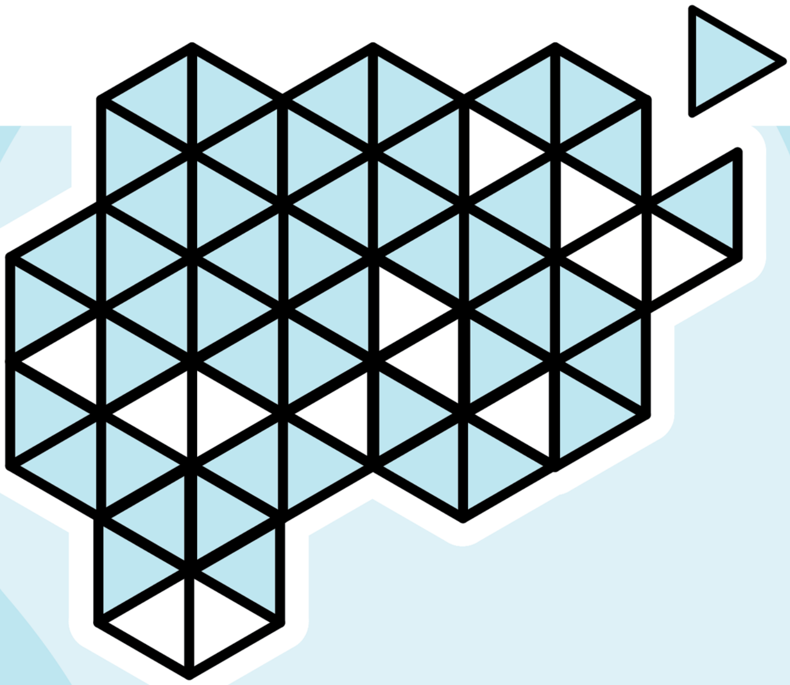
Anastasia Kozlova | Doctorate in Design Sciences XXVII Cycle
School of Doctoral Studies | IUAV University of Venice, Italy

How DESIGN can contribute to children's neurological rehabilitation?



Case study:
Co-designing Paediatric Rehabilitation Programs For Learning Disabilities

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Part I

1 | Introduction to the research

Enhancing the quality of children's lives is the major priority for every family and for the whole society in general.
Early childhood care emphasizes a holistic approach focusing on the child's physical, emotional, social as well as cognitive development. Early years are crucial in the formation of intelligence, personality and social behaviour. Moreover the early diagnostics of developmental or other cognitive problems, the proper care and effective rehabilitation therapy are the key aspects of positive results in recovery progress and in life facilitation for children with special needs.
That is why the choice of argument for my doctoral thesis in design sciences was made in favour of children's rehabilitation improvement.

Problem Statement

Facts about neurological conditions:
Neurological conditions are a leading cause of disability in the world.

- Over an estimated 1 billion people worldwide are affected by neurological disease and disorders
- Over 6.8 million die every year as a result of neurological diseases and disorders
- The most prevalent neurological conditions are Stroke, Cerebral Palsy, Epilepsy, Dementia, Multiple Sclerosis, Head Injury and various Learning Disorders.
- About 10-20% of school age population has learning difficulties. The most common are Dyslexia (2-10%), Dysgraphia (2-8%), Dyscalculia (1-6%).[1]

Neurological diseases and disorders are some of the most devastating illnesses one can suffer from; they significantly affects not only sufferers, but their families and caregivers as well.

Rehabilitation therapy of neurological disorders normally requires hard, annoying, sometimes painful, repetitive exercises. It usually results an unpleasant experience for young patients and consequently reduces the therapeutic effect.
The existing body of research dedicated to neurological rehabilitation and development of new rehabilitation programs is rather abundant, including some studies focused particularly on children's rehabilitation treatment. Nevertheless the major part of works are limited in means of design approaches and flexibility in project development: little attention is paid to ergonomics, functional aesthetics, age-appropriate engagement issues, consideration of new low-cost interactive technologies, influence of rehabilitation environment and other important factors that are essential for the project development in that area of healthcare design -

[1] Neurological report of World Health Organization. *Neurological Disorders: Public Health Challenges* http://www.who.int/mental_health/neurology/neurological_disorders_report_web.pdf

Design for Children's Rehabilitation.

Unfortunately till today many project teams of mentioned above design sphere consist of medical specialists/therapist/psychologist, engineers, software developers but not coordinating designer and/or design researcher, who suppose to control and manage all particularities and influencing factors, proposing design solutions based on research evidences and dedicated studies in multi-discipline area, tracking along the entire project life-cycle.

Therefore the quality of rehabilitation equipment and consequently its effectiveness may be improved significantly with the help of new innovative design solutions.

Purpose

The purpose of this research is to identify the role of designer in project development of children's rehabilitation programs and to verify the contributes that can be brought into this area by application of proper design approaches, dedicated design research and evidence based design solutions, improving consequently the quality of rehabilitation equipment and efficiency of neurological rehabilitation therapy for children, in particular, rehabilitation of Learning Disorders.

The aim of the first part of the research is to understand and analyse the complex situation in this specific area of children's rehabilitation: existing types of rehabilitation programs, equipment in use, technologies, participants of rehabilitation therapy and relations between them, environmental context and any other possible factors that may have an influence over the perception of therapy and rehabilitation performance in general.

Evaluation of benefits and limitations of existing programs brings to the conclusions to be considered in the second part of the work.

The goal of the second part of study is to find possible solutions to resolve the identified problems in order to improve the efficacy of rehabilitation programs.

Case studies and experimental part will be represented by a design-project of a new rehabilitation platform for Learning Disabilities (Dyslexia and Dysgraphia).

Project will be concluded with the proposal of prototype to be tested and verified to demonstrate if the applied approaches were valid, successful and brought to the positive result, improving children's rehabilitation efficiency.

Importance and Actuality

The present doctoral thesis deals with the specific area of children's healthcare – Neurorehabilitation that has not been confronted by researchers of design yet. So this research direction appears to be promising in terms of new findings and contributions that may be brought to the discipline of Healthcare Design, specially nowadays with the constant progressive growth of interactive technologies, effectively applicable in rehabilitation systems thanks to the benefits of new haptic tactile, tangible, wireless interfaces and flexible, adoptable software.

Furthermore the exploration of specifics of neurological rehabilitation from multidisciplinary perspective performs significant actuality due to the large number of young patients suffering from similar conditions around the world.

Research questions

How design can contribute to children's neurological rehabilitation?

Conducting questions

1. What are the factors influencing children's rehabilitation performance?
2. What are the main benefits and drawbacks of existing programs?
3. How the drawbacks can be eliminated or reduced?
4. How the benefits may be forced?
5. What new interactive technologies may be applied in order to improve therapeutic effect?
6. What design methodological approaches may be applied in order to improve the project development process?
7. What is the role of designer and multidisciplinary researcher in project development of rehabilitation programs?

Research plan

The main methods of research include literature review, observation and interviews.

Literature review provides the information about specifics of disorders and particularities of children's perception of rehabilitation therapy; indicates and analyses existing rehabilitation programs, its therapeutic approaches and technologies applied; reveals the key factors influencing the rehabilitation performance, detects problematic features; explores new interactive technologies applicable for rehabilitation programs equipment; presents general healthcare design principles and methodologies;

Interviews with rehabilitation therapists and the Head of Infant Neuropsychiatry Department in order to obtain their perspective on: rehabilitation process in general, factors influencing the rehabilitation performance, existing problems, needs; suggestions.

Interviews with young patients and their parents (during the experimentation phase of the project) to discover their point of view on general performance of rehabilitation therapy, quality of equipment and appropriateness of approach, level of motivation and engagement, fatigue or other problems faced during the therapy; suggestions of improvement.

Observations, interviews with therapist, patients and their parents, as well as literature review provide a large amount of information about the situation in children's neurorehabilitation, about improvements and benefits that could be brought into this field and about the role of design, multidisciplinary research and new interactive technologies in development of rehabilitation programs for children.

Using findings and conclusions from the part 1 and part 2 of the study, the work proceeds with the development of co-design project in collaboration with Casimiro Mondino National Neurological Institute-Foundation and University of Pavia, and the team of engineers-researcher from NeuroLab DIBRIS of University of Genoa, producing the concept for the new rehabilitation program, its evaluations, creating a first prototype, its testing with the following conclusions on experimental data findings and further recommendations.

2 | Literature review

Introduction

This literature review is aimed to create a complex framework in order to understand the current situation in children's neurological rehabilitation and to map the key factors to be considered throughout the design interventions, technological improvements or proposals of new design solutions or concepts of rehabilitation equipment for better quality and effectiveness of therapeutic experience.

The following review studies the argumets listed below:

- Neurological disorders: overview, classification
- Learning Disabilities
- Models of neurological rehabilitation
- Review of existing rehabilitation programs for Learning Disorders
- Theoretical and methodological bases of Healthcare Design:
    - Evidence-based design principles
    - Theory of Supportive design
    - Neuroesthetics
- Paediatric neurorehabilitation. Play therapy
- Designing for Children
    - User Experience Design for Children
    - Age-appropriate toy Design
- Co-design with children
- Co-design with doctors and researchers
- Factors that influence product development
- Technological review:
    - Tangible interactive interfaces
    - Rehabilitation Robotics
    - Haptic feedback devices

In the 19th century and at the beginning of the 20th, brain research belonged to many different areas that differed in methodology and targets: the morphological, the physiological and the psychological. The latter used to consider the brain as a black box where only the input and output were known but not at all the neuronal components and the way they interact with each other.

At the beginning of the third millennium, due to prolonged ageing, neurodevelopmental disorders are growing and a much deeper knowledge of the brain is necessary. Scientific and technological research, from molecular to behavioural levels, have been carried out in many different places but they have not been developed in a really interdisciplinary way. Research should be based on the convergence of different interconnected scientific sectors, not in isolation, as was the case in the past.[2]

Rita Levi-Montalcini

1986 Nobel Prize in Medicine

[2] Rita Levi-Montalcini Foreword to the book *"Neurological Disorders public health challenges"* published by World Health Organization in 2006

Figure 1 Rita Levi-Montalcini
1986 Nobel Prize in Medicine

Neurological disorders: overview, classification

Neurological disorders

Neurlogical disorder is any disorder of the body nervous system. Structural, biochemical or electrical abnormalities in the brain, spinal cord or other nerves can result in a range of symptoms. Examples of symptoms include paralysis, muscle weakness, poor coordination, loss of sensation, seizures, confusion, pain and altered levels of consciousness.

Interventions for neurological disorders include preventative measures, lifestyle changes, physiotherapy or other therapy, neurorehabilitation, pain management, medication, or operations performed by neurosurgeons.

Neurological disorders can be categorized according to the primary location affected, the primary type of dysfunction involved, or the primary type of cause.

The Merck Manual[3] lists brain, spinal cord and nerve disorders in the following overlapping categories:

Brain

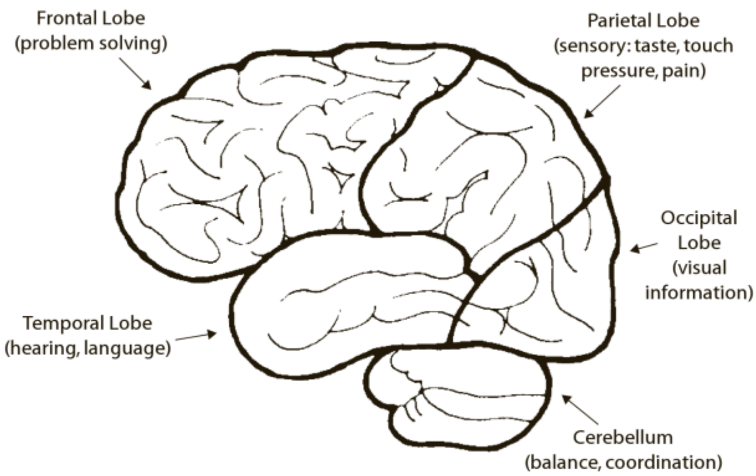
(Figure 2)

Brain damage according to cerebral lobe:

- Frontal lobe damage
- Parietal lobe damage
- Temporal lobe damage
- Occipital lobe damage

Brain dysfunction according to type:

- Aphasia (language)
- Dysarthria (speech)



[3] Robert S. Porter "*The Merck Manual of Diagnosis and Therapy*" Merck Research Laboratories, Online version: http://www.merckmanuals.com/professional/index.html (Retrieved 5/10/2014.)

Figure 2 Anatomy and functions of brain

- Dyspraxia/Apraxia (patterns or sequences of movements)
- Agnosia (identifying things/people)
- Amnesia (memory) Spinal cord disorders

Spinal cord disorders

- Spinal pathology
- Injury
- Inflammation

Peripheral neuropathy and other Peripheral nervous system disorders

Cranial nerve disorder, such as Trigeminal neuralgia

Autonomic nervous system disorders

- Dysautonomia
- Multiple System Atrophy

Seizure disorders

- Epilepsy

Movement disorders of the central and peripheral nervous system

- Parkinson's disease
- Essential tremor
- Amyotrophic lateral sclerosis (ALS)
- Tourette's Syndrome
- Multiple Sclerosis
- Types of Peripheral Neuropathy

Sleep disorders

- Narcolepsy

Migraines and other types of Headache

- Cluster Headache
- Tension Headache

Lower back and neck pain

Central Neuropathy

Neuropsychiatric illnesses

(diseases and/or disorders with psychiatric features associated with known nervous system injury, underdevelopment, biochemical, anatomical, or electrical malfunction, and/or disease pathology)

- Learning Disorders like: Attention deficit hyperactivity disorder, Dyslexia, Dysgraphia, Dyscalculia.
- Autism
- Tourette's Syndrome

- Some cases of obsessive-compulsive disorder
- Parkinson's disease
- Essential tremor
- Huntington's disease
- Alzheimer's disease
- Multiple sclerosis
- Organic psychosis

Delirium and dementia, such as Alzheimer's disease

Dizziness and vertigo

Stupor and coma

Head injury

Stroke (CVA, cerebrovascular attack)

Tumors of the nervous system, e.g. Cancer

Multiple sclerosis and other demyelinating diseases

Infections of the brain or spinal cord (including meningitis)

Prion diseases

Complex regional pain syndrome (a chronic pain condition)

Learning Disabilities overview

Learning disabilities are neurological disorders characterized by difficulties in acquiring certain academic and social skills, conditions that cause a discrepancy between potential and actual levels of academic performance as predicted by the person's intellectual abilities. Learning disabilities involve impairments or difficulties in concentration or attention, language development, or visual and aural information processing. Diagnosis includes cognitive, educational, speech and language, medical, and psychologic evaluations. Treatment consists primarily of educational management and sometimes medical, behavioral, and psychologic therapy.

Specific learning disabilities affect the ability to understand or use spoken or written language, do mathematical calculations, coordinate movements, or focus attention on a task. These disabilities include problems in reading, mathematics, spelling, written expression or handwriting, and understanding or using verbal and nonverbal language. Most learningdisabilities are complex or mixed, with deficits in more than one system.

Classifications

The two most widely used classification systems are those of the American Psychiatric Association and the World Health Organization (WHO)."[4]

Edition DSM-5 classifies learning disabilities under "Neurodivelopmental Disorders" It subclassifies disorders into the following categories:

Attention deficit disorder of childhood

- 314.00 Attention deficit disorder without mention of hyperactivity
- 314.01 Attention deficit disorder with hyperactivity

Significant problems of attention, hyperactivity, or acting impulsively that are not appropriate for a person's age. In school-aged individuals inattention symptoms often result in poor school performance.

Communication disorders

Deficits in language, speech, or in any behaviors affecting verbal and nonverbal communications

- 315.39 Language disorder

Persistent deficits in comprehension or production of language (e.g. spoken, written, sign language) substantially below age level, beginning in the early developmental period, and not due to other disorders or conditions

- 315.39 Speech sound disorder

Persistent deficits in speech sound production, below that expected of age and developmental level, not due to other impairments such a physical, neurological or hearing disorders or conditions

- 315.35 Childhood-onset fluency disorder (stuttering)

Disturbance in normal speech patterns and fluency that interferes with normal achievement

- 315.39 Social (pragmatic) communication disorder

Primary deficits in understanding and following social practices of verbal and nonverbal communication in normal settings that functionally impair the individual; not better explained by other deficits

Specific learning disorder

A neurodevelopmental disorder of biological origin manifested in learning difficulty and problems in acquiring academic skills markedly below age level and manifested in the early school years, lasting for at least 6 months; not attributed to intellectual disabilities, developmental disorders, or neurological or motor disorders

Specify if:

- 315.00 With impairment in reading

[4] *Diagnostic and Statistical Manual of Mental Disorders* [DSM] and *International Classification of Diseases* [ICD]
Educational professionals prefer the DSM classification for its academic relevance. A variety of specific academically related disorders are outlined in the DSM.

- 315.2 With impairment in written expression
- 315.1 With impairment in mathematics

Specify current severity: Mild, Moderate, Severe.

Motor disorders

- 315.4 Developmental coordination disorder

The classification system commonly used by therapists is the ICD. The ICD codes are state mandated diagnostic codes used for billing and infonnation purposes. In the recently revised ICD-10 the category "specific delays in development," which included "other specific leaming difficulties," was changed to "disorders of psychological development." The term "learning" is no longer part of this classification. This updated classification is as follows:

Disorders of Psychological Development:

- Including specific developmental disorders (SDD) of speech and language (including acquired aphasia with epilepsy)
- SDD of scholastic skills
- SDD of motor function
- Pervasive developmental disorder

Disability	Manifestation
ADHD	Problems of attention, hyperactivity, or acting impulsively. Difficulty in processing information as quickly and accurately as same age students.
Dyslexia	Problems with reading
Phonologic dyslexia	Problems with sound analysis and memory
Surface dyslexia	Problems with visual recognition of forms and structures of words
Dysgraphia	Problems with spelling, written expression, or handwriting
Dyscalculia	Problems with mathematics and difficulties with problem-solving
Ageometria	Problems due to disturbances in mathematical reasoning
Anarithmia	Disturbances in basic concept formation and inability to acquire computational skills
Dysnomia	Difficulty recalling words and information from memory on demand

Table 1. Common Learning Disabilities

Learning disabilities may be congenital or acquired. No single cause has been defined, but neurologic deficits are evident or presumed. Genetic influences are often implicated. Other possible causes include:

- Maternal illness or use of toxic drugs during pregnancy
- Complications during pregnancy or delivery (eg, spotting, toxemia, prolonged labor, precipitous delivery)
- Neonatal problems (eg, prematurity, low birth weight, severe jaundice, perinatal asphyxia, postmaturity, respiratory distress)

Potential postnatal factors include exposure to environmental toxins (eg, lead), CNS (central nervous system) infections, cancers and their treatments, trauma, undernutrition, and severe social isolation or deprivation.

Individuals with learning disabilities can face unique challenges that are often pervasive throughout the lifespan. Depending on the type and severity of the disability, interventions and current technologies may be used to help the individual learn strategies that will foster future success. Some interventions can be quite simplistic, while others are intricate and complex.

Symptoms and Signs

Children with learning disabilities typically have at least average intelligence, although such disabilities can occur in children with lower cognitive function as well. Symptoms and signs of severe disabilities may manifest at an early age, but most mild to moderate learning disabilities are usually not recognized until school age, when the rigors of academic learning are encountered. Affected children may have trouble learning the alphabet and may be delayed in paired associative learning (eg, color naming, labeling, counting, letter naming). Speech perception may be limited, language may be learned at a slower rate, and vocabulary may be decreased. Affected children may not understand what is read, have very messy handwriting or hold a pencil awkwardly, have trouble organizing or beginning tasks or retelling a story in sequential order, or confuse math symbols and misread numbers.

Disturbances or delays in expressive language or listening comprehension are predictors of academic problems beyond the preschool years. Memory may be defective, including short-term and long-term memory, memory use (eg, rehearsal), and verbal recall or retrieval. Problems may occur in conceptualizing, abstracting, generalizing, reasoning, and organizing and planning information for problem solving. Visual perception and auditory processing problems may occur; they include difficulties in spatial cognition and orientation (eg, object localization, spatial memory, awareness of position and place), visual attention and memory, and sound discrimination and analysis.

Some children with learning disabilities have difficulty following social conventions (eg, taking turns, standing too close to the listener, not understanding jokes); these difficulties are often components of mild autism spectrum disorders as well. Short attention span, motor restlessness, fine motor problems (eg, poor printing and copying), and variability in performance and behavior over time are other early signs. Difficulties with impulse control, non–goal-directed behavior and overactivity, discipline problems, aggressiveness, withdrawal and avoidance behavior, excessive shyness, and excessive fear may occur. Learning disabilities and attention-deficit/hyperactivity disorder often occur together.[5]

Diagnosis

Cognitive, behavioral, medical, and psychologic evaluations

Children with learning disabilities are typically identified when a discrepancy is recognized between academic potential and academic performance. Speech and language, intellectual, educational, medical, and psychologic evaluations are necessary for determining deficiencies in skills and cognitive processes. Social and emotional-behavioral evaluations are also necessary for planning treatment and monitoring progress.

Cognitive evaluation typically includes verbal and nonverbal intelligence testing and is usually done by school personnel. Psychoeducational testing may be helpful in describing the child's preferred manner of processing information (eg, holistically or analytically, visually or aurally). Neuropsychologic assessment is particularly useful in children with known CNS injury or illness to map the areas of the brain that correspond to specific functional strengths and weaknesses. Speech and language evaluations establish integrity of comprehension and language use, phonologic processing, and verbal memory.

Behavioral assessment and performance evaluation by teachers' observations of classroom behavior and determination of academic performance are essential. Reading evaluations measure abilities in word decoding and recognition, comprehension, and fluency. Writing samples should be obtained to evaluate spelling, syntax, and fluency of ideas. Mathematical ability should be assessed in terms of computation skills, knowledge of operations, and understanding of concepts.

Medical evaluation includes a detailed family history, the child's medical history, a physical examination, and a neurologic or neurodevelopmental examination to look for underlying disorders.

[5] *Merck Manual Online. Pediatrics. Learning and Developmental Disorders. Overview of Learning Disabilities.* Last full article revision March 2013 by Stephen Brian Sulkes, MD

Although infrequent, physical abnormalities and neurologic signs may indicate medically treatable causes of learning disabilities. Gross motor coordination problems may indicate neurologic deficits or neurodevelopmental delays. Developmental level is evaluated according to standardized criteria.

Psychologic evaluation helps identify ADHD, conduct disorder, anxiety disorders, depression, and poor self-esteem, which frequently accompany and must be differentiated from learning disabilities. Attitude toward school, motivation, peer relationships, and self-confidence are assessed.[5]

Treatment

- Educational management
- Medical, behavioral, and psychologic therapy
- Occasionally drug therapy

Treatment centers on educational management but may also involve medical, behavioral, and psychologic therapy. Effective teaching programs may take a remedial, compensatory, or strategic (ie, teaching the child how to learn) approach. A mismatch of instructional method and a child's learning disability and learning preference aggravates the disability.

Some children require specialized instruction in only one area while they continue to attend regular classes. Other children need separate and intense educational programs.[5]

Some Management Interventions include:
Mastery model:

- Learners work at their own level of mastery.
- Practice
- Gain fundamental skills before moving onto the next level

This approach is most likely to be used with adult learners or outside the mainstream school system.

Direct Instruction:

- Highly structured, intensive instruction
- Emphasizes carefully planned lessons for small learning increments
- Scripted lesson plans
- Rapid-paced interaction between teacher and students
- Correcting mistakes immediately
- Achievement-based grouping
- Frequent progress assessments

Classroom adjustments:

- Special seating assignments
- Alternative or modified assignments
- Modified testing procedures
- Quiet environment

Special equipment:

- Word processors with spell checkers and dictionaries
- Text-to-speech and speech-to-text programs
- Talking calculators
- Books on tape
- Computer-based activities

Classroom assistants:

- Note-takers
- Readers
- Proofreaders
- Scribes

Special Education:

- Prescribed hours in a resource room
- Placement in a resource room
- Enrollment in a special school for learning disabled students
- Individual Education Plan (IEP)
- Educational therapy[6]

Motor control models and neurological rehabilitation models

Therapists use theoretical models based on a cumulative history of clinical experience and scientific understanding to design their therapeutic rehabilitation approaches. Figure 3 illustrates how motor control models and neurologic rehabilitation models are not generated spontaneously but rely on and incorporate earlier models.[7]
According to Fay B. Horak these are three general models of motor control and three general models of neurologic rehabilitation that form the basis for most of the common approaches to therapeutic intervention for neurologically impaired patients.

Motor control models

Normal motor control implies the ability of the central nervous system to use current and previous information to coordinate effective and

[6] Sternberg, R. J., & Grigorenko, E. L. (1999). *Our labeled children: What every parent and teacher needs to know about learning disabilities.* Reading, MA: Perseus Publishing Group
Sternberg has argued that early remediation can greatly reduce the number of children meeting diagnostic criteria for learning disabilities. He has also suggested that the focus on learning disabilities and the provision of accommodations in school fails to acknowledge that people have a range of strengths and weaknesses, and places undue emphasis on academic success by insisting that people should receive additional support in this arena but not in music or sports.

