everyday life? How can we provide systems that keep memory and functionality even through changes in hardware, software, and human needs and abilities due to ageing? These are questions our group is already investigating but that require concerted efforts with other groups due to their complexity and multi-disciplinary nature.

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