[7] Fay B Horak: *Assumptions underlying motor control for neurologic rehabilitation.*
In: Contemporary Management of Motor Control Problems: Proceedings of the II STEP Conference. Alexandria, Va: Foundation for Physical Therapy. 1991: 11-27.

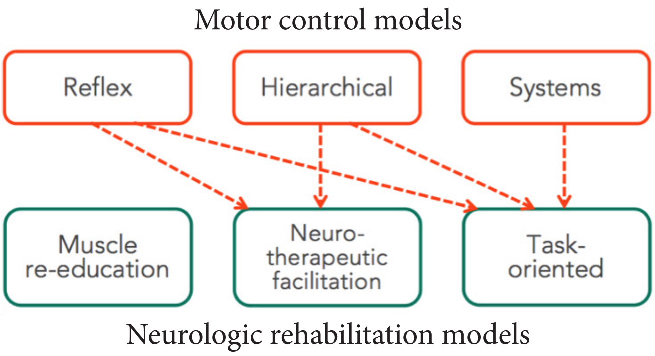


Figure 3. General models of motor control and neurologic rehabilitation

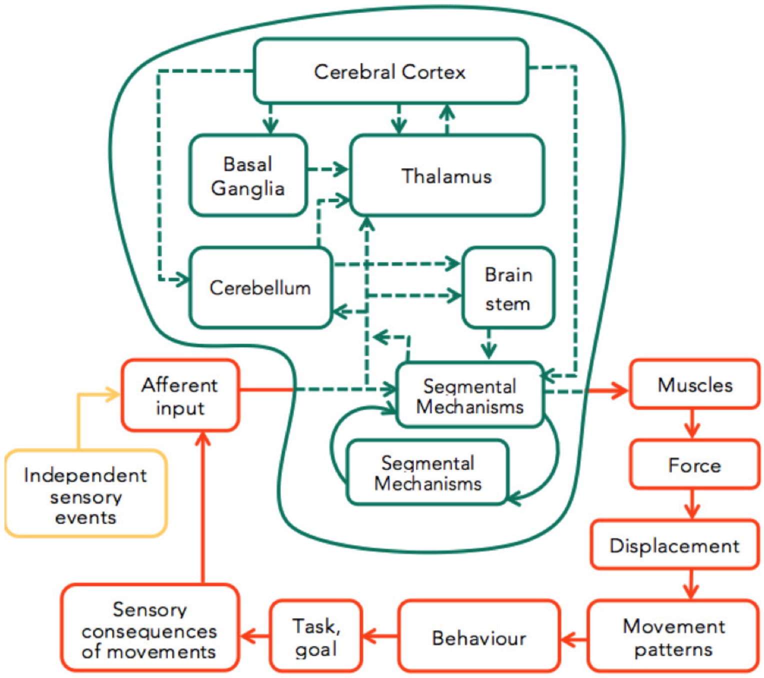


Figure 4. Wiring diagram of anatomical connections of motor control.

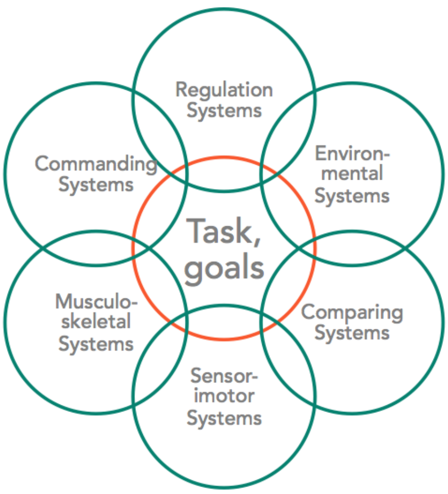


Figure 5. System model of motor control

efficient functional movements by transforming neural energy into kinetic energy. This transformation is accomplished by activation of muscles that generate forces to affect their world.

The nervous system delivers impulses to muscles and the muscles in turn develop contractile force to move (or to prevent movement of) the limbs in order to displace (or to prevent displacement of) joints. The nervous system almost always activates large groups of muscles that control displacements at many joints, and these movement patterns allow functional behaviors to accomplish task goals. These movement patterns may be represented back to the nervous system in different forms through sensory afferent signals that are, themselves, under neural control. (see figure 4)

In the reflex control model the goal of the nervous system is to control muscle activation; in the hierarchical model the goal is to control movement patterns; and in the systems model the goal is to control motor performance in behavioral tasks.

Reflex control model:

- Sensory inputs control motor outputs
- Movement is summation of reflexes
- Sensation is necessary for movement

Implications: identifying reflexes controlling movement in newborns and in brain-injured persons; when therapists appropriately stimulate patients, they can elicit stereotyped reflex responses. Another recommendation of the reflex model, which is important for physical therapy intervention, is that therapists need to be skilled at stimulating “good” reflexes that cause normal movements and skilled at avoiding ”bad” reflexes that interfere with normal movement.

Hierarchical control model:

- Central programs control muscle activation patterns
- Organization is top-down
- Separation of voluntary and reflex

Control of movement is organized hierarchically from lowest levels in the spinal cord, to intermediate levels in the brain stem, to highest levels in the cortex. Voluntary movements are initiated internally by the will, with specific goals in mind, and are manifested in an infinite variety of forms, depending on the purpose of the movement. In contrast, reflex movements are initiated by sensory stimuli in a fixed relation between the intensity and form of the stimuli and the intensity and form of the response.

Treatment progressions are designed to progress from the most automatic, lower levels controlled by therapeutic sensory stimulation to the least automatic, higher levels voluntarily controlled, such as skilled tasks. A related clinical implication of the hierarchical model is that motor flexibility comes only from the highest levels.

Systems model of motor control:

- Interactive systems control behavior to achieve task goals
- Adaptive, anticipatory mechanisms
- Normal strategies to limit degrees of freedom

According to the systems model, movements are not peripherally or centrally driven but emerge as a result of an interaction among many systems, each contributing to different aspects of control. As illustrated in the systems model in Figure 5, there are no higher and lower levels of control because there are many systems that distribute control at the same level. The control of movement includes neurologic systems for comparing, commanding, and recording motor control not only inside the nervous system but also in systems outside the nervous system, such as the musculoskeletal system and the environment. Thus motor control is achieved through functions regulating motor control for different types of movements in different environments.

The major assumption of the systems model is that the nervous system is organized to control the end points of motor behavior: the accomplishment of task goals. According to the systems model, normal movements are coordinated not because of muscle activation patterns prescribed by sensory pathways or by central programs but because strategies of motion emerge from interaction of the systems; they emerge to limit the degrees of freedom over which the nervous system exerts control. Therefore, control is not over muscles or sensory receptors, like in the reflex model, or over muscle activation patterns, like in the hierarchical model, but over abstract aspects of motor behavior, such as the relations among kinematic variables and the accomplishment of task goals.

Another assumption of the systems model is that the nervous system adapts to and predicts constraints placed on movement by the physical laws associated with the musculoskeletal system and its environment. By continually comparing anticipated and actual interactions with the world, the nervous system constantly modifies its model to realize the most effective, kinematically efficient means to accomplish task goals.

Normal movement strategies represent appropriate interaction with musculoskeletal and environmental settings, therapists attempt to assess and manipulate those settings, such as by having tasks practiced in a variety of postures and under varying surface, visual, and biomechanical conditions. Because many normal muscle activation patterns could accomplish one task goal, therapists who use a systems model are trying to help the nervous system learn to solve motor deficits in a variety of ways rather than activating a particular muscle activation pattern.

A clinical advantage of the systems model is that it can account for the flexibility and adaptability of motor behavior in a variety of environmental conditions. In the systems model, both functional goals and environmental constraints are thought to play a major role in determining movement.

The challenge for the therapist is to identify functional goals in motor tasks and to adapt environmental settings to reduce the degrees of freedom that must be controlled by the nervous system.

Neurological Rehabilitation Models

Physical therapy needs well-defined models of neurologic rehabilitation that outline the aims of the therapeutic intervention in physiologic and functional terms. These rehabilitation models need to reflect the current state of scientific knowledge in many areas, including motor control, motor learning, recovery of function, nervous system plasticity, psychology, sociology, ergonomics, neuroaesthetics, design. The rehabilitation team's responsibility is to develop, modify, test, and determine the usefulness of these models.

The most common therapeutic techniques depend on one of three neurologic rehabilitation models:

1) the muscle re-education model;
2) the facilitation model; and
3) the task-oriented, or systems-based, model. (See table 2)

Each therapeutic rehabilitation model is useful in assessing aspects of neurologic damage and in developing specific therapeutic exercises. They are not completely independent of one another, but they build on and depend on one another.

Task-oriented model of neurologic rehabilitation based on all three motor control models: reflex, hierarchical and systems.

Unlike the muscle re-education or the facilitation models, the task-oriented model does not assume that therapeutic influence on motor control should be aimed only peripherally at the musculoskeletal system and environment or only centrally at the nervous system. It targets both peripheral and central systems. From the systems model of motor control, the task-oriented model assumes that control of movement is organized around goal-directed, functional behaviors rather than on muscles or movement patterns

Table 2. General Aims and Dissatisfaction of Neurologic Rehabilitation Models

Therapeutic Aims		
Muscle Re-education	*Neurotherapeutic Facilitation*	*Task-oriented*
• Isolate muscle actions by focusing on individual muscles with proprioceptive inputs • Maximize strength and use of motor units remaining • Avoid secondary complications and compensatory patterns • Teach functional activities • Provide orthopedic support	• Facilitate normal movement patterns • Modify CNS from the experience of normal movement patterns • Fractionalize movements by breaking up abnormal synergies • Inhibit abnormal tone and primitive reflexes • Do not allow CNS to learn abnormal movement patterns	• Practice ability to achieve task goals • Teach motor problem solving (ie, adaptability to contexts) • Learn strategies to coordinate efficient, effective behaviors • Develop effective compensations • Use musculoskeletal and environmental settings
Dissatisfaction		
Muscle Re-education	*Neurotherapeutic Facilitation*	*Task-oriented*
• CNS plasticity not considered • Cannot isolate muscle action in upper motor neuron lesions • Not lack of muscle activation but abnormal patterns often a problem	• No carryover to functional activities • Patients are passive recipients • Does not take into account musculoskeletal and environmental effects • Inhibition of primative reflexes does not release normal movements	• Hard to quantify effective, efficient compensations • Less “hands-on,” too “cognitive” • How to retrain anticipatory control and use of prior experience • Hard to provide time-consuming practice of skills

Because the same task may be accomplished effectively with a wide variety of movement patterns, therapists do not limit training to one "normal" movement pattern but allow patients to learn alternative movement strategies to coordinate motor behaviours as efficiently as possible.

Because the nervous system is not a passive recipient of sensory stimuli but actively seeks to control its own perceptions and actions, the patient must actively and voluntarily practice motor performance motivated by the goal of accomplishing specific tasks. Because the voluntary and automatic systems are thought to be very interrelated, patients are encouraged to assist voluntarily in accomplishing a motor behaviour with the therapists' encouragement.

Because the nervous system is thought to be adapting continually dynamically to its environment and musculoskeletal conditions, therapists attempt to manipulate those environmental and musculoskeletal systems to allow efficient, purposeful motor behaviours.

Review of existing neurorehabilitation programs

There are several types of rehabilitation, such as physical, occupational, and vocational rehabilitation. Physical therapy is the main measure of treatment for people with limb coordination deficits since it helps the patient to restore the muscles, bones, and nervous system through thermal treatment and exercises. The main goal of exercises is to restore the original range of motion and to strengthen the affected limb.

The concept of "task-specific learning" based on neuroplasticity suggests that activities of daily living may be trained and improved through continuous repetition in neurological patients. Functional movement and sensory stimulation play an important role in the rehabilitation of neurological patients following stroke, spinal cord injury, traumatic brain injury, as well as in patients with multiple sclerosis, cerebral palsy or other neurological disorders.

Administering intensive functional locomotion therapy with manual training requires sufficient staff, is labor intensive and allows only relatively short training sessions. Furthermore manually assisted gait therapy can be challenging, especially in obese patients or in patients who are spastic.

This has led to the development of various methods of rehabilitative training.

The most diffused contemporary rehabilitation programs for motor functioning deficit include: robotic approach such as exoskeleton based robotics[8,9], virtual reality (VR) based approach and augmented reality

[8] Yupeng R., P. Hyung-Soon, and Z. Li-Qun, *"Developing a whole-arm exoskeleton robot with hand opening and closing mechanism for upper limb stroke rehabilitation,"* in Rehabilitation Robotics, 2009. ICORR 2009. IEEE International Conference on, 2009, pp. 761-765.

[9] Kiguchi K.,R.A.R.C. Gopura, and L. Yang, *"SUEFUL-7: A 7DOF upper-limb exoskeleton robot with muscle-model-oriented EMG-based control,"* in Intelligent Robots and Systems, 2009. IROS 2009. IEEE/RSJ International Conference on, 2009, pp. 1126-1131.

(AR) based approach.

Generally, robotic systems aim to train for severe impairments and classified as expensive assistive device while VR and AR based systems aim for minor impairment or later stage of rehabilitation training at low cost. The latter approaches provide with better encouragement and motivation as these systems employ game based exercise as a training platform.[10] . Some researchers developed the combination of robotic and VR based approach as in[11]. Research studies had confirmed that the embedded of VR in rehabilitation system provides positive results[12,13] which reflect on several developments.[14,15] Stand-alone VR based rehabilitation system integrated with biofeedback system also can be found in [16] (M. Sha, M. Varley et al., 2010).

Although VR based developments have proven with positive results, additional attachment of tracking device to the patient, their bulkiness and total immersive in virtual world are inconvenient and dangerous for patients especially if the patient is a child.

Therefore, Augmented Reality (AR) based rehabilitation exercises have been developed for better and safer interactive environment. Augmented reality is the combination of real world and virtual world that enhance the user perception of reality. The user can view the computer generated virtual environment that is overlaid on top of real environment. As far as AR based rehabilitation system is concerned, J. W. Burke et al.[17,18] have developed several exercises for upper-limb stroke patients.

Burke and his team have identified three aspects of game design, which are important for optimising the user experience in a rehabilitation context: meaningful play, conservative handling of failure and challenge:

- Meaningful play

Meaningful play emerges from a game through the relationship between a player's actions and the system's outcome. A good game should provide clear, consistent and meaningful feedback in response to the player's actions. Feedback can be communicated aurally (sound effects, speech), visually (ability to see arm/hand in the game, numerical scores, progress bars) and through haptic technology (vibration). Meaningful play is important to rehabilitation as it is crucial that a person with stroke playing the game is aware of their goals, what actions they need to take to achieve those goals and whether or not they are achieving those goals (both short-term and long-term) in order for them to engage effectively with the rehabilitation game.

- Conservative handling of failure

Due to a number of factors such as poor motor control and possible unfamiliarity with playing video games, the likelihood of people

[10] Yee Mon Aung and Adel Al-Jumaily. *AR based Upper Limb Rehabilitation System.* In The Fourth IEEE RAS/EMBS International Conference on Biomedical Robotics and Biomechatronics, Roma, Italy. pp. 213-218, June 24-27, 2012

[11] Meadmore K.L, C. Zhonglun, D. Tong, A. M. Hughes, C. T. Freeman, E. Rogers, et al., *"Upper limb stroke rehabilitation: The effectiveness of Stimulation Assistance through Iterative Learning (SAIL),"* in Rehabilitation Robotics (ICORR), 2011 IEEE International Conference on, 2011, pp. 1-6.

[12] Henderson A, Korner-Bitensky N, Levin M. *Virtual reality in stroke rehabilitation: a systematic review of its effectiveness for upper limb motor recovery.* Top Stroke Rehabilitation. 2007 Mar-Apr; 14(2):52-61.

[13] da Silva CM, Bermudez IBS, Duarte E, Verschure PF. *Virtual reality based rehabilitation speeds up functional recovery of the upper extremities after stroke: a randomized controlled pilot study in the acute phase of stroke using the rehabilitation gaming system.* Restor Neurol Neurosci. 2011;29(5):287–298.

[14] Broeren J., K. Sunnerhagen, and M. Rydmark, *"A kinematic analysis of a haptic handheld stylus in a virtual environment: a study in healthy subjects,"* Journal of NeuroEngineering and Rehabilitation, vol. 4, p. 13, 2007.

[15] Perry J.C, J. Rosen, & S. Burns, *"Upper-Limb Powered Exoskeleton Design,"* Mechatronics, IEEE/ASME Transactions on, vol. 12, pp. 408-417, 2007.

with stroke experiencing failure in a game, certainly initially, is high. Handling failure in a positive way by encouraging and rewarding all engagement with the game will make it more likely that players will not feel discouraged should they not perform as well as they had hoped.

- Challenge

Finally, games for rehabilitation can be designed to dynamically adapt the level of challenge depending on the performance of the player. This is important to ensure that the person with stroke is presented with a level of challenge suitable to their skills. If the game is too difficult, the player could become frustrated and give up; similarly, if the game is too easy, the player could quickly become bored.

[16] Sha M., M. Varley, S. Lik-Kwan, and J. Richards, *"EMG Biofeedback Based VR System for Hand Rotation and Grasping Rehabilitation,"* in Information Visualisation (IV), 2010 14th International Conference, 2010, pp. 479-484.

[17] Burke J.W., M.D. McNeill J., Charles D.K., Morrow P.J., Crosbie J.H. , and McDonough S.M., *"Augmented Reality Games for Upper-Limb Stroke Rehabilitation,"* in Games and Virtual Worlds for Serious Applications (VS-GAMES), 2010 Second International Conference on, 2010, pp. 75-78.

[18] Burke J.W., Morrow P. J. , M. D. J. McNeill, S. M. McDonough, and D. K. Charles, *"Vision Based Games for Upper-Limb Stroke Rehabilitation,"* in Machine Vision and Image Processing Conference, 2008. IMVIP '08. International, 2008, pp. 159-164.

Technology	Description
Robotics	Robotic systems aim to train severe impairments and challenging patients. It is rather expensive, due to complexity of equipment and require obligatory clinic stay. There are different techniques such as: active assisted exercise, active resistive exercise, passive exercise and adaptive exercise. Passive are used for the patients with severe impairment who have no voluntary activation of their arm muscles yet.
Combined approach: Robotics+VR	Enhanced robotic functional therapy with virtual performance feedback. Provides motivating and instructive functional feedback in virtual environments. Variability of virtual environments. Documentation of therapy progress. Clinic stay.
Augmented Reality	AR based rehabilitation exercises is a non-immersive, safer interactive environment. It is a combination of real world and virtual world that enhance the user perception of reality. Computer generated virtual environment overlay on real environment. Require AR markers recognizable by webcam. Limited play area by the perspective of webcam. Low precision of tracking, lose of signal if the marker is overlapped from camera view.
Virtual Reality	Treats minor impairments, or at later stage of rehabilitation progress. Provides engagement, motivation and flexibility. May be either clinic or home based. Lower cost of equipment. Great number of programs exists, more or less effective. Notable drawbacks are complete immersion in virtual environment; limitations of tracking devices.

Table 3. The most diffused technologies in contemporary rehabilitation therapy for neurological motor disorders.

As soon as this research is aimed to study Learning Disabilities (LD) rehabilitation programs in particular, some examples of existing Educational Therapy Programs are needed.
Dyslexia and Dysgraphia are the case studies' target diseases, so the detailed review of existing therapies for them will be accomplished in the part 2.
For other LD and motor disorders the examples of rehabilitation therapeutic programs will be given below.
As for Dyscalculia and Math disorders, there are some assessment tools to facilitate the everyday life like hand-held talking calculators, colour coding, digital watches, large screen displays, big number buttons and large keypads.
Rehabilitation programs for this kind of LD are based on particular teaching approaches and learning tools.

The Addacus™

(http://www.addacus.co.uk)
Addacus (also known as "Beat Dyscalculia") is a highly structured, multi-sensory numeracy programme that can be used to teach maths to children of all ages and abilities but is specifically designed as an intervention programme for children in Key Stage 1 and 2 who are struggling with the core curriculum. It is particularly effective for those with dyscalculia, dyslexia and autism. It has also been used with children in Key Stage 3 who are working below the expected levels.(Figure 6).

Tablet or computer applications for children with special needs:

http://a4cwsn.com/

Endless Numbers

Kids will have a blast learning number recognition, sequences, quantity, numerical patterns, and simple addition with the sympathetic Endless monsters. Each number features interactive sequences and equation puzzles with numbers that come alive, and a short animation that provides context and meaning to each number.

- Delightful animations reinforce number recognition, quantity, and counting.
- Interactive number puzzles reinforce basic numeracy skills.
- There are no high scores, failures, limits or stress. Child can interact with the app at their own pace. (Figure 7)

Luminosity

Human Cognition Project (http://www.lumosity.com/)
Sophisticated, scientifically designed brain training games.
Personalized training program creation.

Figure 6 The Addacus™ rehabilitation programme for children with Dyscalculia

Figure 7 Screenshot from “Endless numbers“ rehabilitation game app for children with Dyscalculia

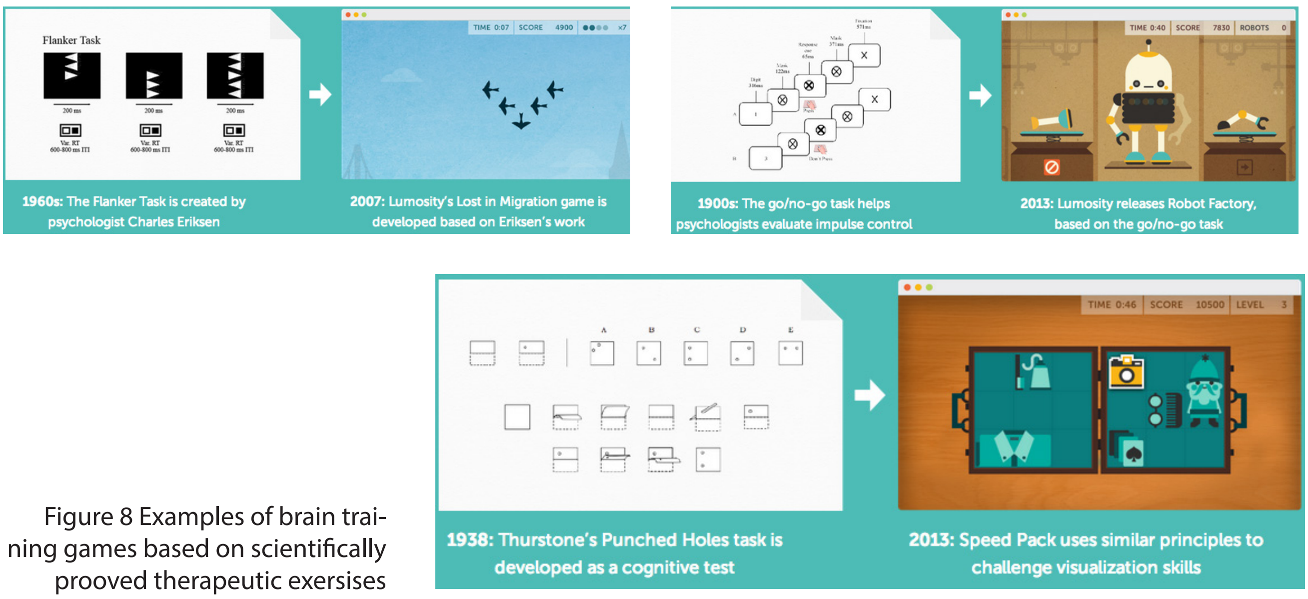


Figure 8 Examples of brain training games based on scientifically prooved therapeutic exersises

Scientific brain training approaches were transformed into 40+ delightful games (Figure 8)

- Memory
- Attention
- Flexibility
- Problem solving

Examples of rehabilitation programmes for motor disorders

Armeo® Power - Robotic arm exoskeleton
Armeo® Spring - Exoskeleton with integrated spring mechanism (Fig.9)
Armeo® Boom - Overhead sling suspension system by Hocoma
The ARMEO® therapy concept
This is a sustainable and powerful therapy concept for individuals who have suffered strokes, traumatic brain injury or neurological disorders resulting in hand and arm impairment.

Clinical trials indicate that therapies are more effective if the patient initiates the exercise and remains motivated through the often lengthy rehabilitation process, a recovery period in which one-to-one therapist attention may not be economically viable.

The Armeo Therapy Concept improves the efficiency of therapy treatments because the exercises are self-initiated, self-directed, functional and intense. Even severely impaired patients can practice independently, without the constant presence of a therapist, allowing patients to exploit their full potential for recovery.

The Augmented Performance Feedback provided by the shared software platform, encourages and motivates patients to achieve a higher number of repetitions, and this leads to better, faster results and improved long-term outcomes.

Timocco

Growing with Timocco© virtual motion gaming system that accelerates the development of motor and cognitive skills including: (Figure 10)

- Bi-lateral coordination
- Crossing the midline
- Hand-eye coordination
- Attention
- Posture
- Visual Discrimination
- Early Learning
- Communication
- Short-term memory
- Team work

Providing the motivation kids need to keep developing their motor, co-

Figure 9 Armeo® Spring Pediatric
Functional arm and hand therapy
for children

Figure 10 Timocco© virtual motion
gaming system

gnitive, and communication skills.
Timocco was designed for rehabilitaion of LD, Developmental Coordination Disorder, Autism, Cerebral Palsy, ADHD. Includes 50+ therapeutic games.

Augmented reality (AR) games for upper limb stroke rehabilitation
These games are designed for rehabilitating finer movements such as reach, grasp, manipulation and release of objects. The advantage of using this technology is that real objects of different shape, size and weight can be used, with the potential of rehabilitating meaningful and transferable skills. The games work with a standard PC and webcam and so are very low-cost and potentially suitable for home use. The games are currently in early stages. They are developed using the Microsoft XNA framework (C#) and ARToolKitPlus.
Project by J. W. Burke, et al. School of Computing and Information Engineering, University of Ulster, Coleraine, Northern Ireland. (ibid[17,18])

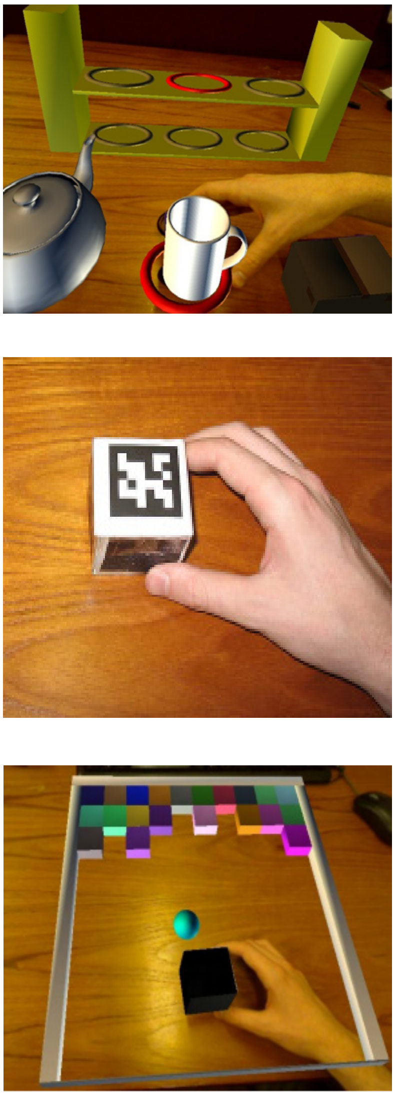


Figure 11 Augmented reality (AR) games for upper limb motor rehabilitation

To conclude, the review of neuro rehabilitation programs showed the importance of development of new efficient training methods due to challenges in manual therapy (e.g. high-demand labour intense of medical personal, limited time of therapeutic sessions, costs etc.)
Fortunately technological progress offers today a variety of innovations applicable to neurorehabilitation field. Among them sophisticated robotic devices such as exoskeletons and other smart training robots, the cost of which is constantly decreasing because of their wide diffusion and growth of low-cost technologies research development. Virtual reality, augmented reality and their combinations with robotics are as well in their apogee. Further detailed study of modern technologies can be found in chapter “Technological review”.

Theoretical and methodological bases of Healthcare Design

Evidence-based design principles

Evidence-based design is a field of study that emphasizes the use of credible evidence to influence the design process. The approach has become popular in Healthcare in an effort to improve patient and staff well-being, patient healing, stress reduction and safety.

An individual using evidence-based design makes decisions based on the best information available from research, from project evaluations, and from evidence gathered from the operations of the client. Critical thinking is required to develop an appropriate solution to the design problem. The available information will rarely offer a precise fit with a client's unique situation. Therefore, research that is specific to the project's objectives is almost always required. In the final analysis, an evidence-based design should result in demonstrated improvements in the organization's outcomes, economic performance, productivity, customer satisfaction, and cultural measures.[19]

Research relevant to healthcare design can come from many areas: [20]

1. Environmental psychologists focus on stress reduction, which includes:
   - social support (patients, family, staff);
   - control (privacy, choices);
   - positive distractions (artwork, music, entertainment);
   - influence of nature (plants, flowers, water, wildlife, nature sounds).
2. Clinicians focus on medical and scientific literature, which includes:
   - treatment modalities (models of care, technology);
   - quality & safety (infections, errors, falls);
   - exercise (exertion, rehabilitation).
3. Administration refers to management literature:
   - financial performance (margin, cost per patient day, nursing hours);
   - operational efficiency (transfers, utilization, resource conservation);
   - satisfaction (patient, staff, physician, turnover).

Methodology and strategies

In the first instance, evidence-based design methodology could be di-

[19] Website "The Center for Health Design" http://www.healthdesign.org/ (Retrieved 12/09/2013)

[20] Stout C.E., Hayes R.A. *The evidence-based practice: methods, models, and tools for mental health professionals*, John Wiley and Sons, January 2005

vided in four subsequent steps:

- reviewing existing research literature to select significant findings and recommendations;
- matching referenced findings with data gathered from site visits, surveys results, subject matter experts;
- predicting the outcomes of design decisions;
- tracking the positive outcomes for design implementation.
- Some strategies for the implementation of Evidence-Based Design
- Start with problems: identify the problems the project is trying to solve and for which the facility design plays an important role. For example: adding or upgrading technology, expanding services to meet growing market demand.
- Use an integrated multidisciplinary approach with consistent senior involvement, ensuring that everyone with problem-solving tools is included. It is essential to stimulate synergy between different community to maximize efforts, outcomes and interchanges.
- Maintain a patient-and-family-centered approach: patient and family experiences are key to define aims and to assess outcome efficacy.
- Use strategic partnerships to accelerate innovation, in order to create innovative new products.

Theory of Supportive design[21]

According to Ulrich increasing scientific evidence shows that poor design works against the well-being of patients and in certain instances can have negative effects on physiological indicators of wellness.
The effects of supportive design are complementary to the healing effects of drugs and other medical technology, and foster the process of recovery.

Stress: A Major Obstacle to Healing

A starting point for a theory of psychologically supportive design is the well-documented fact that most patients experience considerable stress. In very general terms, there are two major sources of stress for patients:

- illnesses that involve, for instance, reduced physical capabilities, uncertainty, and painful medical procedures;
- physical-social environments that, for instance, can be noisy, invade privacy, or provide little social support.

Patient stress has a variety of negative psychological, physiological, and often behavioral manifestations that work against wellness. In addition to patients, stress is a problem for families of patients, visitors in health

[21] One of the highly cited authors in the area of Design for Healthcare is Robert S. Ulrich, who developed a theory of Supportive Design.

Ulrich, R. (1990) *Effects of Interior Design on Wellness: Theory and recent Scientific Research.* Journal of Health Care Interior Design. p. 97-109

Ulrich, R. (2000) *'Effects of healthcare environmental design on medical outcomes', 'Design & Health: The Therapeutic Benefits of Design'.* Proceedings of 2nd International Congress on Design and Health, Karolinska Institute, Stockholm, Sweden

Ulrich, R., Quan, X., Zimring, C., Joseph, A. & Choudhary, R. (2004) *The Role of the Physical Environment in the Hospital of the 21st Century: A Once-in-a-Lifetime Opportunity.* Concord, CA: Center for Health Design.

facilities, and for healthcare staff.

The theory of supportive design:

on the basis of research and theory in the behavioral sciences and health related fields, it is justified to propose that healthcare environments will likely support dealing with stress and thereby promote wellness if they are designed to foster:

1. A sense of control with respect to physical-social surroundings.
2. Access to social support.
3. Access to positive distractions in physical surroundings.

What criteria were used to select these three components of supportive design? First, in the case of each component there is evidence from different scientific studies that it can influence wellness down to the level of physiological effects and health-related indicators. Further, these components, especially control and social support, have been found to affect stress and wellness across a wide range of groups of people and situations.

1. Sense of Control

The large body of scientific evidence indicates that humans have a strong need for control and the related need of self-efficacy with respect to environments and situations. Many studies have found that lack of control is associated with such negative consequences as depression, passivity, elevated blood pressure, and reduced immune system functioning. [22]

In context of children's rehabilitation in should be underlined the importance of familiar, safe, calming environment for stress reduction during the therapeutic exercises. Evidently the ideal atmosphere for a child (especially the one with special needs) is the home acquainted environment where he can experience the best sense of control and self-confidence, which profits to effectiveness of undergoing rehabilitation therapy.

That point must be taken in account while projecting children's rehabilitation equipment, providing the option of it domestic application (simplicity of devises, low cost, possibility of remote control of therapist).

2. Social Support

Patients derive important benefits from frequent or prolonged contact with family and friends who are helpful, caring, or otherwise supportive. Many studies in the fields of behavioral medicine and clinical psychology have found that individuals with high social support, compared to those with low support, experience less stress and have higher levels of wellness. Studies have found links between low social support and both higher rates of illness and less favorable recovery indicators follow-

[22] Carpman, J.R., Grant, M.A. and Simmons, D.A. (1986) *Design That Cares: Planning Health Facilities for Patients and Visitors*. Chicago: American Hospital Association.

ing serious illness.

For children's cognitive rehabilitation programs, first of all parents and relatives should provide a social support aspect in a household environment as it was mentioned above.

For that reason the projected system must be adapted to easy participation of more persons in a rehabilitation activity (game), inspiring a child for interaction and communication.

3. Positive Distractions

Research in psychology suggests that human well-being is usually fostered when physical surroundings provide a moderate degree of positive stimulation — that is, levels of stimulation that are neither too high nor too low. If stimulation levels are high due to sounds, intense lighting, bright colors, and other environmental elements, the cumulative impact on patients will likely be stressful. Positive distraction is an environmental feature of element that elicits positive feelings, holds attention and interest without taxing or stressing the individual, and therefore may block or reduce worrisome thoughts. Findings from a growing number of studies indicate that responses to positive distractions also involve positive changes across different physiological systems (e.g. reduced blood pressure).

The most effective positive distractions are mainly elements that have been important to humans throughout millions of years of evolution: happy, laughing, or caring faces, animals, nature elements such as trees, plants, and water.

Even though the mentioned above aspect of positive distraction was studied for the hospital environmental context, however its general principle valid also for rehabilitation systems projecting because it is based on general psychology research. Thereby it is important to consider a moderate level of positive stimulation designing the interaction effects: sounds, intense of lighting signals, brightness of colors should be neither high nor low keeping a child positively engaged without over irritation and annoying by too much aggressive interaction response.

Neuroesthetics

Neuroesthetics is a relatively recent sub-discipline of empirical aesthetics. Empirical aesthetics takes a scientific approach to the study of aesthetic perceptions of art and music. Neuroesthetics received its formal definition in 2002 as the scientific study of the neural bases for the contemplation and creation of a work of art. Neuroesthetics uses neuroscience to explain and understand the aesthetic experiences at the neurological level. [23]

Neuroesthetics is an attempt to combine neurological research with aesthetics by investigating the experience of beauty and apprecia-

[23] Nalbantian, Suzanne (December 2008). *"Neuroaesthetics: neuroscientific theory and illustration from the arts"*. Interdisciplinary Science Reviews 33 (4): 357–368

tion of art on the level of brain functions and mental states. The recently developed field seeks the neural correlates of artistic judgment and artistic creation. It is widely accepted that visual aesthetics, namely the capacity of assigning different degrees of beauty to certain forms, colors, or movements, is a human trait. (Cela-Conde, Camilo J et al. 2004) The theory of art can be devided into distinct components. The logic of art is often discussed in terms of whether it is guided by a set of universal laws or principles. Connecting in the human experience, the determination of specific brain circuitry involved can help pinpoint the origin of the human response through the use of brain imaging in experimentation.[24]

Researchers who have been prominent in the field combine principles from perceptual psychology, evolutionary biology, neurological deficits, and functional brain anatomy in order to address the evolutionary meaning of beauty that may be the essence of art. It is felt that neuroscience is a very promising path for the search for the quantified evaluation of art. With the aim of discovering general rules about aesthetics, one approach is the observation of subjects viewing art and the exploration of the mechanics of vision. It is proposed that pleasing sensations are derived from the repeated activation of neurons due to primitive visual stimuli such as horizontal and vertical lines. In addition to the generation of theories to explain this, such as Ramachandran's set of laws, it is important to use neuroscience to determine and understand the neurological mechanisms involved.

The link between specific brain areas and artistic activity is of great importance to the field of neuroesthetics. This can be applied both to the ability to create and interpret art. A common approach to uncover the neural mechanisms is through the study of individuals, specifically artists, with neural disorders such as savant syndrome or some form of traumatic injury. The analysis of art created by these patients provide valuable insights to the brain areas responsible for capturing the essence of art.

[24] Ramachandran V.S. and Hirstein W. *The Science of Art. A Neurological Theory of Aesthetic Experience.* Journal of Consciousness Studies, 6, No. 6-7, 1999, pp. 15–51

Paediatric neurorehabilitation. Play therapy

Neurorehabilitation is a complex medical process, which aims to aid recovery from a nervous system injury, and to minimize and/or compensate for any functional alterations resulting from it.

Neurorehabilitation works with the skills and attitudes of the patient, their family and friends. It promotes their skills to work at the highest level of independence possible for them. It also encourages them to rebuild self-esteem and a positive mood. Thus, they can adapt to the new situation and become empowered for successful and committed community integration.

Neurorehabilitation should be:

- Holistic

It should cater for the physical, cognitive, psychological, social and cultural dimensions of the personality, stage of progress and lifestyle of both the patient and their family.

- Patient-focused

Customized health care strategies should be developed, focused on the patient (and family).

- Inclusive

Care-plans should be designed and implemented by multidisciplinary teams made up of highly qualified and motivated practitioners experienced in multidisciplinary teamwork.

- Participatory

Patient and their family's active cooperation is essential. The patient and family must be well-informed, and a trusting relationship with the multidisciplinary team must be built.

- Sparing

Treatment must aim at empowering the patient to maximise independence, and to reduce physical impairment and reliance on mobility aids.

- Lifelong

The patient's various needs throughout their life must be catered for, by ensuring continuity of care all the way through from injury onset to the highest possible level of recovery of function. This may include addressing medical complications of the injury or illness later in life.

- Resolving

Treatment has to include adequate human and material resources for efficiently resolving each patient's problems as they arise.

- Community-focused

It is necessary to look for the solutions best adapted to the specific characteristics of the community and to further the creation of community resources favouring the best possible community reintegration of the disabled person.

According to Swaiman's Pediatric Neurology, paediatric rehabilitation has several guiding principles based upon the nature of the discipline, as well as the age and developmental level of the patients requiring treatment. [25]

1. Well-coordinated transdisciplinary therapy team
A fundamental principle of neurorehabilitation is that the process mandates a coordinated transdisciplinary team working in unison to provide integrated evaluations and therapeutic interventions. A variety of "non-medical" issues, such as home and school accessibility, psychosocial adaptation to disability, and school reintegration, mandates that the team include individuals who can address these all-important considerations.

2. Therapeutic strategies predicated on achieving functional improvement
A second essential principle is that the rehabilitation process must concentrate on strategies designed to effect true functional improvement. In paediatric rehabilitation, this means establishing practical management decisions that are endorsed not only by the patient, but also by the family. In order to accomplish this goal, the team must have a clear understanding of the physical, emotional, cognitive, and social consequences of a child's injury[26]

3. On-going reassessment of the child and revision of the treatment program
The degree, extent, and rate of recovery, which varies significantly among children, as well as differences in functioning from setting to setting and task to task in a single child, obligate to continual reassessment. The immature brain's response to injury is both varied and dynamic. This evolving biologic recovery, in combination with substitute/alternative cognitive processes and movement patterns, necessitates an on-going program of assessment and reassessment.

4. Re-evaluations guided by an understanding of normative development (developmental milestones as goals of therapy)
Another fundamental and distinguishing principle of paediatric rehabilitation is that these frequent reassessments of cognitive, motor, and psychosocial deficits, especially when resulting from acquired nervous system injury, must be guided by an understanding of normative development. Detailed understanding of the patterns of cognitive development during maturation is especially important in the rehabilitation of infants and children for several reasons. First, normative developmental milestones can be identified as sequential goals within an individual's

[25] Noetzel M.J.: *Acute pediatric neurorehabilitation*. In: Winn H.R., ed. Youman's neurological surgery, ed 5. Philadelphia: Elsevier Science; 2003, pp. 3783-3791.

[26] Ylivsaker M., Chorazy A.J.L., Feeney T.J., et al: *Traumatic brain injury in children and adolescents: assessment and rehabilitation.* In: Rosenthal M., Griffith E.R., Kreutzer J.S., et al ed. Rehabilitation of the adult and child with traumatic brain injury, ed 3. Philadelphia: FA Davis Company; 1999, pp. 356-392.

therapy program[26]. In addition, as a result of injury or illness, the paediatric patient typically loses age-appropriate developmental capabilities.

Finally, an understanding of cognitive development allows more accurate prediction of the long-term effects of cerebral injury sustained by young children.[27]

5. Interventions initiated as early as possible

A final guiding principle of rehabilitation in the paediatric patient is that intervention should begin as soon as possible. Once the patient is medically stable, therapy can and should be initiated, even while the child is still in the intensive care unit. This early phase of intervention is designed to limit maladaptive behavioural habits and movement patterns, and to prevent or at least minimize complications that can take months to resolve, if not properly and promptly addressed following the acute injury. [25]

The important issue of paediatric rehabilitation programs to emphasise is a child-centred, age-appropriate therapy. Paediatric rehabilitation services have to be designed specifically for kids and the treatment have to be customizable and flexible.

For the cases of serious motor functioning deficits, motor-planning, visual-spatial and coordination impairments rehabilitation process requires repetitive, fatiguing and unpleasant exercises that results into problematic experience for a child, influencing negatively on the therapy outcomes. Thus one of the main challenges of design-engineering and therapeutic team is to render the rehabilitation program engaging and motivating in order to encourage a young patient for accomplishment of the necessary tasks without stress and fatigue in a playful and attractive environment.

Play therapy

Play therapy is generally employed with children aged 3 through 11 and provides a way for them to express their experiences and feelings through a natural, self-guided, self-healing process. As children's experiences and knowledge are often communicated through play, it becomes an important vehicle for them to know and accept themselves and others.

Play therapy is a form of treatment or psychotherapy that uses play to communicate with and help children, to prevent or resolve physical or psychosocial challenges. This supposed to help them towards better social integration, growth and development.

According to the psychodynamic view, people (especially children) will engage in play behavior in order to work through their interior difficulties and anxieties. In this way, play therapy can be used as a

27 Kenneth F. Swaiman, Stephen Ashwal, Donna M Ferriero, and Nina Schor, *Swaiman's Pediatric Neurology, 5th Edition*; Elsevier Inc., 2012

self-help mechanism. Normal play is an essential component of healthy child development.

Play therapy can be divided into two basic types: nondirective and directive. Nondirective play therapy is a non-invasive method in which children are encouraged to work toward their own solutions to problems through play. It is typically classified as a psychodynamic therapy. In contrast, directive play therapy is a method that includes more structure and guidance by the therapist as children work through emotional and behavioral difficulties through play. It often contains a behavioral component and the process includes more prompting by the therapist. Directive play therapy is more likely to be classified as a type of cognitive behavioral therapy.[28]

Designing for Children

User Experience Design for Children

Specific design recommendations by Gerry Gaffney and James Hunter based on interviews and observational sessions with approximately 100 children in primary and high schools, and cross-referenced with other sources, on how to design effectively for kids aged 5 to 16 (from Presentation "Children of the revolution" at UX Australia 2011 User Experience Conference and Workshop).[29]

Sometimes it seems that kids today are born with an innate understanding of technologies their parents had to learn.
Is this true? What are the implications of designing for "digital natives"?

Key considerations

- Children constitute a widely diverse range of behaviours and ability.
- In early primary years, children will be pre-literate or have very limited reading skills.
- In later primary school, skills develop rapidly, but there is wide variance between children of the same age.
- Children are highly social, dependent on peers for feedback, and highly conscious of their relationship with the adult world.
- Online behaviour shows an extreme disinclination to read extraneous information, and an expectation of immediate response from user interfaces.
- Trends mean that rapid changes in online preferences are likely.
- For many children, computers and mobile devices are synonymous with games. A more "serious" focus emerges in later high school years.

[28] Ray, D., Bratton, S., Rhine, T., & Jones, L. (2001). *The effectiveness of play therapy: Responding to the critics.* International Journal of Play Therapy, 10(1), 85-108.

[29] Gerry Gaffney, James Hunter (August 2011) *Presentation "Children of the revolution"* at UX Australia 2011 User Experience Conference and Workshop. Available online Recomendations: http://infodesign.com.au/usabilityresources/designingforchildren/
Presentation and Audio: http://uxaustralia.com.au/conference-2011/children-of-the-revolution

Figure 12 Illustration by Gina Ellis
User experience design for children

- Contrary to popular belief, children are not imbued with an innate understanding of digital technologies.

General principles

- Provide age-appropriate materials.
- Be cautious of designing for exceptional children. Inclusive design practices will enable the broadest possible range of children to participate in your technology.
- Leverage knowledge children may have gained on social networking sites and games.
- Maintain frequent contact with your target user groups, so that you can understand trends and changing behaviours.

Early primary years

- Use text redundantly with images so that pre-literate users can access your product.
- Use simple text.
- Use fonts that approximate how children learn to write.

For example, many fonts use "a" and "q" in variants that do not match how some children are taught to write those letters.

- Do not use dialog boxes.
- Don't require explicit "save" operations. Save work automatically.
- Exclude extraneous content.
- Provide highly interactive and engaging applications.
- Avoid visually noisy interfaces – they are distracting.
- Provide large target areas.
- Allow children to personalise.
- If applications will be used on a smartboard, do not use a footer that can be accidentally activated by children leaning against the surface.
- Avoid errors.
- Support cooperative use, with two or more children using your product at the same time.
- Design to support teachers and parents or guardians, who are likely to be assisting or supervising usage.

Later primary years

- Use simple text.
- Provide content that appears more "grown up" than that for early primary years.

- Provide time-saving shortcuts.
- Leverage knowledge children may have from social media and popular games.
- Avoid appearing to patronise.
- Apply sensible defaults.

High school years

- Provide more sophisticated personalisation capability.
- Support social networking.
- Don't attempt to appropriate or emulate children's behaviour or speech
- Provide increasingly "grown-up" content towards later years.

Age Appropriate Toy Design

Age Devision

According to Weihua Zhang and Ren Peng in their article "Toy Design matched with Children Age" [30] children's age level is divided into the following stages:

Birth to 2 years old:

Children in this period mainly learn to walk, talk, and kinds of actions. They usually have a strong desire to explore outside, also like communicating with the elder. So plaything focused on these children should be simple,easy to operate, appropriate to children's interaction with parents.

2 years to 3 years old:

At this point they could walk by themselves, act rough and have preliminary identification and awareness of thinking. In addition, intelligence and physical strength begin to develop dramatically. So their ability of thinking ought to be enhanced on the basis of the initial recognition.

3 years to 5 years old:

Now they could master skillful action, general ability to distinguish, preliminary independent thinking with certain curiosity, and they like imitating adults' movement consciously.

5 years to 7 years old:

There is no doubt about their communication skill and imagination at this age range. They are very lively, fond of outdoor games, and want complex and stimulating toys with a variety of functions.

From the above age division it could be found that children in every stage have different characteristic of growth and needs of capability enhancement and intellectual development. While the reality is that many

[30] Weihua Zhang, Ren Peng. (2010) *Toy Design matched with children of target age.* Conference: Computer-Aide Design & Conceptual Design (CAIDCD); IEEE 11th International Conference on, Volume:2

products' explanations on applicable age are very vague.

Activity Centered Design

Among all age groups the personalities of children aged from birth to 2 is most difficult to grasp. As the infants, their expressions are very simplex and deliver unclearly. Designers always feel difficult to capture their true needs, feelings, experience of playing. Moreover, the buyers of toy product are mostly the adult, which embodies a typical separation of purchaser and user. Many companies and designers develop products just under their own supposition and parents' expectation to pursue sales. Therefore, many toys are designed for meeting parents' wish rather than children's interests. Toys developed like this, of course, could not satisfy children's demand and longing. Since there are so many uncertainties and difficulties to achieve the real need. How should design be conducted?

After a long-term observation of children's operating and daily behavior. ACD (Activity Centered Design) is applied naturally. ACD is a design method that requires designers to focus on typical activities and help designers shape users' requirements from the activities of users. Children always tend not to like many existing toys which are produced according to other people's wish. But what could be found is their favorite actIvItIes, habitual actions, and specific behaviors such as grasping, throwing, pressing etc. Design is made to fulfill their requirement to do a particular action including those illustrated above. Perhaps what children are fond of is the feel of conducting this motion on products.

The key point of this approach is to dilute products' function and emphasize the operation of children. The function needs of specific product would be affected by different family circumstances, geographic regions and even gene. Diverse backgrounds of life would lead to distinct function demand. While children at this age range have similar activities, most of which are aimed at perceiving the unknown world. Through the means, meeting these demands that let children act as what they most want, could make product easy to operate and improve their interest of playing toys.

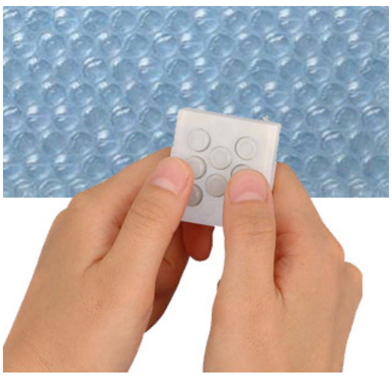


Figure 13 Activity Centered Design Example: PuchiPuchi Virtual Bubblewrap

The concept of Activity Centered Design developed for some rapid development requirements is widely used now, which makes the life circle much shorter. These features of design are quite useful in the design for children's toys.

Fig. 13 shows a typical product derived from behavior, the idea comes out from the research in which it is found that children deeply like to press bubbles or capsule holes. This product without specific function is designed only to meet the need of pressing. What children want is such a movement and feeling on this material. What is done in this product design is only diverting the activity, material property,and style of the toy. Furthermore, it can let children experience from listening and vision through adding music and light elements.

Goal Directed Design(GDD)

When kids are three to five years old, they have a certain ability to think, identify, and communicate. Designers and parents can talk with them with little problem and try to find out their needs. So GDD (Goal Directed Design) is adopted in practice. It is a dogma that tackles the product development process by defining specific product requirements and interface behavior based on research and user needs. That means, on the one hand, children's entertainment is expected to be realized, on the other hand, parents' requirements such as study also would be satisfied meanwhile.

This is an all-new product which is operated by children's riding. In past children played racing game by controlling the handle, while parents hope children take more exercise rather than always stay home playing games. The purpose of this concept is to fulfill the common demand of both parents and children better, so children can have fun and take exercise together. After physical exertion they would be tired and need rest, which can prevent them from indulging in entertainment.

Content Development

Generally, children are more mature than past generation at these ages. So elder children nowadays have started enjoying emotional entertainment such as cartoon, electronic games. In this time the development of toys also need to focus on content selection. Taking Leapfrog's products (www.leapfrog.com) as an example, what the company sold to elder children is software contents games and toys which bundle studying and entertainment together.

Anyway, when design toys designers should pay special attention to the characteristics of children at all age under current context and choose flexible design method to correspond to different needs. These are extremely important not only in commercial interests of enterprise, but also in social significance. Accurate toy concept could be only produced under clear age position, correct understanding of target user and appropriate design process, only through which it would exist less setbacks to pursue.

Co-design with children

Knowing about children's development and being aware of potential risks does not provide enough information to design technologies. Children need to be involved in some way as well. Following is an overview of the different ways in which children can participate in the design process, paying particular attention to techniques where children participate as design partners.

A. Druin (2002) developed a classification method of ways children can participate in design process: as users, testers, informants or design partners.[31] Furthermore, she states that each role supersedes and encompasses the next, with all testers also being users, all informants being testers, and all design partners being informants.

Children as Users

Children's participation as users often occurs at the beginning or at the end of the design process. Ethnographies are an example of the type of activities that can occur when children participate as users. These activities often involve observation. At the beginning of the design process, they can help assess children's interests, their current activities and how they currently use technology. At the end of the design process they can provide an understanding of how the technology that was developed affects children's lives and how or what they learn.

The main drawback of this approach is that children do not directly affect the design of the technology as it is being designed and provide no feedback until the work is completed. Thus, while participation of children as users is likely to be useful, when used by itself could significantly increase the chances of a technology being developed that will not serve children's needs or take their abilities into account.

Children as Testers

Perhaps the most common way in which children participate in the design process in both research and practice projects is as testers. When in this role, children test competing products, prototypes, and completed products so that designers and developers can obtain feedback on their designs as well as valuable information on making a technology competitive. Testing works very well with iterative design methodologies, which most researchers and practitioners agree provide advantages over traditional "waterfall" methodologies. Certainly, catching problems with designs as early as possible can greatly reduce costs and improve the quality of technologies, no matter the target user population. Testing can include techniques that are also used for adults including usability testing, peer-tutoring, Wizard of Oz[32], and active intervention.

While children participating as testers can go a long way toward

[31] Druin, *"The role of children in the design of new technology,"* Behaviour and Information Technology, vol. 21, no. 1, pp. 1–25, 2002.

[32] In the field of human-computer interaction, a *Wizard of Oz* experiment is a research experiment in which subjects interact with a computer system that subjects believe to be autonomous, but which is actually being operated or partially operated by an unseen human being.

developing quality technologies, the approach still does not provide children with a voice in the design process. All design decisions are still made by adults who may not quite remember what it is like to be a child.

Children as Informants

The next step up in involvement is for children to participate as informants. The concept of children participating as informants comes from research activities conducted by Scaife et al.[33] In this role, children share ideas and opinions with the design team acting as consultants at key points in the development and design process. This role provides a compromise that enables children to contribute their ideas to the design process and at the same time is flexible enough that it works for short-term projects or for projects that require a quick turnaround. Children can participate in this role through interviews, questionnaires, focus groups, and similar activities. A. Antle,[34] proposed using personas (user profiles) to keep in mind the characteristics of child informants when they are not available.

Children as Design Partners

In Druin's classification, children's highest level of involvement in the design process is when they join it as design partners. The idea of this role is for children to be equal partners in the design team. It does not mean that children tell adults what to do, but rather that design ideas come from the process of adults and children collaborating.

In Druin's research at the University of New Mexico and the University of Maryland, the design partnerships have involved the collaboration of academic researchers with groups of six to eight children. The researchers meet with the children twice a week during the school year at a research lab. Rather than work on one project at a time, the group of children are most often involved in several projects, which enables them to see progress and see something new every time they meet with adult researchers.
Druin adapted and developed a set of techniques to work with child design partners and called them cooperative inquiry.[31, 35]

The techniques used under cooperative inquiry are: technology immersion, contextual inquiry, and participatory design. Technology immersion is used to introduce and expose children and possibly some adult design partners to the capabilities and possibilities of a particular technology. It is also useful as a way of understanding how well a particular technology may fit children's needs and abilities. Technology immersion tends to be most useful at the beginning of projects.

Contextual inquiry involves children and adult researchers observing each other while using a technology. In these sessions, children

33 Scaife M., Y. Rogers, F. Aldrich, and M. Davies (1997) *"Designing for or designing with? Informant design for interactive learning environments"* in Proceedings of Human Factors in Computing Systems 97, pp. 343–350, ACM Press.

34 Antle A., (2004) *"Supporting children's emotional expression and exploration in online environments"* in Proceedings of Interaction Design and Children, pp. 97–104, ACM Press.

35 Druin A. (1999) *"Cooperative inquiry: Developing new technologies for children with children"* in Proceedings of Human Factors in Computing Systems (CHI 99), pp. 223–230, ACM Press.

and adults get to express their opinions about what works well, what does not and what they would like to change about the technology. This can lead to useful discussions in the design team that can provide feedback on competing technologies, as well as on prototypes of technologies being developed.

In participatory design sessions, children and adults collaborate in developing low-fidelity prototypes of technologies. Early in the design process, or if they are designing something with physical attributes, they can use a variety of art supplies such as paper, markers, card - board, boxes, socks, and wires. If designing an application for use on a computer, they may later concentrate on drawing sketches on large pieces of paper. Participatory design sessions are useful for producing design ideas at the beginning of the process and anytime new features need to be added, or new solutions need to be developed.

The advantage of children joining as design partners is that they will provide more input into the design process, which is likely to result in technologies that better address their needs, interests, and abilities. The main challenge of children participating in this role is that it often takes time to develop these partnerships. Most children are not ready to contribute as partners right away because they are not used to being in such a role.

In addition, if working on one project at a time, it may be difficult to make enough progress on prototypes to make it worth meeting with children on a regular basis. It may also be difficult to put such teams together as not all researchers have suitable places to meet with children for design activities, and it is also difficult to recruit a group of children that can meet on a regular basis.

Another issue with design partnerships is that working with small groups of children could bias designs toward these children. This problem can be dealt with by testing the technology with a wider and more representative set of children. Other researchers have adapted cooperative inquiry techniques to their unique situations including children of different ages and abilities and locations other than research labs. [36, 37, 38, 39, 40, 41]

[36] Gibson L., F. Newall, and P. Gregor (2003) *"Developing a web authoring tool that promotes accessibility in children's designs"* in Proceedings of Interaction Design and Children pp. 23–30, ACM Press.

[37] Gibson L., P. Gregor, and S. Milne (2002) *"Designing with 'Difficult' children"* in Proceedings of Interaction Design and Children International Workshop, pp. 42–52, Shaker Publishing.

[38] Guha M.L, A. Druin, G. Chipman, J. A. Fails, S. Simms, and A. Farber (2004) *"Mixing ideas: A new technique for working with young children as design partners"* in Proceedings of Interaction Design and Children, pp. 35–42, ACM Press.

[39] Knudtzon K., A. Druin, N. Kaplan, K. Summers, Y. Chisik, R. Kulkarni, S. Moulthrop, H. Weeks, and B. Bederson (2003) *"Starting an intergenerational technology design team: A case study"* in Proceedings of Interaction Design and Children, pp. 51–58, ACM Press.

[40] Rode J.A, M. Stringer, E. F. Toye, A. R. Simpson, and A. F. Blackwell (2003) *"Curriculum-focused design"* in Proceedings of Interaction Design and Children, pp. 119–126, ACM Press.

[41] Taxen G., A. Druin, C. Fast, and M. Kjellin (2001) *"KidStory: A technology design partnership with children"* Behaviour and Information Technology, vol. 20, no. 2, pp. 119–125.

Co-design in Healthcare and Medicine

How participatory design[42] can be applied to scientific research in the field of healthcare and medicine?

User-centred practices are already employed to support patient-side healthcare activities[43], not as much has been done to investigate how different design methodologies can engage researchers, being a crucial workforce for medicine.[44]

How can designers intervene into research to evolve its equipment? How can industrial design get involved as a structured discipline into the development of science? What can designers improve in the performance of the final product? How can design research support research in medical science?

Within healthcare contexts, local solutions are frequently more effective as they reflect the physical, emotional and cognitive needs of specific patients and engage all stakeholders in a specific local context.

By using open horizontal innovation networks, where assistive devices can be easily shared and physically hacked by other allied health professionals, general patterns can be detected and translated into standard universal design objects. This generative design thinking approach is more than feasible with digital trends such as crowd sourcing, user-generated content and peer production.

Different aspects of this open innovation process within a 'design for disability' context and suggests the first steps in an iterative co-design methodology that brings together expertise from professional designers, occupational therapists, patients and other stakeholders. The overall aim is to gain more insights into designing qualitative occupational experiences for disabled users. [44]

Current state: rejection and abandonment

Healthcare has a long tradition in the use of technical aids to replace or support body functions of peoples with disabilities. Within the field of 'design for disability', two main approaches emerged in the twentieth century. In the late 1960s, universal design was inextricably bound up with architectural accessibility. It became clear that many of the environmental adaptations needed to accommodate people with disabilities actually benefited everyone. Slowly, universal design evolved from removing physical barriers to people with disabilities towards integration of all people within all environments. Universal design became a general design approach in which designers ensure that their products and services meet the needs of the widest possible audience, irrespective of age or ability.[45] As a design method, universal design resulted in a set of general guidelines and accessibility standards on different scopes that can be applied in traditional design processes.

[42] Margolin, V 1997, *'Getting to know the user',* Design Studies, vol. 3, no. 18, pp. 227-235.

[43] Driver, A, Peralta, C, Moultrie, J 2011, *'Exploring how industrial designers can contribute to scientific research',* International Journal of Design, vol. 5, no. 1, pp. 17-28.

[44] De Covreur, L, Grossens, R 2011, *'Design for (every)one: co-creation as a bridge between universal design and rehabilitation engineering',* CoDesign: International Journal of Co- Creation in Design and the Arts, vol. 7, no. 2, pp. 107-121.

[45] Story, M.F., Mueller, J.L., and Mace, R.L., 1998. *The universal design file: a guide to designing for people of all ages and abilities.* Raleigh, NC: NC State University.

A second approach emerged to cater for the return of thousands of disabled veterans during World War II. This modern rehabilitation movement, guided by surgeons, recommended multidisciplinary scientific and engineering endeavours in rehabilitation.[46] Efforts to improve prosthetics and orthotics resulted in a speciality that adopted scientific principles and engineering methodologies. As a design method, this second approach became known as rehabilitation engineering and resulted in the development of assistive technology.

Although coming from quite different histories and directions, the effects of universal design and assistive technology are the same: increasing independence, improving the quality of life, and reducing the physical and attitudinal barriers between people living with and without disabilities.[47] Paradoxically, several studies on the field report also high rates of rejection and abandonment. Some of the reasons pointed out as responsible for these phenomena are lack of fitness, high costs and stigma.[48] Today, there are 600 million people living with disabilities who lack proper assistive devices or whose assistive devices does not yet fit well.

Key problem: the lack of contextual push

Universal design aspires to address the needs of the widest possible audience in the mainstream, whereas assistive technology attempts to meet the specific needs of individuals. From an industrial design point of view, both have more than one opposed characteristic (Figure 14). Universal design is based on the principle of economies of scale, which involves mass-production techniques and traditional design processes.

In contrast, the force of innovation within rehabilitation engineering is characterised by a technology push strategy. New inventions are pushed through medical research and development without proper consideration of whether or not they satisfy a user need.[49] In most cases, assistive technology products are produced in small batches owing to tailored and high-end aspects that make them almost unaffordable without the help of government agencies or charitable bodies. Because of the rarity of niche markets, the diversity and variations of specific assistive devices are very limited, they lack aesthetic beauty and brand the user with a product stigma. Most of the time, rehabilitation technologists are forced to use standard assistive products that approximate the user's requirements as well as possible. Furthermore, the low rate of assistive device use has been associated with a lack of information regarding the devices.[50] The clients are rarely seen as the customer, because they neither paid for their equipment nor had a major say in the choice of the equipment purchased.

The bottom line, however, is that both approaches have difficulties in incorporating the experiential knowledge of disabled users into

[46] Brandt, E.N. and Pope, A.M.P., 1997. *Enabling America: assessing the role of rehabilitation science and engineering.* Washington, DC: National Academy Press.

[47] Hoening, H., Taylor, D.H. Jr., and Sloan, F.A., 2003. *Does assistive technology substitute for personal assistance among the disabled elderly?* American Journal of Public Health, 93, 330–337.

[48] Pape, T.L.-B., Kim, J., and Weiner, B., 2002. *The shaping of individual meanings assigned to assistive technology: a review of personal factors.* Disability and Rehabilitation, 24 (1/2/3), 5–20.

[49] Gregor, P., Sloan, D., and Newell, A.F., 2005. *Disability and technology: building barriers or creating opportunities?* Advances in Computers, 64, 283–346.

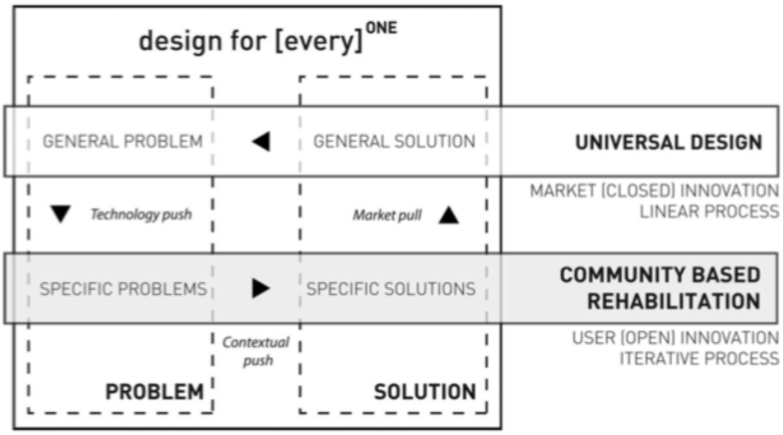


Figure 14 Macro framework: Design for (every)one [44]

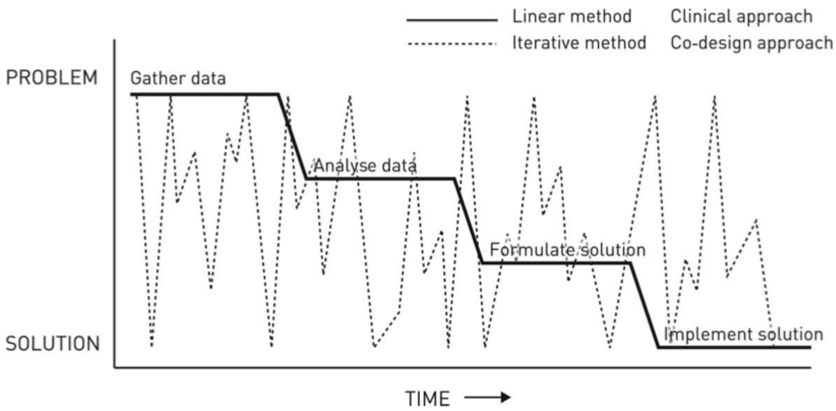


Figure 15 Wicked problems. (Adapted from Conklin 2005)

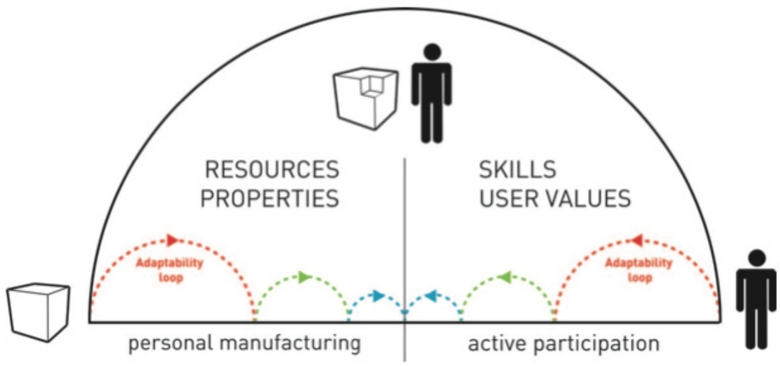


Figure 16 Incremental adaptation: artefact meets user and user meets artefact.

their design process. The lack of contextual push calls for new types of research, such as cultural probes and generative tools which sketch out the user experience spectrum.[51] Every single contextual disability is connected with individual conflicts of values, goals, skills and specific interests. Therefore, if one wants to design meaningful assistive devices, one should take into account the whole product ecology[52] of an individual context.

Rehabilitation engineering has a history of trial and error through iterative processes between rehabilitation technologists and patients. Still, this process takes place only in rehabilitation institutions. In real life people do not live in institutions; they live in their community with family, friends and colleagues. "Design for (every)one"[44] proposed by Lieven De Couvreura and Richard Goossens aims to close this context gap by introducing user-driven innovation on the level of rehabilitation engineering.

Macro framework: Design for (every)one

The World Health Organization (WHO 2010) redefined the meaning of disability as not being intrinsically part of the person, but rather a function of the person's interaction with the environment. This social redefinition has led to a new strategy, namely community-based rehabilitation (CBR)[53], which deals with contextual disability. The strength of CBR programmes is that they can be made available in areas with limited infrastructure, as programme leadership is based on self-organisation of a community. CBR programmes built around assistive devices involve people with disabilities themselves, their families and appropriate professionals. Design for (every)one sketches out a holistic framework (Fig. 14) where assistive technology manufacturers build horizontal user innovation networks next to their mainstream design processes, supported by the methodology of community-based rehabilitation programmes.

The ideal Design for (every)one framework is a self-organising open network wherein disabled people and their caregivers become conscious actors, rather than being objects of pity and in need of care. Giving the right expressive tools, occupational therapists and their patients can become manufacturers themselves.

The start of the Design for (every)one framework (shown in Figure 14) focuses on the core of innovation development within the level of rehabilitation engineering. Within rehabilitation institutions and assistive technology companies, teams still tend to have exclusively clinical or engineering backgrounds; the dominant culture is one of problem solving and cost-cutting. Innovation within these fields is mainly technologically driven: it lacks the tools to address social complexity and emotional responses.

[50] Gitlin, L. and Schemm, R., 1996. *Maximizing assistive device use among older adults* (online). University of Pittsburgh. Available from: http://www.wheelchairnet.org/wcn_prodserv/Docs/TeamRehab/RR_96/9604art2.PDF

[51] Stappers, P.J., et al., 2009. *Designing for other people's strengths and motivations: three cases using context, visions, and experiential prototypes.* Advanced Engineering Informatics, 23, 174–183.

[52] Forlizzi, J., 2008. *The product ecology: understanding social product use and supporting design culture.* International Journal of Design, 2 (1), 11–20.

[53] International Labour Organization, United Nations Educational, Scientific and Cultural Organization, and World Health Organization, 2004. CBR: *a strategy for rehabilitation, equalization of opportunities, poverty reduction and social inclusion of people with disabilities* (online). Available from: http://www.ilo.org/skills/what/pubs/lang–en/doc- Name–WCMS_107938/index.htm

Traditional thinking that is embedded in these disciplines follows an orderly and linear top–down process (Fig. 15), working from the problem towards the solution. Once you have the problem specified and the requirements analysed, you are ready to formulate a solution, and eventually to implement that solution. This is illustrated by the 'waterfall' line in Figure 15.
Problems can be technically very complex, they belong to a class of similar problems that have already been solved. However, because a person's health and well-being are part of very mutable systems, these linear processes do not apply to the category of problems built around assistive technology. The interplay among practices, politics and economics has created hidden interdependencies and changing requirements.
On top of that, as already pointed out, there is no such thing as an average 'disabled person' living in an 'average context'.

Problems involving disabled people have a certain 'wicked component', which demands an opportunity-driven approach, requiring decision making, doing experiments, launching pilot programmes and testing prototypes. A certain amount of trial and error is necessary in untangling the physical, emotional and cognitive needs of specific patients. Problem understanding can only come from creating possible solutions by building knowledge collaboratively through validating specific solutions with individual disabled users.[54]

This is the point where co-design methodology comes in as a powerful engine for user innovation. Co-design can be used as a set of iterative techniques and approaches that puts users at its heart, working from their perspectives, and engaging latent perceptions and emotional responses. In a way, co-design could very well be regarded as a new type of DIY, adapted to modern times (Hoftijzer 2009). In combination with physical prototypes (led by designers or caregivers), co-design becomes a tangible pragmatic approach that continuously shifts between 'what is needed?' and 'what can be built?' This polarity forms the basis of "Design for (every)one".

In every cycle more insights are gained on both levels. This incremental adaptation process makes use of low-end prototyping techniques for translating user values into product properties and vice versa (Figure 16). The main aim is to bring appropriate technologies and users skills incrementally closer through alternation between human-centred design and activity-centred design (Norman 2005), creating applications that support the patient and designing the right activity to achieve his or her personal goal. The ideal point where a technology and a user meet 100% will rarely be reached as users are moving targets with ever-changing requirements and evolving skills. In a way, products are never finished. A new way to think about rehabilitation engineering is

[54] Miller, P. and Parker, S., 2004. *Disablism* (online). Demos. Available from: http:// www.demos.co.uk/publications/disablism

perceiving it as an infinite design process that stimulates continuous innovation led by the challenges and skills of disabled users, living in continuously changing ecologies.

The key roles

The key roles in this co-design processes are forming a trialogue around the aspects of assistive technology: activity, user(s) and technology (Figure 17). It is preferable to talk about archetypal roles than key players because in some situations one key player can fulfil more than one role. For example, a caregiver can fulfil the role of self-manufacturer, an occupational therapist is in some cases the patient, or a self-manufacturer can also be the occupational therapist. It is important to notice that there are three roles with different perspectives and each of them creates new possibilities with different skills.

Key role activity: occupational therapist

Occupational therapy is as an allied healthcare profession concerned with promoting health and well-being through qualitative occupations.[55] The occupational therapist keeps this overall goal of assistive technology in mind. With his or her clinical background, the key role occupational therapist sketches the medical constraints and possibilities for each individual patient. Occupational therapists can break down activities into achievable components and they can teach new ways of approaching tasks. Within this activity-centred design approach, activity analysis is an often applied technique. It is defined as a process of dissecting an activity into its component parts and a task sequence, allowing people to identify inherent properties and skills required for its performance.

[55] WFOT, 2004. World Federation of Occupational Therapists (online). Available from: http:// www.wfot.org/information.asp

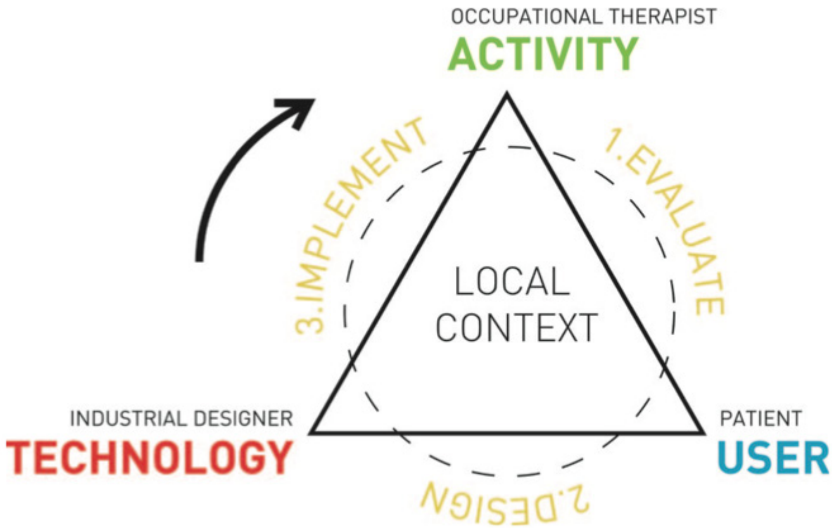


Figure 17 Trialogue between key roles and iterative actions in Design for (every)one methodology.

The occupational therapist detects which type of assistive device the patient needs to achieve his or her goals, and by doing so sets the starting point for the first design, or customisation iterations. In most cases the patient and therapist have already physically hacked a universal assistive device; doing so can be seen as a translation of a latent need or a hidden solution for the problem. The therapist evaluates the flow[56] experienced in every iteration through the behaviour and feedback of the patient.

Key role user(s): patient/caregiver

The patient is given the position of 'expert of his/her experience'.[57] He or she seeks assistance in fulfilling a meaningful goal. In some cases, when the patient has difficulty communicating his or her feedback verbally, the caretaker plays an important role as translator. Depending on the level of creativity[58], patients join the design process by expressing themselves in creating, using or adapting the assistive prototypes. Owing to the iterative character of the methodology, it is important that patients are cognitively capable of building on past user experiences. The perceived value of a product is critical and determines the strategy of the following iterations. While reducing or eliminating negative experiences and enhancing more positive values, the patient also slowly adapts to his or her new assistive device.

Although the nature of an everyday task could look simple, the context in which it takes place is always characterised by intricate interaction patterns among the user, the assistive appliance and the environment. Next to all of the user experiences, all of these interactions are mapped in a user–product–environment model. Who are the stakeholders? What can they contribute? What are their requirements? If they are not included in the thinking and decision-making processes, certain stakeholders may seek to undermine or even sabotage the project.

Key role technology: industrial designer/user-manufacturer

The industrial designer becomes the technology facilitator between the occupational therapist and the patient. He or she continuously translates user values and feedback through behaviour into product properties. With this human-centred design approach he tries to augment the skills and ability of the patient through adapting the technology. In this stage, the industrial designer's main job is to ideate and create tools and prototypes, which enable the occupational therapist to communicate on a physical level with a patient. In some 'in vivo' test cases it is difficult to obtain full-time engagement because the patient is sometimes too fatigued or in too much pain to complete the user testing. Time is precious; therefore we have to plan a scenario for each user-testing activity and avoid overloading the patient with too much information. The more varied and pronounced the concepts, the quicker the user can

[56] Csìkszentmihàlyi, M., 1990. *Flow: thepsychology of optimal experience*. New York: Harper and Row.

[57] Sleeswijk Visser, F., et al., 2005. *Contextmapping: experiences from practice*. CoDesign, 1, 119–149.

[58] Sanders, E.B.N. and Stappers, P.J., 2008. *Co-creation and the new landscapes of design.* CoDesign, 4, 5–18.

provide converging feedback. When evaluating concepts, it is important to strive for the highest level of measurement (from nominal, ordinal to interval) by means of discovering the different aspects that are relevant for the user. In most cases, aspects of iterated concepts will be perceived as 'better', 'good enough' or 'worse' than the previous iterations. It is task of the industrial designer to document this process and leave as many traces as possible so that the user community can harness the lessons learnt from the project.

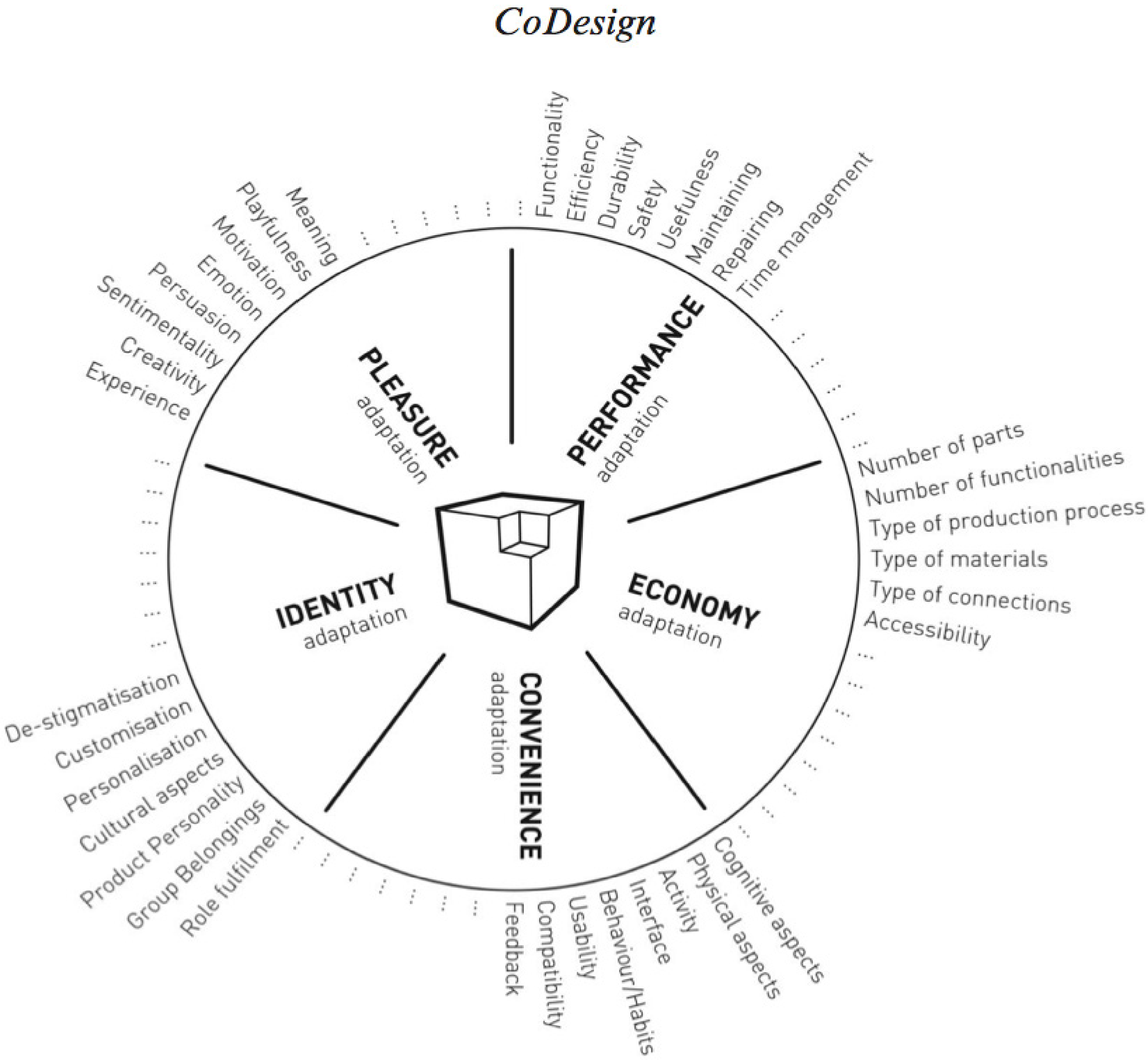


Figure 18 Setting the adaptation strategy (based on the user-value adaptation theory of Boztepe[59]).

Co-construction: adaptation strategies

At the beginning of each process, a clear status needs to be sketched as a reference point. Sharing tangible models at this early stage sets the basis for understanding, agreement and action. That is why we use a comprehensive and yet manageable set of adaptation strategies that guide the key players in the complexity of perceived value. This semi-structured method is based on the user-value adaptation theory of Suzan Boztepe[59] and draws from five main strategies (Fig. 18): performance, economy, convenience, identity and pleasure adaptation. Each strategy highlights a range of related aspects that could play a relevant role in certain contexts. There is no way to provide a finite catalogue of all potential aspects. Based on the experiential feedback of the patient, unique aspects are categorised and a specific strategy is set to guide the process.

A second goal of the Design for (every)one framework is to strengthen the analysis of field data and to produce intelligent conclusions that extend far beyond predictable outcomes.

Although adaptations are designed and implemented according to a linear methodology, the user always experiences these five main aspects simultaneously. It is important not to avoid side-remarks but rather to use them as descriptions for the next adaptation strategy. The aim of the key players is to find the patterns among these aspects and to build a model that describes the relevant relationships.

[59] Boztepe, S., 2007. *Toward a framework of product development for global markets: a user-value-based approach.* Design Studies, 28, 513–533.

Factors that influence product development

Product Analysis is the process of identifying, looking at or disassembling a product and identifying its main features. The aim is to understand more about a product and improve it in the future. Many factors influence the development of a product some are listed here.

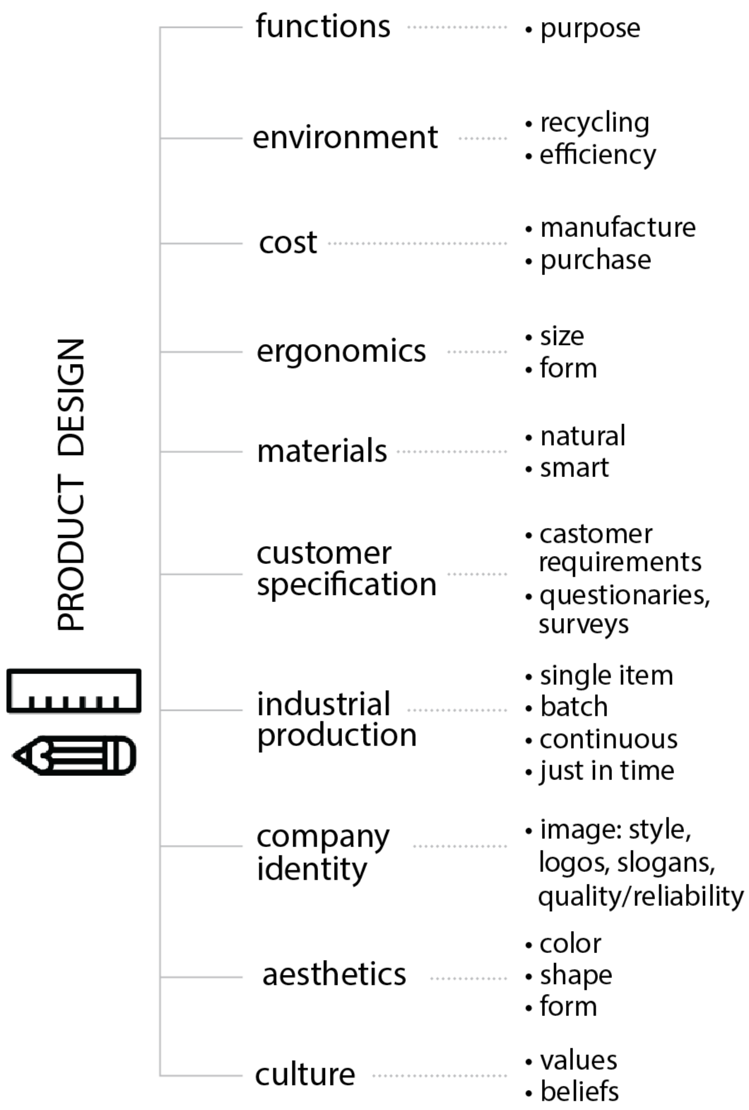


Figure 19 Factors that influence product development

Cost:
The cost of the materials and labour required to manufacture the product. The price potential customers are prepared to pay for the product.
Materials:
The availability of materials and the development of new, hi-technology

materials can have an influence on the final design of a product.

Customer requirements:
The customer may have great influence over the way a product is designed and developed. During product development potential customers should be questioned about type of design that they would prefer and their ideas may be taken in consideration.

Industrial production:
All products are manufactured through one of the following manufacturing techniques: Single Item / Prototype / One Off; Batch Production; Continuous Production; Just in Time.
The desirable production mode may also influence on the final product design.

Aesthetics
The shape and form of the product may determine the layout of circuits or mechanisms inside it. Aesthetics can also alter the production / manufacturing techniques through which it is made.

Culture
Some products are aimed at different cultures and countries. A product acceptable in one culture may be looked up one as offensive or less desirable in another.

Technological review

Tangible interactive interfaces

Recently Tangible user Interfaces have emerged as a new interface type that interlinks the digital and physical worlds. Tangible interfaces show a potential to enhance the way in which people interact with and control digital information. In the following chapter there will be discussed development of tangible technology, methods and approaches for designing, building, and evaluating Tangible Interfaces.
For a long time, it seemed as if the human–computer interface was to be limited to working on a desktop computer, using a mouse and a keyboard to interact with windows, icons, menus, and pointers while no alternative interaction styles existed. Over the past two decades, human–computer interaction researchers have developed a wide range of interaction styles and interfaces.
Novel input devices that appeal to users' skill of interaction with the real non-digital world gain increasing popularity (e.g., the Wii Remote controller, multi-touch surfaces). Simultaneously, computers were placed in every-day objects and environments, and products integrate computational and mechatronic components.

Comparison of Implementation Technologies [60]

The following properties are used to compare the Tangible Interface implementation technologies:

- Physical properties sensed. What physical properties can be sensed using a particular technology?
- Cost. What is the relative cost of the different components comprising a sensing technology?
- Performance. Is the system efficient in terms of processing and response times? What factors affect the system's efficiency?
- Aesthetics. To what extent does a sensing technology affect the appearance of an object?
- Robustness and reliability. Can the system perform its required functionality for a long period of time? Can the system withstand changing conditions?
- Setup and calibration. What is required to get the system in a usable mode?
- Scalability. Can the system support an increasing number of objects or users?
- Portability. To what extent does a sensing technology compromise the portability of a system?

[60] Shaer O. and Hornecker E. (2010), *"Tangible User Interfaces: Past, Present, and Future Directions", Foundations and Trends®* in Human–Computer Interaction: Vol. 3: No. 1–2, pp 4-137.

[61] Brewer, BR; McDowell, SK; Worthen-Chaudhari, LC (Nov–Dec 2007). *"Poststroke upper extremity rehabilitation: a review of robotic systems and clinical results."*. Topics in stroke rehabilitation 14 (6): 22–44.

Table 4 comparison of implementation technologies using the above properties. [60]

Property	RFID	Computer Vision	Microcontrollers
Physical properties sensed	Identity, presence	Identity, presence, shape, color, orientation,position, relative position and sequence	Light intensity, reflection, motion, acceleration,location, proximity, position, touch, temperature, gas concentration, radiation etc.
Cost	Tags are cheap and abundunt. The cost of readers varies, but is generally inexpensive (short distance readers)	Fiducial tags are practically free. The cost of highquality cameras continuously decreases. A high-resolution progector i relatevely expnsive.	Generally inexpensive. The cost of sensors and actuators vary according to type.
Performance	Tags are read in real time, no latency, associated with additional processing.	Dependent on image quality. Tag-specific algorithms are typically fast and accurate. A large number of tags or low quality imagetake longer processing. Motion blur is an issue when tracking moving objects.	Generally designed for high-performance. Stand-alone systems typically perform better than computer-based systems.

Aesthetics	Tags can be embedded in physical objects without altering their appearance.	Fiducial marker can be attached to almost any object (ideally to its bottom)	Sensors and actuators can be embedded within objects. Wires may be trea-ted to have a minimal visual affect.
Robustness and reliability	Tags do not degrade over time, impervious to dirt, dut sensitive to moisture and temperature. Nearby technology may interfere with RFID signal. Tags can only be embedded in materials opaque to radio signals.	Tag-based systems are relatevely robust and reliable. However tags can degrade over time. De-tection only within line of sight.	Typically designed for robu-stnessand reliability. Batte-ries needed to be charged. The robustness and reliabi-lity of sensors and actuators vary. Wiring may need to be checked.
Setup and calibration	Minimal. No line of sight or contact is needed betwe-en tags and reader. The ap-plication must maintain a database that associates ID with desired functionality.	Address a variaty of factors including occlusion, lighting conditions, lens setting and progector calibration.	Connect microcontroller to computer; wire sensors and actuators; embed hardware in interaction objects; fa-bricate tailored interaction objects to encase hardware.
Scalability	The number of simulta-niously detected tags is limited by the reader. No practical limitation on the number of tagged objects.	The maximun number of tracked tagged objects depends on the tag design (typically a large number)	Typically constrained by the number of I/O ports avai-lable on a microcontroller.

Rehabilitation Robotics

Rehabilitation robotics is a field of research dedicated to understanding and augmenting rehabilitation through the application of robotic devices. Rehabilitation robotics includes development of robotic devices tailored for assisting different sensori-motor functions[61] (e.g. arm, hand, leg), development of different schemes of assisting therapeutic training,[62] and assessment of sensori-motor performance (ability to move) of patient;[63] here, robots are used mainly as therapy aids instead of assistive devices.[64] Rehabilitation using robotics is generally well tolerated by patients, and has been found to be an effective adjunct to therapy in individuals suffering from motor impairments, especially due to stroke.

Overview

Rehabilitation robotics can be considered a specific focus of biomedical engineering, and a part of human-robot interaction. In this field, clinicians, therapists, and engineers collaborate to help rehabilitate patients.

[62] Marchal-Crespo, L; Reinkensmeyer, DJ (Jun 16, 2009). *"Review of control strategies for robotic movement training after neurologic injury."*. Journal of neuroengineering and rehabilitation 6: 20.

[63] Balasubramanian, S; Colombo, R; Sterpi, I; Sanguineti, V; Burdet, E (November 2012). *"Robotic assessment of upper limb motor function after stroke."*. American journal of physical medicine & rehabilitation / Association of Acade ic Physiatrists 91 (11 Suppl 3): S255–69.

[64] Krebs, H.I., et al. (2004). *Rehabilitation robotics: Pilot trial of a spatial extension for MIT-Manus.* Journal of NeuroEngineering and Rehabilitation, 1(5).

Prominent goals in the field include: developing implementable technologies that can be easily used by patients, therapists, and clinicians; enhancing the efficacy of clinician's therapies; and increasing the ease of activities in the daily lives of patients.

Function

The rehabilitation robots are designed with applications of techniques that determine the adaptability level of the patient. There are different techniques such as: active assisted exercise, active constrained exercise, active resistive exercise, passive exercise and adaptive exercise.

In active assisted exercise, the patient moves his or her hand in predetermined pathway without any force pushing against it. Active constrained exercise is the movement of the patient's arm with an opposing force; if it tries to move outside of what it is supposed to.

Active resistive exercise is the movement with opposing forces. These machines (like MIT-Manus, Bi-ManuTrack and MIME) make the active resistive exercise possible.

Passive exercise needs to be pushed from the patient.

Finally, an adaptive exercise is an excessive workout that the robot has never done and is adapting to the new unknown pathway. These devices Bi-ManuTrack and MIME support the adaptive exercise possible. The active constrained exercise is supported by all the machines that are mentioned.[65]

Over the years the number of rehabilitation robotics has grown but they are very limited due to the clinical trials. Many clinics have trails but do not accept the robots because they wish they were remotely controlled. Having Robots involved in the rehabilitation of a patient has a few positive aspects. One of the positive aspects is the fact that you can repeat the process or exercise as many times as you wish. Another positive aspect is the fact that you can get exact measurements of their improvement or decline. You can get the exact measurements through the sensors on the device. While the device is taking a measurement you need to be careful because the device can be disrupted once it is done because of the different movements the patient does to get out. [65]
The rehabilitation robot can apply constant therapy for long periods. The rehabilitation robot is a wonderful device to use according to many therapist and scientist and patients that have gone through the therapy. In the process of a recovery the rehabilitation robot is unable to understand the patient's needs like a well experienced therapist would.[66]
The robot is unable to understand now but in the future the device will be able to understand. Another, plus of having a rehabilitation robot is that there is no physical effort put into work by the therapist.
Lately, the rehabilitation robotics has been used in training medicine,

[65] Munih, M., & Bajd, T. (2011). *Rehabilitation robotics.* Technology & Health Care, 19(6), 483-495.

[66] Carrera, I., Moreno, H., Saltarén, R., Pérez, C., Puglisi, L., & Garcia, C. (2011). *ROAD: domestic assistant and rehabilitation robot.* Medical & Biological Engineering & Computing, 49(10), 1201-1211. doi:10.1007/s11517-011-0805-4

surgery, remote surgery and other things, but there have been too many complaints about the robot not being controlled by a remote. Many people would think that using an industrial robot as a rehabilitation robot would be the same thing, but this is not true. Rehabilitation robots need to be adjustable and programmable, because the robot can be used for multi reasons. Meanwhile, an industrial robot is always the same; there is no need to change the robot unless the product it is working with is bigger or smaller. [65]

Current Areas of Research

Current robotic devices include exoskeletons for aiding limb or hand movement such as the Tibion Bionic Leg, the Myomo Neuro-robotic System, MRISAR's STRAC (Symbiotic Terrain Robotic Assist Chair) and the Berkeley Bionics eLegs; enhanced treadmills such as Hocoma's Lokomat; robotic arms to retrain motor movement of the limb such as the MIT-MANUS, and finger rehabilitation devices such as tyromotion's AMADEO. Some devices are meant to aid strength development of specific motor movements, while others seek to aid these movements directly. Often robotic technologies attempt to leverage the principles of neuroplasticity by improving quality of movement, and increasing the intensity and repetition of the task. Over the last two decades, research into robot mediated therapy for the rehabilitation of stroke patients has grown significantly as the potential for cheaper and more effective therapy has been identified.[67]

The MIT-MANUS in particular has been studied as a means of providing individualized, continuous therapy to patients who have suffered a stroke by using a performance-based progressive algorithm.[68] The responsive software allows the robot to alter the amount of assistance it provides, based on the patient's speed and timing of movement. This allows for a more personalized treatment session without the need for constant therapist interaction. An additional benefit to this type of adaptive robotic therapy is a marked decrease in spasticity and muscle tone in the affected arm. Different spatial orientations of the robot allow for horizontal or vertical motion, or a combination in a variety of planes. [64] The vertical, anti-gravity setting is particularly useful for improving shoulder and elbow function.

Haptic feedback devices

Haptic technology, haptics, or kinesthetic communication , is tactile feedback technology which recreates the sense of touch by applying forces, vibrations, or motions to the user. [69]
This mechanical stimulation can be used to assist in the creation of virtual objects in a computer simulation, to control such virtual objects, and to enhance the remote control of machines and devices (telerobot-

[67] Hillman, M. (2004). *Rehabilitation robotics from past to present: A historical perspective.* In Z.Z. Bien & D. Stefanov (Eds.), Advances in Rehabilitation Robotics (25-44). Berlin: Springer-Verlag.

[68] Krebs, H.I., et al. (2003). *Rehabilitation robotics: Performance-based progressive robot-assisted therapy.* Automatic Robots, 15, 7-20.

[69] Robles-De-La-Torre G. *"International Society for Haptics: Haptic technology, an animated explanation".* www.Isfh.org

ics). It has been described as "doing for the sense of touch what computer graphics does for vision".[70] Haptic devices may incorporate tactile sensors that measure forces exerted by the user on the interface.
Haptic technology has made it possible to investigate how the human sense of touch works by allowing the creation of carefully controlled haptic virtual objects. These objects are used to systematically probe human haptic capabilities, which would otherwise be difficult to achieve. These research tools contribute to the understanding of how touch and its underlying brain functions work.
The word haptic, from the Greek: ἁπτικός (haptikos), means "pertaining to the sense of touch" and comes from the Greek verb ἅπτεσθαι (haptesthai), meaning "to contact" or "to touch."

Design, by generation

Haptics are enabled by actuators that apply forces to the skin for touch feedback, and controllers. The actuator provides mechanical motion in response to an electrical stimulus.

First

Most early designs of haptic feedback use electromagnetic technologies such as vibratory motors, like a vibrating alert in a cell phone or a voice coil in a speaker, where a central mass is moved by an applied magnetic field. These electromagnetic motors typically operate at resonance and provide strong feedback, but produce a limited range of sensations and typically vibrate the whole device, rather than an individual section.

Second

Second generation haptics offered touch-coordinate specific responses, allowing the haptic effects to be localised to the position on a screen or touch panel, rather than the whole device. Second generation haptic actuator technologies include electroactive polymers, piezoelectric, electrostatic and subsonic audio wave surface actuation. These actuators allow to not only alert the user like first generation haptics but to enhance the user interface with a larger variety of haptic effects in terms of frequency range, response time and intensity. A typical first generation actuator has a response time of 35-60ms, a second generation actuator has a response time of 5-15ms. User studies also showed that haptic effects with frequencies below 150 Hz are preferred by users. Frequencies of 250–300 Hz, which is the typical range of electromagnetic systems are well suited for alerts but are perceived as annoying over time, which is why first generation haptic systems used to enhance the user interface are often deactivated by the users.

Third

Third generation haptics deliver both touch-coordinate specific responses and customisable haptic effects. The customisable effects are

[70] Robles-De-La-Torre G. *Virtual Reality: Touch / Haptics*. In Goldstein B (Ed.), "Sage Encyclopedia of Perception". Sage Publications, Thousand Oaks CA (2009)."

created using low latency control chips. To date two technologies have been developed to enable this; audio haptics and electrostatic haptics.

A new technique that does not require actuators is called reverse-electrovibration. A weak current is sent from a device on the user through the object they are touching to the ground. The oscillating electric field around the skin on their finger tips creates a variable sensation of friction depending on the waveform, frequency, and amplitude of the signal.[71]

Fourth

Fourth generation haptics deliver pressure sensitivity, enabling how hard you press on a flat surface to affect the response.

Commercial applications

Video games

Haptic feedback is commonly used in arcade games, especially racing video games. In 1976, Sega's motorbike game Moto-Cross, was the first game to use haptic feedback which caused the handlebars to vibrate during a collision with another vehicle.

Simple haptic devices are common in the form of game controllers, joysticks, and steering wheels. Some automobile steering wheel controllers, for example, are programmed to provide a "feel" of the road. As the user makes a turn or accelerates, the steering wheel responds by resisting turns or slipping out of control.

In 2007, Novint released the Falcon, the first consumer 3D touch device with high resolution three-dimensional force feedback; this allowed the haptic simulation of objects, textures, recoil, momentum, and the physical presence of objects in games.

In 2013, Valve announced a line of Steam Machines micro-consoles, including a new Steam Controller unit that uses weighted electromagnets capable of delivering a wide range of haptic feedback via the unit's trackpads.

Personal computers

In 2008, Apple's MacBook and MacBook Pro started incorporating a "Tactile Touchpad" design with button functionality and haptic feedback incorporated into the tracking surface. Products such as the Synaptics ClickPad followed thereafter.

Virtual reality

Haptics are gaining widespread acceptance as a key part of virtual reality systems, adding the sense of touch to previously visual-only solutions. Most of these solutions use stylus-based haptic rendering, where the user interfaces to the virtual world via a tool or stylus, giving a form of interaction that is computationally realistic on today's hardware. Sys-

71 Bau, Olivier; Ivan Poupyrev (July 2012). *"REVEL: Tactile Feedback Technology for Augmented Reality"*. ACM Transactions on Graphics 31 (4): 1. PDF online: http://www.disneyresearch.com/wp-content/uploads/revel_siggraph_paper.pdf

tems are being developed to use haptic interfaces for 3D modelling and design that are intended to give artists a virtual experience of real interactive modelling. Researchers from the University of Tokyo led by Hiroyuki Shinoda have developed 3D holograms that can be "touched" through haptic feedback using "acoustic radiation" to create a pressure sensation on a user's hands.

Medicine

Haptic interfaces for medical simulation may prove especially useful for training in minimally invasive procedures such as laparoscopy and interventional radiology, as well as for performing remote surgery. A particular advantage of this type of work is that surgeons can perform more operations of a similar type with less fatigue. Haptic interfaces are also used in rehabilitation robotics. [72]

In ophthalmology, haptic refers to supporting springs, two of which hold an artificial lens within the lens capsule after the surgical removal of cataracts.

Robotics

The Shadow Hand uses the sense of touch, pressure, and position to reproduce the strength, delicacy, and complexity of the human grip. [73] The SDRH was developed by Richard Greenhill and his team of engineers in London as part of The Shadow Project, now known as the Shadow Robot Company, an ongoing research and development program whose goal is to complete the first convincing artificial humanoid. The Shadow Hand has haptic sensors embedded in every joint and finger pad, which relay information to a central computer for processing and analysis.

The first PHANTOM, which allows one to interact with objects in virtual reality through touch, was developed by Thomas Massie while a student of Ken Salisbury at MIT. [74]

Arts and design

Touching is not limited to feeling, but allows interactivity in real-time with virtual objects. Thus, haptics are used in virtual arts, such as sound synthesis or graphic design and animation. The haptic device allows the artist to have direct contact with a virtual instrument that produces real-time sound or images. For instance, the simulation of a violin string produces real-time vibrations of this string under the pressure and expressiveness of the bow (haptic device) held by the artist. This can be done with physical modelling synthesis.

Designers and modellers may use high-degree-of-freedom input devices that give touch feedback relating to the "surface" they are sculpting or creating, allowing faster and more natural workflow than traditional methods.[75]

[72] Jacobus, C., et al., *Method and system for simulating medical procedures including virtual reality and control method and system*, US Patent 5,769,640

[73] "Shadow Robot Company: The Hand Overview" http://www.shadowrobot.com

[74] Geary, James (2002). *The body electric: an anatomy of the new bionic senses.* Rutgers University Press. p. 130. ISBN 0-8135-3194-2.

[75] http://geomagic.com/en/products-landing-pages/sensable

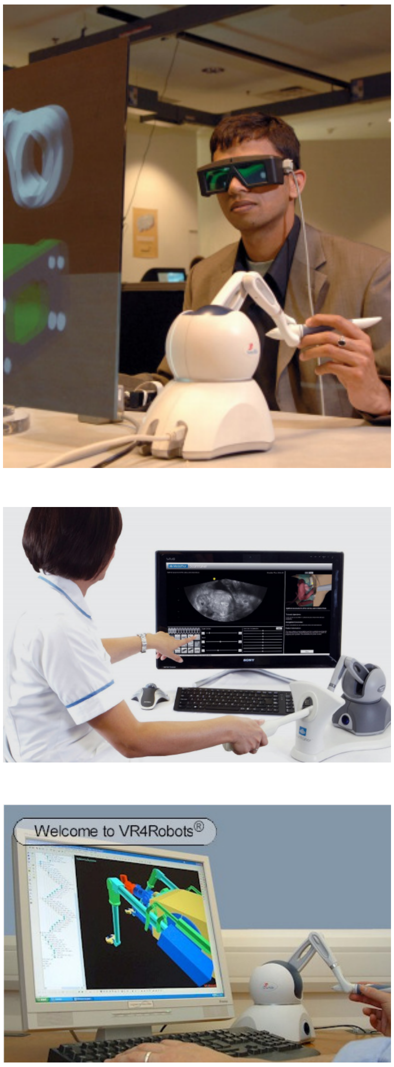


Figure 20 Examples of Geomagic haptic devices' applications:
- 3D virtual assembly simulation developed by the Iowa State University Virtual Reality Applications Center, in conjunction with John Deere;
- ScanTrainer (MedaPhor Ltd.) virtual-reality ultrasound training simulator;
- VR4Robots® (Oxford Technologies Ltd) powerful functionality for driving virtual robotic mechanisms, interacting with the virtual environment, and simulating robotic operations.

Geomagic® Haptic Devices (http://geomagic.com)

Geomagic is one of the leading company in the field of haptics. Their devices (Figure 20), provide true three-dimensional input with force feedback, integrating a sense of touch into research and commercial applications as well as in the Geomagic® Freeform® and Geomagic® Claytools® 3D modelling systems.
These haptic devices can accurately measure the 3D spatial position (along the x, y and z axes) and the orientation (pitch, roll and yaw) of the hand-held stylus. The devices use motors to create the forces that push back on the user's hand to simulate touch and interaction with virtual objects. 3DOF (Degrees of Freedom) and 6DOF models are available.
On several models, the device's end effectors can be customized to simulate a variety of tools. Original equipment manufacturer applications include medical simulations and training exercises in which the stylus emulates the physical sensations – like probing, puncturing, drilling or cutting – of using a syringe, scalpel, arthroscope or another medical instrument.
Range of Commercial, Scientific and Research Applications:

- Robotic Control
- Virtual Assembly
- Collision Detection
- Training and Skills Assessment
- Molecular Modelling
- Rehabilitation
- Nano Manipulation
- 3D Modelling
- Applications for the Visually
- Impaired
- Entertainment and Virtual Reality
- Consumer Product Design

Novint Falcon (http://www.novintcustom.com/)

Novint Falcon 3D Touch controller is another type of haptic manipulation device from lower-cost segment (standard kit is about $250). It allows to feel a realistic sense of touch, weight, shape, texture and force in video games. Whether the game is for fun or for training, the Falcon brings a new level of immersion and control into gaming experience. Quick exchangeable grips (handles) enhance even more the immersive experience.
Custom development projects with Falcon haptic controller include the following areas (Figure 21):

- Medical applications: Simulation & Training

The sense of touch is crucial for medical training. Many diagnostic, surgical and interventional procedures require that physicians train and utilize their sense of touch, which made effective medical training utilizing computers infeasible, until now. The addition of 3D touch to a simulation environment can improve training outcomes by accentuating key elements of the scenario or procedure being practiced, by providing the user with opportunities to develop functional muscle memory, by increasing the level of immersion, and simply by making the virtual world more enjoyable to experience.

- Planning & Analysis

Novint's software technologies make it possible to interact with and interpret scanned data sets (e.g. MRI, CT, 3D ultrasound data) directly and intuitively using touch. Novint technology can, for instance, allow physicians to analyse 3D structures (e.g. tumors, arterial calcifications) more effectively than when 2D media, such as traditional film, is used.

- Modelling & Visualization

The use of haptics as an additional sensory channel in the exploration of multivariate 3D data sets can be an extremely powerful interpretive strategy. The addition of touch can help the user better understand, for example, the topology and topography of a terrain map.

- Telerobotics

Novint's hardware technologies serve as highly-effective and affordable Operator Control Units for telerobotic systems. Custom modifications can enhance operator performance even further by providing tactile cues regarding the status of the "slave" system. The grasper grip attachment shown at left, for instance, allows the operator to feel the object being held between the jaws of a robotic arm.

- Product Marketing

Salesforce may be equipped with 3D interactive, touch-enabled demonstrations for kiosks, booths, or live sales calls, in order to build excitement, draw traffic, reinforce key messaging, and create positive associations with your products and brands.

Figure 21 Novint Falcon application examples:
- Virtual Reality Dental Training System (VRDTS) (by Harvard School of Dental Medicine and Novint) Dental students can work with a virtual decayed tooth and learn to probe it for diagnosis, use a drill to prepare a tooth for cavity repair, fill the prepared cavity with amalgam and carve the amalgam to match the original tooth contour. It enables the student to feel the difference between enamel, dentin, caries, amalgam and pulp throughout the procedure. The student's operation can be tracked precisely in real time, providing quantifiable feedback to both student and teacher.
- The Needle Simulator allows for a virtual demonstration of a specialized injection procedure into the synovial space of shoulder and knee joints. custom grip provides key additional feedback aspects of the procedure: the look, feel and action of an actual syringe; syringe orientation (tilt angle); and plunger resistance (hydraulic).

3 | Conclusions of Part 1

Literature review of present doctoral research on children's neurological rehabilitation revealed the knowledge of specific approaches in treatment of different types of neurological disorders and the particularities of its perception by children. Several existing rehabilitation programs were indicated and analysed in terms of appropriateness and efficiency.

Through the whole review of related literature, chapter-by-chapter various key factors influencing the rehabilitation performance, as well as problematic issues were accumulated into the list of "aspects to consider".

Besides that general theoretical healthcare design principles and methodologies were accurately studied in order to put them into practice during the development of projects of case studies. In addition new interactive technologies potentially applicable for children's rehabilitation programs design were explored for the eventual implementation.

The following diagram "Factors to consider developing children's rehabilitation project " (Figure 22) summarises and introduces findings from part 1 in a schematic structured way.

Diagram: Factors to consider developing children’s rehabilitation project

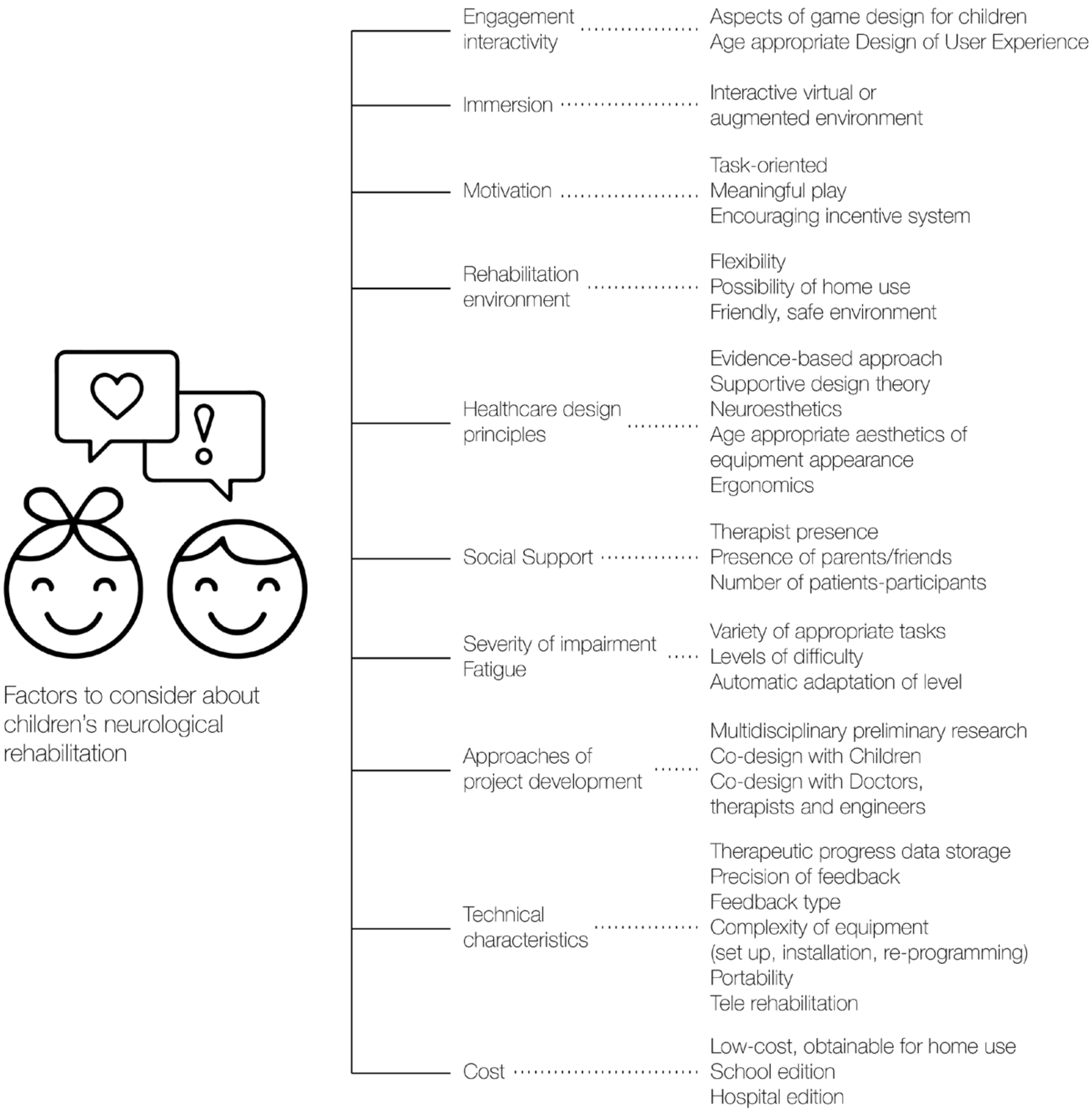


Figure 22 Diagram: Factors to consider developing children’s rehabilitation project

Part II

1 | Confronting the problem:

Observation and interviews in field with doctors and therapists.

Identifying and studying target diseases

During the consultations at Mondino National Neurological Foundation - Institute of Pavia, Infant Neuropsychiatry Department there were identified two main fields of children's neurological rehabilitation for possible design interventions.

1. Learning disorders and in particular reading and writing disorders (Developmental Dyslexia and Dysgraphia)

2. Motor disorders like limb paralysis caused by injuries or Cerebral Palsy (e.g. Hemiplegia)

Reading disorders: Developmental Dyslexia

Dyslexia is the most common learning disability. Of all students with specific learning disabilities, 70%-80% have deficits in reading. A reading disability can affect any part of the reading process, including difficulty with accurate or fluent word recognition, or both, word decoding, reading rate, prosody (oral reading with expression), and reading comprehension. Before the term "dyslexia" came to prominence, this learning disability used to be known as "word blindness."
Common indicators of reading disability include difficulty with phonemic awareness—the ability to break up words into their component sounds, and difficulty with matching letter combinations to specific sounds (sound-symbol correspondence).[76]

Developmental dyslexia (DD) is a neurodevelopmental disorder identified in about 10% of children which refers to a pattern of learning difficulties characterized by problems with accurate or fluent word recognition, poor decoding and poor spelling abilities, despite normal intelligence, and adequate access to conventional instruction. [77]

Spatial and temporal attention in developmental dyslexia

Although the dominant view posits that developmental dyslexia arises from a deficit in phonological processing, emerging evidence suggest that DD could result from a more basic cross-modal letter-to-speech sound integration deficit. Letters have to be precisely selected from irrelevant and cluttering letters by rapid orienting of visual attention before the correct letter-to-speech sound integration applies. In a study of Milena Ruffino et al.[78] the time-course of spatial attention was investigated measuring target detection reaction times (RTs) in a cuing paradigm, while temporal attention was investigated by assessing impaired identification of the first of two sequentially presented masked visual objects. Spatial and temporal attention were slower in dyslexic

[76] Handler S.M. et al (March 2011). *"Learning disabilities, dyslexia, and vision."* Pediatrics 127 (3): pp. e818 -e856.

[77] American Psychiatric Association (2013). *Diagnostic and Statistical Manual of Mental Disorders (Fifth ed.).* Arlington, VA: American Psychiatric Publishing

[78] Ruffino Milena, Gori Simone, Daniela Boccardi, Massimo Molteni and Andrea Facoetti; (22 May 2014): *Spatial and temporal attention in developmental dyslexiaAction video games make Dyslexic children read better*. Frontiers in Human Neuroscience, Volume 8, Article 331.

children with a deficit in pseudo-word reading (N = 14) compared to chronological age (N = 43) and to dyslexics without a deficit in pseudoword reading (N = 18), suggesting a direct link between visual attention efficiency and phonological decoding skills. Individual differences in these visual attention mechanisms were specifically related to pseudo-word reading accuracy in dyslexics. [78]

Results demonstrate that both spatial and temporal attention were impaired only in dyslexics with a poor phonological decoding (DDP−), confirming the relationship between visual attentional mechanisms and graphemic parsing processes. It is important to note that attentional graphemic parsing precedes the letter-to-speech sound integration.

Clearly, these results are inconsistent with the hypothesis that DD is an exclusively phonological deficit. The present link between deficits in spatial and temporal attention and impaired phonological decoding is consistent with the hypothesis that visual selection (i.e., the perceptual-noise exclusion mechanism) operates on graphemes as the basic component of the phonological assembly process.[79] Both spatial [80, 81] and temporal [82,83] processing windows in which noise interferes with the signal appear to be broader in dyslexics than normally reading children. In this study, we demonstrated that these deficits are specific in poor phonological decoders, and this can be attributed to the perceptual-noise exclusion deficit. [80]

Furthermore, results demonstrate, for the first time, that the relationship between visual attention and phonological decoding skills in dyslexia is explained by a sluggish shifting of spatial attention rather than a general perceptual noise exclusion mechanism.
Andrea Facoetti and his team suggest innovative training programs not only for treatment but also for the possible prevention of DD at the pre-reading stage.

Writing disorder: Dysgraphia

Dysgraphia is a deficiency in the ability to write, primarily in terms of handwriting, but also in terms of coherence. [84] Dysgraphia is a transcription disability, meaning that it is a writing disorder associated with impaired handwriting, orthographic coding (orthography, the storing process of written words and processing the letters in those words), and finger sequencing (the movement of muscles required to write).[85] It often overlaps with other learning disabilities such as speech impairment, attention deficit disorder, or developmental coordination disorder. [86] In the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV), dysgraphia is characterized as a learning disability in the category of written expression when one's writing skills are below those expected

[79] Perry, C., Ziegler, J. C., and Zorzi, M. (2007). *Nested incremental modeling in the development of computational theories: the CDP+ model of reading aloud.* Psychol. Rev. 114, 273–315.

[80] Sperling, A. J., Lu, Z. L., Manis, F. R., and Seidenberg, M. S. (2005). *Deficits in perceptual noise exclusion in developmental dyslexia.* Nat. Neurosci. 8, 862– 863.

[81] Geiger, G., Cattaneo, C., Galli, R., Pozzoli, U., Lorusso, M. L., Facoetti, A., et al. (2008). *Wide and diffuse perceptual modes characterized dyslexics in vision and audition.* Perception 37, 1745–1764.

[82] Montgomery, C. R., Morris, R. D., Sevcik, R. A., and Clarkson, M. G. (2005). *Auditory backward masking deficits in children with reading disabilities.* Brain Lang. 95, 450–456.

[83] Facoetti, A., Ruffino, M., Peru, A., Paganoni, P., and Chelazzi, L. (2008). *Sluggish engagement and disengagement of non-spatial attention in dyslexic children.* Cortex 44, 1221–1233.

[84] Chivers, M. (1991). *Definition of Dysgraphia (Handwriting Difficulty).* Dyslexia A2Z. Retrieved from http://www.dyslexiaa2z.com/learning_difficulties/dysgraphia/dysgraphia_definition.html

[85] Berninger, V.W.; B.J. Wolf (2009). *Teaching students with dyslexia and dysgraphia: Lessons from teaching and science.* Baltimore, Maryland: Paul H. Brooks Publishing Co. pp. 1–240.

[86] Nicolson RI, Fawcett AJ (January 2011). *"Dyslexia, dysgraphia, procedural learning and the cerebellum".* Cortex 47 (1): 117–27.

given a person's age measured through intelligence and age appropriate education. The DSM is not clear in whether or not writing refers only to the motor skills involved in writing, or if it also includes orthographic skills and spelling. [86]

There are at least two stages in the act of writing: the linguistic and the motor-expressive-praxic stage. The linguistic stage involves the encoding of auditory and visual information into symbols for letters and written words. This is mediated through the angular gyrus, which provides the linguistic rules which guide writing. The motor stage is where the expression of written words or graphemes is articulated. This stage is mediated by Exner's writing area of the frontal lobe. [87]

Classification

Dysgraphia is often, but not always, accompanied by other learning disabilities such as dyslexia or attention deficit disorder, and this can impact the type of dysgraphia a person might have. There are three principal subtypes of dysgraphia that are recognized. There is little information available about different types of dysgraphia and there are likely more subtypes than the ones listed below. Some children may have a combination of two or more of these, and individual symptoms may vary in presentation from what is described here. Most common presentation is a motor dysgraphia/agraphia resulting from damage to some part of the motor cortex in the parietal lobes.

Dyslexic

People with dyslexic dysgraphia have illegible spontaneously written work. Their copied work is fairly good, but their spelling is usually poor. Their finger tapping speed (a method for identifying fine motor problems) is normal, indicating that the deficit does not likely stem from cerebellar damage.

Motor

Motor dysgraphia is due to deficient fine motor skills, poor dexterity, poor muscle tone, or unspecified motor clumsiness. Letter formation may be acceptable in very short samples of writing, but this requires extreme effort and an unreasonable amount of time to accomplish, and it cannot be sustained for a significant length of time, as it can cause arthritis-like tensing of the hand. Overall, their written work is poor to illegible even if copied by sight from another document, and drawing is difficult. Oral spelling for these individuals is normal, and their finger tapping speed is below normal. This shows that there are problems within the fine motor skills of these individuals. People with developmental coordination disorder may also suffer from dysgraphia. Writing is often slanted due to holding a pen or pencil incorrectly.

[87] Roux FE, Dufor O, Giussani C, et al. (October 2009). *"The graphemic/motor frontal area Exner's area revisited"*. Annals of Neurology 66 (4): 537–45

Spatial

A person with spatial dysgraphia has a defect in the understanding of space. They will have illegible spontaneously written work, illegible copied work, and problems with drawing abilities. They have normal spelling and normal finger tapping speed, suggesting that this subtype is not fine motor based. [85, 88]

Signs and symptoms

In order to be diagnosed with dysgraphia, one must have a cluster, but not necessarily all, of the following symptoms:

- Cramping of fingers while writing short entries
- Odd wrist, arm, body, or paper orientations such as bending an arm into an L shape
- Excessive erasures
- Mixed upper case and lower case letters
- Inconsistent form and size of letters, or unfinished letters
- Misuse of lines and margins
- Inefficient speed of copying
- Inattentiveness over details when writing
- Frequent need of verbal cues
- Referring heavily on vision to write
- Poor legibility
- Handwriting abilities that may interfere with spelling and written composition
- Having a hard time translating ideas to writing, sometimes using the wrong words altogether
- May feel pain while writing

Dysgraphia may cause students emotional trauma often due to the fact that no one can read their writing, and they are aware that they are not performing to the same level as their peers. Emotional problems that may occur alongside dysgraphia include impaired self-esteem, lowered self-efficacy, heightened anxiety, and depression. They may put in extra efforts in order to have the same achievements as their peers, but often get frustrated because they feel that their hard work does not pay off.[85, 88]

The causes of Dysgraphia can be different: lesion, minor neurological disorders (Cerebral Dysfunction Minimum), sensory deficits, irregularities in lateralization, wrong posture, wrong perception and spatial organization, motor problems, emotional instability.

Can compete obviously the wrong use of the desk space, or the lack of a proper education and attention paid to these issues; fewer and fewer children are taught “how to” write and even fewer are practicing

[88] Berninger VW, May MO (2011). *“Evidence-based diagnosis and treatment for specific learning disabilities impairing written and/or oral language”*. J Learn Disabil 44 (2): 167–83.

pre-writing drawing exercises in kindergartens.

Motor disorders: Infantile cerebral palsy

Cerebral palsy is a general term for a group of permanent, non-progressive movement disorders that cause physical disability, mainly in the areas of body movement. There may also be problems with sensation, depth perception, and communication ability. Difficulty with cognition and epilepsy are found in about one-third of cases.
Physiotherapy programs are designed to encourage the patient to build a strength base for improved gait and volitional movement, together with stretching programs to limit contractures.

CP commonly causes hemiplegia. Those with hemiplegia have limited use of the limbs on one side of the body, and have normal use of the limbs on the other side. Hemiplegics often adapt by ignoring the limited limbs, and performing nearly all activities with the unaffected limbs, which can lead to increased problems with muscle tone, motor control and range of motion. An emerging technique called constraint-induced movement therapy (CIMT) is designed to address this. In CIMT, the unaffected limbs are constrained, forcing the individual to learn to use the affected limbs. [89]

Existing therapies for dyslexia and dysgraphia rehabilitation

There is some evidence that the use of specially tailored fonts may provide some measure of assistance for people who have dyslexia. [90, 91] Among these fonts are Dyslexie (FIg. 23a) and OpenDyslexic (Fig. 23b), which were created with the notion that many of the letters in the Latin alphabet are visually similar and therefore confusing for people with dyslexia. Dyslexie, along with OpenDyslexic, put emphasis on making each letter more unique to assist in reading. [92]
There is a range of online applications for patients with LD, one of the sites to browse them is http://a4cwsn.com/ (some apps for Dyslexia and Dysgraphia are shown below).

Visual Attention TherAppy

Therapy app (Fig. 24) designed to improve reading, scanning, concentration, memory, attention to detail, and speed of processing. Race against time to find letters and symbols in a field of adjustable size – perfect for rehab therapists, brain injury survivors, and special needs classrooms. Scanning from left to right all the way across the page is an essential skill for reading, both for children learning to read and for those with brain injury causing visual or attention deficits.
2 functioning modes:

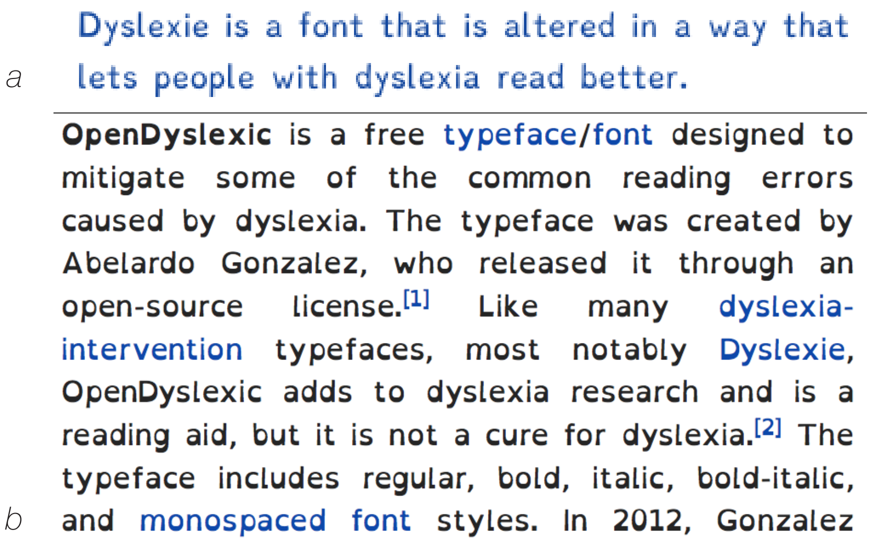
[89] Hoare, BJ.; Wasiak, J.; Imms, C.; Carey, L. (2007). *"Constraint-induced movement therapy in the treatment of the upper limb in children with hemiplegic cerebral palsy."* Cochrane Database Syst Rev (2)

[90] Nalewicki, Jennifer (31 October 2011). *"Bold Stroke: New Font Helps Dyslexics Read"*. Scientific American. Scientific American, a Division of Nature America, Inc. Retrieved 31 October 2011.

[91] de Leeuw, Renske (December 2010). *"Special Font For Dyslexia?"* University of Twente. p. 32. PDF: http://www.ilo.gw.utwente.nl/ilo/attachments/032_Masterthesis_Leeuw.pdf.

[92] Sawers, Paul. *"Dyslexie: A typeface for dyslexics"*. Retrieved January 5, 2015 from: http://thenextweb.com/shareables/2011/06/30/dyslexie-a-typeface-for-dyslexics/

Figure 23 a. Dyslexie font (Designer - Christian Boer, 2008; Proprietary License; Variations: Dyslexie regular, bold, italic, italic bold).
b. An example of OpenDyslexic typeface (Designer - Abelardo Gonzalez, 2003; Open-source license; Variations: regular, bold, italic, bold-italic)


a

Dyslexie is a font that is altered in a way that lets people with dyslexia read better.

b

OpenDyslexic is a free typeface/font designed to mitigate some of the common reading errors caused by dyslexia. The typeface was created by Abelardo Gonzalez, who released it through an open-source license.[1] Like many dyslexia-intervention typefaces, most notably Dyslexie, OpenDyslexic adds to dyslexia research and is a reading aid, but it is not a cure for dyslexia.[2] The typeface includes regular, bold, italic, bold-italic, and monospaced font styles. In 2012, Gonzalez

Figure 24 Screenshots from TherAppy by Tactus Therapy Solutions Ltd.

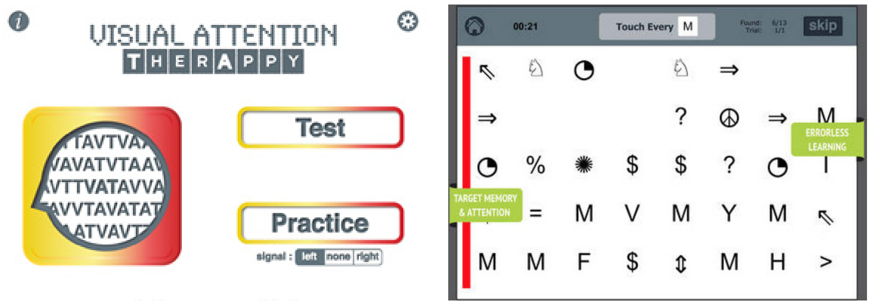


Figure 25 Screenshots from eReading apps by Brain Integration, LLC

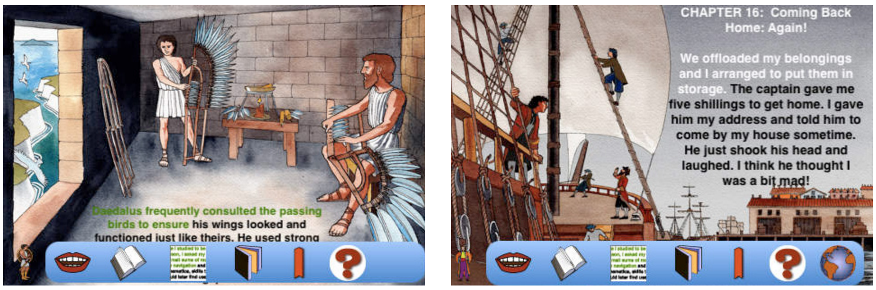
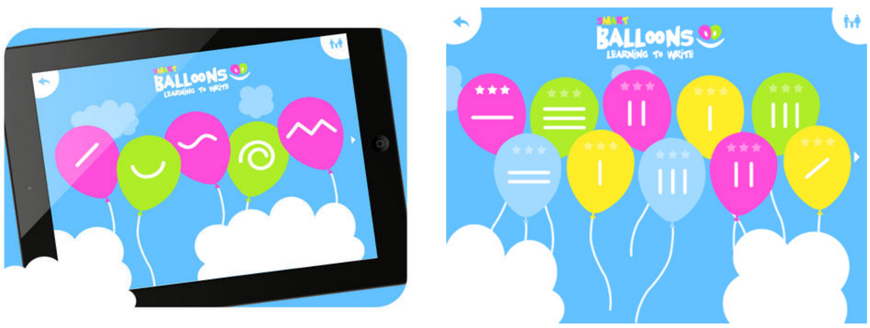


Figure 26 Finger-writing application "Smart Balloons: Learning to Write" by Friml Jan



Test – check if there's a problem in scanning or attention
Practice – move left to right, finding 1 or 2 targets in order
Email results of the test (indicates which quadrant is most often neglected) and practice to track progress in speed and accuracy over time.

eReading: Greek Myths, Gulliver's travels and more
http://ereadingbook.com/
Reading apps for children with dyslexia, LD, FASD, autism, slow readers, and other language based issues.
Stories have original illustrations, combined with narrations and highlighting of the text on each page. Application provides fun reading experience. (Fig. 25)

Smart Balloons: Learning to Write
Is an application of "finger writing" with pre-writing exercises. Includes variety of the basic shapes involved in the letters of the alphabet. Developed in cooperation with special education teachers of DYS-Center®. Each shape training features 3 difficulty levels – full line tracing, dotted line tracing and freehand which has only a few reference points to guide the child's hand. (Fig. 26)

Traditional paper worksheets for dysgraphia are still widely used by therapists, teachers and parents. Even though it is less interactive and not as fun as gadgets and applications, it is still the most natural way of hand-writing practice.
To facilitate the grip problems of dysgraphic patients it is helpful to use pen or pencil grips, there is a great variety of forms and colours which lets the young patient to personalize his "writing device" according to his taste. (Fig.27)

The Kid-o A to Z magnatab (https://kidotoys.com/)
This game seems to be a kind of interactive paper worksheet, still remaining in a physical form (not a tablet application) attracting with it's curious magnetic feature.
The Kid-o A to Z magnatab is a handwriting game for children 3 years and upwards. Children can learn and practise handwriting using the play-board and magnetic pen. Ball bearings rise up when the pen passes over. The game is very fascinating and absorbing for children - helping concentration skills.
The A to Z magnatab improves writing skills and gains extra educational support. It is ideal for children at playgroup and early school year ages.

Figure 27
- Example of worksheets for dysgraphic patients: "Tracing guides"
- Rubber pensil grips;
- Right Handed Pencil Ellie Grip

Figure 28 The Kid-O Magnatab:
- lowercase letters a-z;
- 0-9 numbers;
- uppercase cursive letters A-Z.

Problematic factors influencing rehabilitation process

Interviewing doctors and therapists from Infant Neuropsychiatry Department of Mondino National Neurological Institute (prof. Umberto Balottin, Head of the Infant Neuropsychiatry Department; Dr. Marina Zoppello, Psychologist and psychotherapist; Dr. Luca Capone, Psychologist and psychomotricist) the following problematic factors emerged from their experience:

Dr. Luca Capone (Specialized on motor disorders):
The biggest difficulty is to keep child engaged during the whole therapeutic session. It is really hard to find some activity that is interesting enough for the patient to concentrate his attention on doing it for relatively long period of time. I've tried Nintendo Wii with some hemiplegic patients who needed repetitive physical exercises, that was a good solution for the first time because children were happy and motivated to attend therapeutic sessions, since for them it was just a fun experience of gaming, like for any other healthy child. However some substantial drawbacks came out, e.g. hemiplegic patients with hand paralysis affronted some difficulty in holding the motion stick due to its uncomfy form not suitable for ergonomic needs of this kind of patients; variety of games, as soon as patient tried all the available games he tends to get bored with them, they need new and new playing scenarios and environments to stay tuned.

Dr. Marina Zoppello (Specialized in Learning Disorders):
In my practice the most important problem is lack of modern interactive materials for treatment of disorders of reading, writing, memory, attention etc. We still use paper worksheets, books or some standard computer programs for reading, which are definitely not engaging or interactive. Another serious issue is that every patient with learning disability is very special and different one from another, almost all of them have more than one disorder, many of them have sever psychiatric problems, anxiety, nervousness, extreme sensitivity, or even signs of depression or aggression. That means these children need a very careful treatment and attention, super flexible and adoptive rehabilitation systems and environments, individual approaches in rehabilitation.

prof. Umberto Balottin:
It is crucial in our field to have therapeutic progress data under control: collecting different parameters like time, speed, pressure, accurateness, body position etc. during rehabilitation sessions means being able analyse and give precise and exact exercises for further improvement. Keeping database with patient's results gives also a great opportunity for

the future researches, studies and comparison of various methodologies and techniques and equipment used during rehabilitation sessions. The factor of cost is unfortunately influential as well, since it is quite hard to get funding for innovations and development of the department.
The following diagram "Doctors' point of view on problematic factors influencing children's rehabilitation process " (Fig. 28) symmerises findings from field research: Interviewing doctors at Mondino Neurological Institute, Pavia.

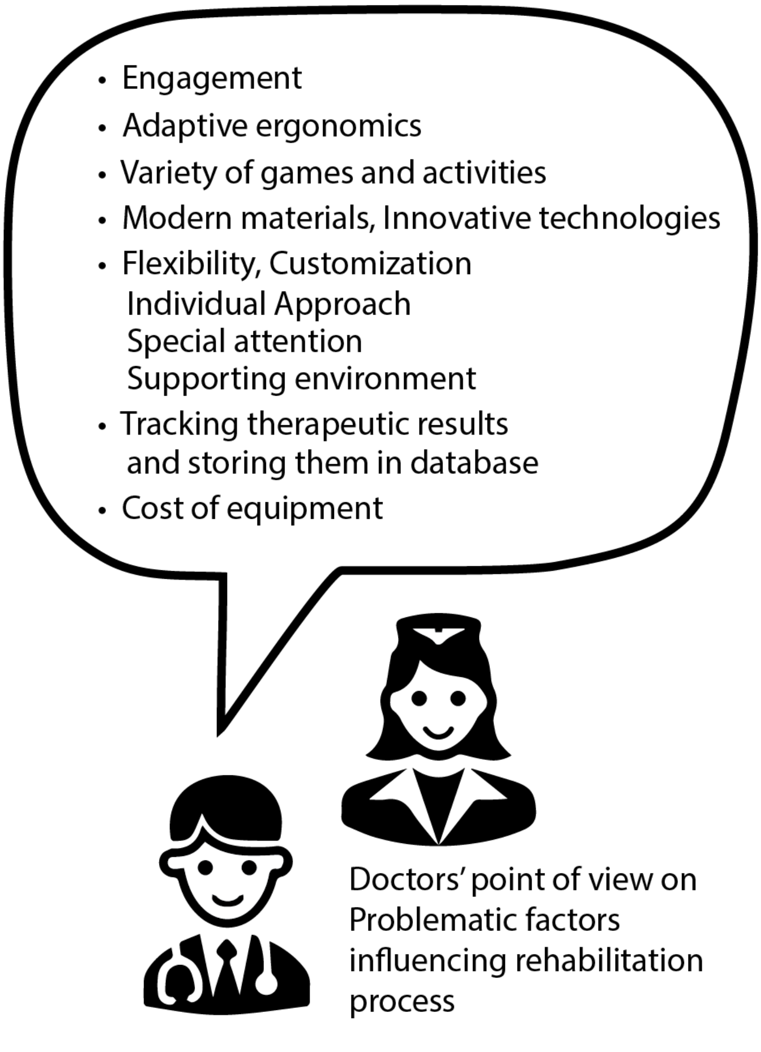


Figure 28 Summary Diagram: Doctors' point of view on problematic factors influencing children's rehabilitation process

Part III

Case study 1 “Dyslexia”

Link between Visual Spatial Attention and Reading Acquisition

While discussing the possible solutions for the Dyslexia rehabilitation system with the team of Mondino Neurological Institute of Pavia (prof. Ballotin, the head of Infant Neuropsychiatry Department, psychotherapist Dr. Zoppello, psychomotricist Dr. Capone), it emerged the study of the researcher Andrea Facoetti from the Developmental and Cognitive Neuroscience Lab, University of Padua, who hypothesized and proved experimentally the link between visual spatial attention and reading acquisition.

Action video games make Dyslexic children read better

Dyslexia remediation is far from being fully achieved, and the current treatments demand high levels of resources. The team of researchers from University of Padua demonstrates that only 12 hr of playing action video games not involving any direct phonological or orthographic training drastically improve the reading abilities of children with dyslexia. Reading, phonological, and attentional skills were tested in two matched groups of children with dyslexia before and after they played action or non-action video games for nine sessions of 80 min per day. We found that only playing action video games improved children’s reading speed, without any cost in accuracy, more so than 1 year of spontaneous reading development and more than or equal to highly demanding traditional reading treatments. Attentional skills also improved during action video game training. It has been demonstrated that action video games efficiently improve attention abilities. [93, 94]

Results showed that this attention improvement can directly translate into better reading abilities, providing a new, fast, fun remediation of dyslexia that has theoretical relevance in unveiling the causal role of attention in reading acquisition.

Stereoscopy for spatial attention training

Since our team was very enthusiastic about the results of Andrea Facoetti [83], we decided to work in the same direction proposing some kind of design improvement for even better efficiency.
Prof. Antonucci, my supervisor, from University of Genoa, who has a great experience in field of scientific research on new interactive and smart technologies and equipment, suggested “Why not to add the third dimension?”. The rehabilitation video games may be projected in 3D, with the very high definition, providing the immersion issue, to the pro-

[93] Green, C.S., and Bavelier, D. (2003). *Action video game modifies visual selective attention.* Nature 423, 534–537.

[94] Green, C.S., Pouget, A., and Bavelier, D. (2010). *Improved probabilistic inference as a general learning mechanism with action video games.* Curr. Biol. 20, 1573–1579.

cess of exercising.
The validity of idea was immediately confirmed by prof. Ballotin, the Head of Infant Neuropsychiatry Department, who explained that with the addition of deepness into the gaming experience can activate more nearby cerebral zones, accelerating the recovery of neural connections and consequently making the rehabilitation process more efficient.
Moreover, Dr. Capone, the psychomotricist of Infant Department noticed that actually that kind of spatial exercises in stereoscopic environment, that may be effectuated by means of motion control technologies, will be definitely useful also for the patients with motor disorders like hemiplegia and other paralysis, as the rehabilitation program for them require different types physical activity, repetitive movement exercises, so our engaging and motivating therapeutic game will suite them well.
Thereby our rehabilitation system for Dyslexia became the Multifunctional one.
Right after the confirmation of the direction for further development, we turned to study the market of modern stereoscopic technologies and equipment that may suit well to our case.

3D User Interfaces

3D User Interfaces: Theory and Practice[95] defines a 3D user interface as simply "a UI that involves 3D interaction." This simply delays the inevitable, as we now have to define 3D interaction. The book states that 3D interaction is "human-computer interaction in which the user's tasks are performed directly in a 3D spatial context."

The most prominent types of 3D UIs involve a physical 3D spatial context, used for input. The user provides input to the system by making movements in physical 3D space or manipulating tools, sensors, or devices in 3D space, without regard for what this input is used to do or control. Of course, all input/interaction is in some sense in a physical 3D spatial context (a mouse and keyboard exists in 3D physical space), but the intent here is that the user is giving spatial input that involves 3D position (x, y, z) and/or orientation (yaw, pitch, roll) and that this spatial input is meaningful to the system.

Thus, the key technological enabler of 3D UIs of this sort is spatial tracking.[96, 97] The system must be able to track the user's position, orientation, and/or motion to enable this input to be used for 3D interaction. For example, the Microsoft Kinect tracks the 3D positions of multiple body parts to enable 3D UIs, while the Apple iPhone tracks its own 3D orientation, allowing 3D interaction. There are many different technologies used for spatial tracking;
This tracked spatial input can be used for iconic gestures, direct pointing at menu items, controlling characters in a game, specifying 3D shapes,

[95] Bowman, Doug A., Kruijff, Ernst, LaViola, Joseph J. and Poupyrev, Ivan (2005): *3D User Interfaces: Theory and Practice.* Addison-Wesley Professional

[96] Meyer, Kenneth, Applewhite, Hugh L. and Biocca, Frank A. (1992): *A Survey of Position Trackers.* In Presence: Teleoperators and Virtual Environments, 1 (2) pp. 173-200

[97] Welch, Greg and Foxlin, Eric (2002): *Motion Tracking: No Silver Bullet, but a Respectable Arsenal.* In IEEE Computer Graphics and Applications, 22 (6) pp. 24-38

and many other uses. 3D UIs based on spatial input can be found in a variety of settings: gaming systems, modelling applications, virtual and augmented reality systems, large screen visualization setups, and art installations, etc.

Video Gaming

Most people today are aware of 3D UIs because of the great success of "motion gaming" systems like the Nintendo Wii, the Microsoft Kinect, and the Sony Playstation Move. All of these systems use spatial tracking to allow users to interact with games through pointing, gestures, and most importantly, natural movements, rather than with buttons and joysticks. For example, in an archery game a user can hold two tracked devices—one for the handle of the bow and the other for the arrow and string—and can pull back the arrow, aim, and release using motions very similar to archery in the real world.

The Wii and Move both use tracked handheld devices that also provide buttons and joysticks, while the Kinect tracks the user's body directly. There's a clear tradeoff here. Buttons and joysticks are still useful for discrete actions like confirming a selection, firing a weapon, or changing the view. On the other hand, removing encumbrances from the user can make the experience seem even more natural.

3D UIs are a great fit for video gaming [98,99], because the emphasis is on a compelling experience, which can be enhanced with natural actions that make the player feel as if he is part of the action, rather than just indirectly controlling the actions of a remote character.

Motion Control Comparison (Nintendo Wii, Sony Playstation Move and Microsoft Kinect)

Motion Controllers seem to be the new trend in the gaming world these days with Sony and Microsoft releasing their own peripherals to compete with Nintendo's Wii. (Fig. 29) It has now been a while since these motion activated peripherals came out and it's time to see how they stack up now. All three options have their strengths and weaknesses. To find out how they compare keep reading onward.

Nintendo Wii

The first and original version of the motion control era was the Nintendo Wii. Even though its successor, the Wii U has been announced, the Wii is still a strong contender. Since the Wii was built from the ground up as a motion based gaming system its entire library has support for the control setup. In 2009 MotionPlus add-on was released, that improved accuracy. The Wii uses a sensor bar with IR Sensors to detect the

[98] LaViola, Joseph J. (2008): *Bringing VR and Spatial 3D Interaction to the Masses through Video Games.* In IEEE Computer Graphics and Applications, 28 (5) pp. 10-15

[99] Wingrave, Chadwick A., Williamson, Brian, Varcholik, Paul, Rose, Jeremy, Miller, Andrew, Charbonneau, Emiko, Bott, Jared N. and LaViola, Joseph J. (2010): *The Wiimote and Beyond: Spatially Convenient Devices for 3D User Interfaces.* In IEEE Computer Graphics and Applications, 30 (2) pp. 71-85

position of the controller from the console. It also features a gyroscope and accelerometer to determine angle, pitch, and speed at which the controller is moved. As far as accuracy goes it's in between the Kinect and Move.

Playstation Move

The Move is known for being the most accurate of the motion controls (and for looking a bit inappropriate as well). The Move not only features its own library of motion-specific games, but also older titles. The Move uses a Bluetooth connection to interact with the game and like the Wii-Mote it features gyroscopes and accelerometers to provide speed and tilt. The glowing ball on top is used in conjunction with the Eye Camera to determine the location of the controller in relation to the console. It's extremely accurate and can detect even the slightest of movement.

Microsoft Kinect

It was released in November 2010 and like the Move it's an add-on peripheral to the Xbox 360. The Kinect is known for being a completely controller-less experience. The Kinect's library is made up mostly of Kinect specific games, but there are some games that allow for either the regular controller or Kinect. The Kinect features both full body tracking and full voice recognition and you can use both those methods to navigate around the menu. The Kinect is a bar-style design that consists of a VGA camera, IR Sensor, and depth sensor. Using these three, it can detect where you are and your body position. It also features a motorized stand that will adjust itself to the optimum angle for use.

Figure 29 Motion ControlSystems (Nintendo Wii, Sony Playstation Move and Microsoft Kinect)

Figure 30 Anaglyph, Polarized and Shutter 3D glasses

Table 5. Comparative table of motion controller's characteristics Wii vs Play Station vs Kinect

Motion controller	Nintendo Wii	PlayStation Move	Microsoft Kinect
motion detection	yes - 6-axis sensors (with addition of Wii Motion-Plus) - XY detection by IR sensor	yes - 6-axis sensors built-in - XYZ detection by camera	yes - controller free; sensors track body movements
buttons	yes	yes	no
feedback	yes - vibration and audio feedback	yes - color changing sphere and vibration feedback	yes - audio feedback
build-in rechargeable batteries	no (AA (2) sold separa-tely)	yes	no
Camera			
Camera	no	yes	yes
Augmented Reality	no	yes	yes
Image capture	no	yes	yes
Head tracking	no	yes	yes
Microphones	no	yes (on camera)	yes
Voice command	no	yes	yes
Voice recognition	no	yes	yes
Secondary controller			
Secondary controller	yes	yes	no
build-in rechargeable battery	no	yes	no
wireless	yes - must be tethered to Wii Remote	yes	no
Games			
Resolution	480 p	Supports photos and videos at 4K, but not expected to render games at 4K	Video output up to 4K. (no hardware restriction for games running at 4K)

Stereoscopic Projection: Technologies of 3D displaying

Anaglyph (passive 3d viewers technology)

Anaglyph images were the earliest method of presenting theatrical 3D, and the one most commonly associated with stereoscopy by the public at large, mostly because of non-theatrical 3D media such as comic books and 3D television broadcasts, where polarization is not practical. They were made popular because of the ease of their production and exhibition.

In an anaglyph, the two images are superimposed in an additive light setting through two filters, one red and one cyan. In a subtractive light setting, the two images are printed in the same complementary colours on white paper. Glasses with coloured filters in each eye separate the appropriate images by cancelling the filter colour out and rendering the complementary colour black.

Anaglyph images are much easier to view than either parallel sighting or crossed eye stereograms, although the latter types offer bright and accurate colour rendering, particularly in the red component, which is muted, or desaturated with even the best colour anaglyphs. A compensating technique, commonly known as Anachrome, uses a slightly more transparent cyan filter in the patented glasses associated with the technique. Process reconfigures the typical anaglyph image to have less parallax.

Polarization systems (passive 3d viewers technology)

To present a stereoscopic motion picture, two images are projected superimposed onto the same screen through different polarizing filters. The viewer wears low-cost eyeglasses which also contain a pair of polarizing filters oriented differently (clockwise/counterclockwise with circular polarization or at 90 degree angles, usually 45 and 135 degrees, with linear polarization). As each filter passes only that light which is similarly polarized and blocks the light polarized differently, each eye sees a different image. This is used to produce a three-dimensional effect by projecting the same scene into both eyes, but depicted from slightly different perspectives. Since no head tracking is involved, the entire audience can view the stereoscopic images at the same time. Additionally, since both lenses have the same colour, people with one dominant eye (amblyopia), where one eye is used more, are able to see the 3D effect, previously negated by the separation of the two colours.

Circular polarization has an advantage over linear polarization, in that the viewer does not need to have their head upright and aligned with the screen for the polarization to work properly. With linear polarization, turning the glasses sideways causes the filters to go out of alignment with the screen filters causing the image to fade and for each eye to see the opposite frame more easily. For circular polarization, the polarizing effect works regardless of how the viewer's head is aligned with the screen such as tilted sideways, or even upside down. The left eye will still only see the image intended for it, and vice versa, without fading or crosstalk.

In the case of RealD a circularly polarizing liquid crystal filter which can switch polarity 144 times per second is placed in front of the projector lens. Only one projector is needed, as the left and right eye images are displayed alternately. Sony features a new system called RealD XLS, which shows both circular polarized images simultaneously: A single 4K projector (4096×2160 resolution) displays both 2K images (2048×1080 resolution) on top of each other at the same time, a special lens attachment polarizes and projects the images. (Fig. 30)

Advantages and disadvantages

Compared to anaglyph images, the use of polarized 3D glasses produces a full-colour image that is considerably more comfortable to watch and is not subject to binocular rivalry. However, it requires a significant increase in expense: even the low cost polarized glasses typically cost 50% more than comparable red-cyan filters, and while anaglyph 3-D films can be printed on one line of film, a polarized film was often done with a special set up that uses two projectors. The use of multiple projectors also raises issues with synchronization, and a poorly synchronized film would negate any increased comfort from the use of polarization.

Particularly with the linear polarization schemes popular since the 1950s, the use of linear polarization meant that a level head was required for any sort of comfortable viewing; any effort to tilt the head sideways would result in the polarization failing, ghosting, and both eyes seeing both images. Circular polarization has alleviated this problem, allowing viewers to tilt their heads slightly (although any offset between the eye plane and the original camera plane will still interfere with the perception of depth).

Because neutral-gray linear-polarizing filters are easily manufactured, correct colour rendition is possible. Circular-polarizing filters often have a slight brownish tint, which may be compensated for during projection.

Eclipse method (active shutter 3D viewers technology)

With the eclipse method, a shutter blocks light from each appropriate eye when the converse eye's image is projected on the screen. The projector alternates between left and right images, and opens and closes the shutters in the glasses or viewer in synchronization with the images on the screen.

A variation on the eclipse method is used in LCD shutter glasses. Glasses containing liquid crystal that will let light through in synchronization with the images on the cinema, television or computer screen, using the concept of alternate-frame sequencing.

A drawback of this method is the need for each person viewing to wear expensive, electronic glasses that must be synchronized with the display system using a wireless signal or attached wire. The shutter-glasses are heavier than most polarized glasses, though lighter models are no heavier than some sunglasses or deluxe polarized glasses. However these systems do not require a silver screen for projected images.[100]

Autostereoscopy (display method without viewers)

In this method, glasses are not necessary to see the stereoscopic image. Lenticular lens and parallax barrier technologies involve imposing two (or more) images on the same sheet, in narrow, alternating strips, and using a screen that either blocks one of the two images' strips (in the case of parallax barriers) or uses equally narrow lenses to bend the strips of image and make it appear to fill the entire image (in the case of lenticular prints). To produce the stereoscopic effect, the person must be positioned so that one eye sees one of the two images and the other sees the other.

Both images are projected onto a high-gain, corrugated screen which reflects light at acute angles. In order to see the stereoscopic image, the viewer must sit within a very narrow angle that is nearly perpendicular to the screen, limiting the size of the audience.

Advantages of polarized technology

- Generally inexpensive.
- Do not require power.
- Do not require a transmitter to synchronize them with the display.
- Do not suffer from flicker.
- Lightweight

Disadvantages

- The images for polarized glasses have to share the screen simultaneously, and therefore cannot have full resolution delivered to each eye simultaneously. This disadvantage does not occur on projections where each pixel can contain information for both eyes.
- Associated with the headaches some people attribute to 3D viewing
- Narrow vertical viewing angles compared to Active shutter 3D

[100] Morgan Hal and Dan Symmes Little (1982): *Amazing 3D Broawn & Company* (Canada) Limited, pp. 165–169.

Concept of new multifunctional rehabilitation system:

Tangible video game with virtual immersive age-adapted environments, for visual-spatial attention and motor training

Multifunctional children's stereo-interactive rehabilitation system to exercise visual-spacial attention (for improvement of reading skills of dyslexic patients) and for engaging motor exercises dedicated to children with hemiplegia or other motor difficulties.

- The rehabilitative game takes place in a 3-dimensional interactive environment in front of the wall-screen with stereoscopic projection.
- Players wear lightweight passive polarized glasses adapted for the children's ergonomic needs to perceive an effect of stereoscopic projection.
- Players interact with the game elements via motion controllers, freely moving in space of play-rehab room.
- Motion controllers has and adoptive design in order to suit patients with difficulties to grab and hold controller in their hand (special clasp system, will allow to securely attach controller to the patient's hand or arm).
- Video-game may involve more than one player (play-companion may be the therapist itself, other patient, friend or parent). Additional competitive motivation for better engagement into play therapy.
- Computer software suppose to collect all the results and parameters of rehab-session performance into a patient's personal progress database, in order to analyse and monitor the improvements, automatically augmenting the difficulty level of the game.

Model of rehabilitation program prototype

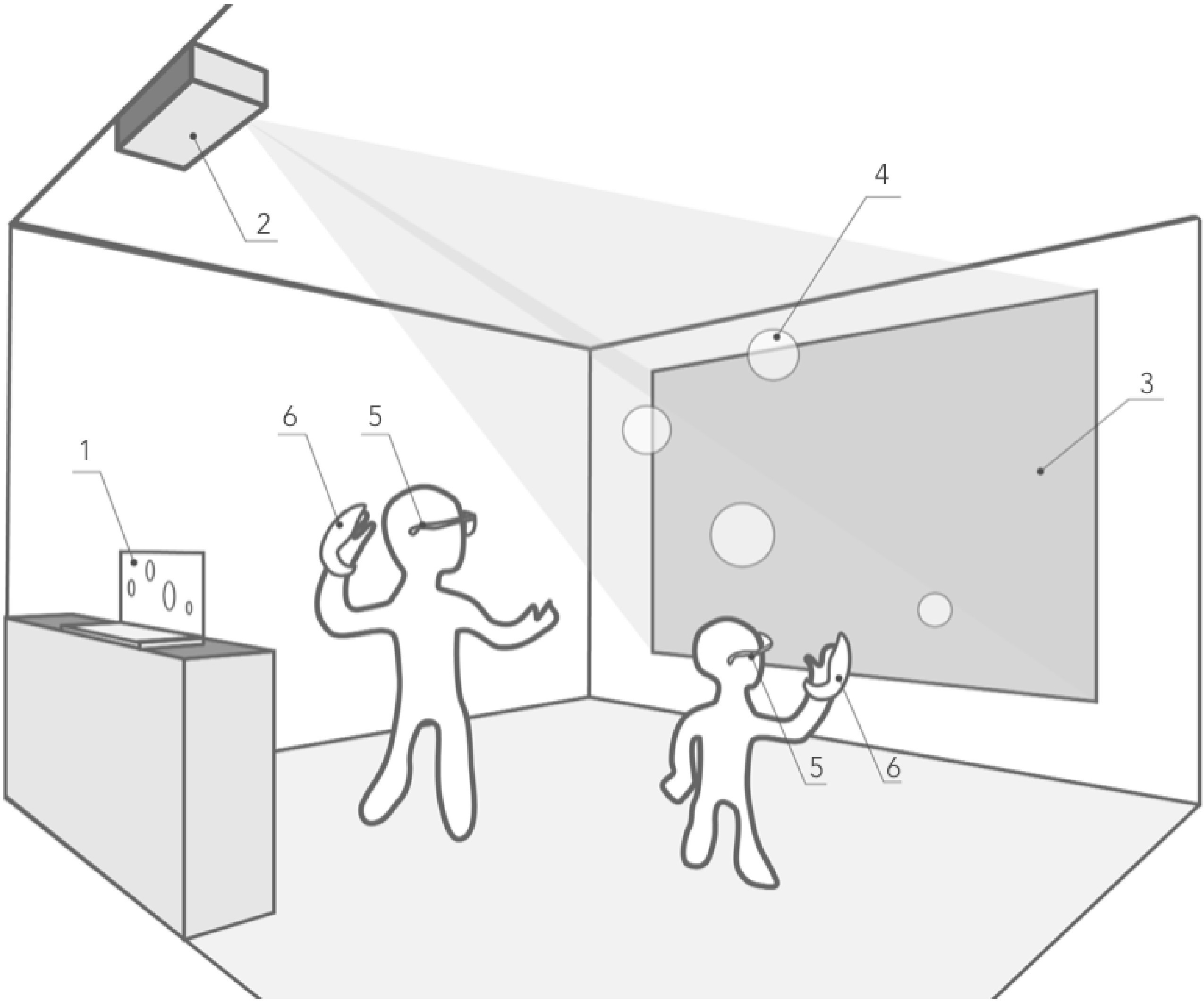


Figure 31 Concept graphic model of Multifunctional Rehabilitation System

1 - Computer with rehabilitation game running on it (individual settings of difficulty and speed, according to the patient's achievements), collecting results into personal patient's database of progress.
2 - Polarized 3D stereoscopic projector with high resolution up to 4K
3 - Special screen for 3D polarized projection
4 - Moving 3D elements of the game to interact with
5 - Passive 3D glasses adapted for children's use
6 - Motion controller (the instrument of interaction with the game; adaptive design, also for children with limb paralysis)

Case study 2 “Dysgraphia“

Developing rehabilitation system with National Neurological Institute Mondino, Pavia and NeuroLab, DIBRIS, Università degli studi di Genova

Once the target disorder was determined, we moved to the step of consultations with therapists, in order to understand the principals of rehabilitation process.

They explained that the basic skills involved in the process of handwriting are: movement coordination, orientation and organization of space and time, the eye-hand coordination, awareness of the body scheme, sequential memory, language, the sense of rhythm (usually poor), the process of symbolization (slow), the ability to discriminate sounds-signs.

Also dysgraphia may be an associated disorder in presence of other learning disability, but not necessarily related to them.

So, the possible intervention program can be divided into two main tracks that need to be undertaken in parallel:

1. Exercises aimed at the development of basic skills
2. Specific writing exercises

The first track of rehabilitation program is supposed to reduce the weaknesses identified in basic skills; The second track aims to promote the recovery of writing skills appropriately.

These two tracks should be offered to the patient in parallel and gradually through play exercises that require the development and enhancement of single skills, as well as exercises-games that require the development of various skills all together, to avoid the delay in conquesting graphomotor ability that gratifies the child, allowing him to be more self-confident, experiencing positive results also at school.

Important basic skills to work on are:

- perception
- space-time organization
- integration of space and time (rhythm)
- body scheme control
- balance and coordination
- relaxation
- laterality
- visual-motor and eye-hand coordination.

The track of specific writing exercises includes activities related to:

- Setting up graphemes and writing in capital printed letters

- Setting up graphemes and writing in cursive

As the next step of project during our brainstorming conversation, therapists, suggest to try the mechanism of mirror neurons activation while practicing the described above rehabilitation interventions. The idea is that by watching and actually feeling the correct handwriting or hand-drawing movement, you learn, and can easily repeat the same on your own; (like as you let someone take your hand with the pen in it and let that someone guide you while writing or drawing a curtain shape; so your eyes may see and your hand may feel how the movement should be executed, and mirror neurons let you repeat the just-learned movement quiet precisely).

Mirror neurons activation mechanism

A mirror neuron is a neuron that fires both when an animal acts and when the animal observes the same action performed by another.[101, 102, 103] Thus, the neuron "mirrors" the behaviour of the other, as though the observer were itself acting. Such neurons have been directly observed in primate species.[104] In humans, brain activity consistent with that of mirror neurons has been found in the premotor cortex, the supplementary motor area, the primary somatosensory cortex and the inferior parietal cortex.[105]

The function of the mirror system is a subject of much speculation. Many researchers in cognitive neuroscience and cognitive psychology consider that this system provides the physiological mechanism for the perception/action coupling [103] They argue that mirror neurons may be important for understanding the actions of other people, and for learning new skills by imitation. Some researchers also speculate that mirror systems may simulate observed actions, and thus contribute to theory of mind skills,[105,106] while others relate mirror neurons to language abilities.[107] Neuroscientists such as Marco Iacoboni (UCLA) have argued that mirror neuron systems in the human brain help us understand the actions and intentions of other people. In a study published in March 2005 Iacoboni and his colleagues reported that mirror neurons could discern if another person who was picking up a cup of tea planned to drink from it or clear it from the table.[108] In addition, Iacoboni has argued that mirror neurons are the neural basis of the human capacity for emotions such as empathy.[109]

Possible functions of Mirror neurons

Understanding intentions

Many studies link mirror neurons to understanding goals and intentions. Fogassi et al. [110](2005) recorded the activity of 41 mirror neurons in the inferior parietal lobe (IPL) of two rhesus macaques. The IPL

[101] Rizzolatti, Giacomo; Craighero, Laila (2004). *"The mirror-neuron system"*. Annual Review of Neuroscience 27: 169–192.

[102] Keysers, Christian (2010). *"Mirror Neurons"*. Current Biology 19 (21): R 971–973.

[103] Keysers, Christian (2011). *The Empathic Brain*. (eBook, Kindle Edition)

[104] Rizzolatti, Giacomo; Fadiga, Luciano (1999). *"Resonance Behaviors and Mirror Neurons"*. Italiennes de Biologie 137: 85–100.

[105] Molenberghs P, Cunnington R, Mattingley J (July 2009). *"Is the mirror neuron system involved in imitation? A short review and meta-analysis"*. Neuroscience & Biobehavioral Reviews 33 (1): 975–980.

[106] Keysers, Christian; Gazzola, Valeria (2006). *Towards a unifying neural theory of social cognition* "Progress in Brain Research" Vol. 156. Anders, Ende, Jungho¨fer, Kissler & Wildgruber (Eds.) PDF: http://www.bcn-nic.nl/txt/people/publications/2006_KeysersGazzola_PBR.pdf

[107] Théoret, Hugo; Pascual-Leone, Alvaro (2002). *"Language Acquisition: Do as You Hear"*. Current Biology 12 (21): R736–7.

[108] Iacoboni, Marco (February 22, 2005). *"Grasping the Intentions of Others with One's Own Mirror Neuron System"*. PLOS Biology.

[109] Blakeslee, Sandra (January 10, 2006). *"Cells That Read Minds"*. New York Times | Science.

[110] Fogassi Leonardo, Pier , Ferrari Francesco, Gesierich Benno, Rozzi Stefano, Chersi Fabian, Rizzolatti Giacomo (2005). *"Parietal lobe: from action organization to intention understanding"*. Science 308 (5722): 662–667

has long been recognized as an association cortex that integrates sensory information. The monkeys watched an experimenter either grasp an apple and bring it to his mouth or grasp an object and place it in a cup. In total, 15 mirror neurons fired vigorously when the monkey observed the "grasp-to-eat" motion, but registered no activity while exposed to the "grasp-to-place" condition.

Learning facilitation

Another possible function of mirror neurons would be facilitation of learning. The mirror neurons code the concrete representation of the action, i.e., the representation that would be activated if the observer acted. This would allow us to simulate (to repeat internally) the observed action implicitly (in the brain) to collect our own motor programs of observed actions and to get ready to reproduce the actions later. It is implicit training. Due to this, the observer will produce the action explicitly (in his/her behaviour) with agility and finesse. This happens due to associative learning processes. The more frequently a synaptic connection is activated, the stronger it becomes.[111]

Empathy

Stephanie Preston [112] and Jean Decety,[113] and Vittorio Gallese [114, 115] and Christian Keysers[103] have independently argued that the mirror neuron system is involved in empathy. A large number of experiments using fMRI, electroencephalography (EEG) and magnetoencephalography (MEG) have shown that certain brain regions (in particular the anterior insula, anterior cingulate cortex, and inferior frontal cortex) are active when people experience an emotion (disgust, happiness, pain, etc.) and when they see another person experiencing an emotion.

More recently, Christian Keysers at the Social Brain Lab and colleagues have shown that people who are more empathic according to self-report questionnaires have stronger activations both in the mirror system for hand actions[116] and the mirror system for emotions, [117] providing more direct support for the idea that the mirror system is linked to empathy. Some researchers observed that the human mirror system does not passively respond to the observation of actions but is influenced by the mindset of the observer.[118] Researchers observed the link of the mirror neurons during empathetic engagement in patient care. [119]

Language

In humans, functional MRI studies have reported finding areas homologous to the monkey mirror neuron system in the inferior frontal cortex, close to Broca's area, one of the hypothesized language regions of the brain. This has led to suggestions that human language evolved from a gesture performance/understanding system implemented in mirror neurons. Mirror neurons have been said to have the potential

[111] Kosonogov V. (2011). *"Listening to action-related sentences impairs postural control"*. Journal of Electromyography & Kinesiology 21: 742–745.

[112] Preston S. D., de Waal F.B.M. (2002). *"Empathy: Its ultimate and proximate bases"*. Behavioral and Brain Sciences 25: 1–72.

[113] Decety J., Jackson P.L. (2004). *"The functional architecture of human empathy"*. Behavioral and Cognitive Neuroscience Reviews 3 (2): 71–100.

[114] Gallese V., Goldman A.I. (1998). *"Mirror neurons and the simulation theory"*. Trends in Cognitive Sciences 2 (12): 493–501.

[115] Gallese V (2001). *"The "Shared Manifold" hypothesis: from mirror neurons to empathy"*. Journal of Consciousness Studies 8: 33–50.

[116] Gazzola, Aziz-Zadeh and Keysers (2006). *"Empathy and the Somatotopic Auditory Mirror System in Humans"* in Current Biology PDF: http://www.bcn-nic.nl/txt/people/publications/gazzola2006sound.pdf

[117] Jabbi, Mbemba; Swart, Marte; Keysers, Christian (2007). *"Empathy for positive and negative emotions in the gustatory cortex"*. NeuroImage 34 (4): 1744–53

[118] Molenberghs et al. (January 2, 2012). *Activation patterns during action observation are modulated by context in mirror system areas.* "Neuroimage". 59(1). pp. 608–15.

[119] Hojat, Mohammadreza, et al. *Empathy and Health Care Quality* "American Journal of Medical Quality | 28.1 (2013)" . pp. 6–7. PDF: http://www.themindfulorganization.com/empathy-and-health-care.pdf

to provide a mechanism for action-understanding, imitation-learning, and the simulation of other people's behaviour.[120] Rates of vocabulary expansion link to the ability of children to vocally mirror non-words and so to acquire the new word pronunciations. Such speech repetition occurs automatically, fast[121] and separately in the brain to speech perception.[122,123] Moreover such vocal imitation can occur without comprehension such as in speech shadowing[124] and echolalia.[125]

Further evidence for this link comes from a recent study in which the brain activity of two participants was measured using fMRI while they were gesturing words to each other using hand gestures with a game of charades – a modality that some have suggested might represent the evolutionary precursor of human language. Analysis of the data using Granger Causality revealed that the mirror-neuron system of the observer indeed reflects the pattern of activity in the motor system of the sender, supporting the idea that the motor concept associated with the words is indeed transmitted from one brain to another using the mirror system.[126]

Automatic Imitation

The term is commonly used to refer to cases in which an individual, having observed a body movement, unintentionally performs a similar body movement or alters the way that a body movement is performed. Automatic Imitation rarely involves overt execution of matching responses. Instead the effects typically consist of reaction time, rather than accuracy, differences between compatible and incompatible trials. Research reveals that the existence of automatic imitation, which is a covert form of imitation, is distinct from spatial compatibility. It also indicates that, although automatic imitation is subject to input modulation by attentional processes, and output modulation by inhibitory processes, it is mediated by learned, long-term sensorimotor associations that cannot be altered directly by intentional processes.

Many researchers believe that automatic imitation is mediated by the mirror neuron system.[127] Additionally, there are data that demonstrate that our postural control is impaired when people listen to sentences about other actions. For example, if the task is to maintain posture, people do it worse when they listen to sentences like this: "I get up, put on my slippers, go to the bathroom". This phenomenon may be due to the fact that during action perception there is similar motor cortex activation as if a human being performed the same action (mirror neurons system).[111]

Motor Mimicry

In contrast with automatic imitation, motor mimicry is observed in naturalistic social situations and via measures of action fre-

[120] Skoyles, John R., *Gesture, Language Origins, and Right Handedness,* Psycholoqy: 11,#24, 2000

[121] Porter Jr, R. J.; Lubker, J. F. (1980). *"Rapid reproduction of vowel-vowel sequences: Evidence for a fast and direct acoustic-motoric linkage in speech"*. Journal of speech and hearing research 23 (3): 593–602.

[122] McCarthy, R.; Warrington, E. K. (1984). *"A two-route model of speech production. Evidence from aphasia"*. Brain : a journal of neurology. 107 (Pt 2) (2): 463–485.

[123] McCarthy, R. A.; Warrington, E. K. (2001). *"Repeating Without Semantics: Surface Dysphasia?"*. Neurocase 7 (1): 77–87.

[124] Marslen-Wilson, W. (1973). *"Linguistic structure and speech shadowing at very short latencies"*. Nature 244 (5417): 522–523.

[125] Fay, W. H.; Coleman, R. O. (1977). *"A human sound transducer/reproducer: Temporal capabilities of a profoundly echolalic child"*. Brain and language 4 (3): 396–402.

[126] Schippers, MB; Roebroeck, A; Renken, R; Nanetti, L; Keysers, C (2010). *"Mapping the Information flow from one brain to another during gestural communication"*. Proc Natl Acad Sci U S A. 107 (20): 9388–93.

[127] Longo, M. R; Kosobud, A.; Bertenthal, B. I. (April 2008). *"Automatic imitation of biomechanically possible and impossible actions: effects of priming movements versus goals"*. J Exp Psychol Hum Percept Perform 34 (2): 489–501.

quency within a session rather than measures of speed and/or accuracy within trials.[128]

The integration of research on motor mimicry and automatic imitation could reveal plausible indications that these phenomena depend on the same psychological and neural processes. Preliminary evidence however comes from studies showing that social priming has similar effects on motor mimicry.[129, 130]

Nevertheless, the similarities between automatic imitation, mirror effects, and motor mimicry have led some researchers to propose that automatic imitation is mediated by the mirror neuron system and that it is a tightly controlled laboratory equivalent of the motor mimicry observed in naturalistic social contexts. If true, then automatic imitation can be used as a tool to investigate how the mirror neuron system contributes to cognitive functioning and how motor mimicry promotes prosocial attitudes and behaviour.[131,132]

[128] Chartrand, T. L; Bargh, J. A (June 1999). *"The chameleon effect: the perception-behavior link and social interaction"*. J Pers Soc Psychol 76 (6): 893–910.

[129] Lakin, J. L; Chartrand, T. L (July 2003). *"Using nonconscious behavioral mimicry to create affiliation and rapport"*. Psychological Science 14 (4): 334–9.

[130] van Baaren, R. B; Maddux, W. W., Chartrand, T. L., De Bouter, C., & van Knippenberg, A (May 2003). *"It takes two to mimic: behavioral consequences of self-construals"*. Journal of Personality and Social Psychology 84 (5): 1093–102.

[131] Heyes, Cecilia (2011). *"Automatic imitation"*. Psychological Bulletin 137 (3): 463–83.

[132] Paukner A, Suomi SJ, Visalberghi E, Ferrari PF (August 2009). *"Capuchin monkeys display affiliation toward humans who imitate them"*. Science 325 (5942): 880–3.

Technological solution proposal, prototype description

System components and its functions

Equipment kit (Fig. 32) consists of robotic arm (or haptic manipulation device like The Geomagic Touch formerly Phantom Omni, Novint Falcon or similar) [1] with the pen (stylus) [2] attached to its endpoint and a tablet [3] with interactive game application running on it. The whole system is controlled by the laptop [4] with the administrator's version of program (for doctors, therapists, or parents). Contains the database of virtual patient's folders with all the parameters of therapeutic performance, possibility of remote monitoring.
In the table below the description of functioning of hard- and software interfaces may be found.

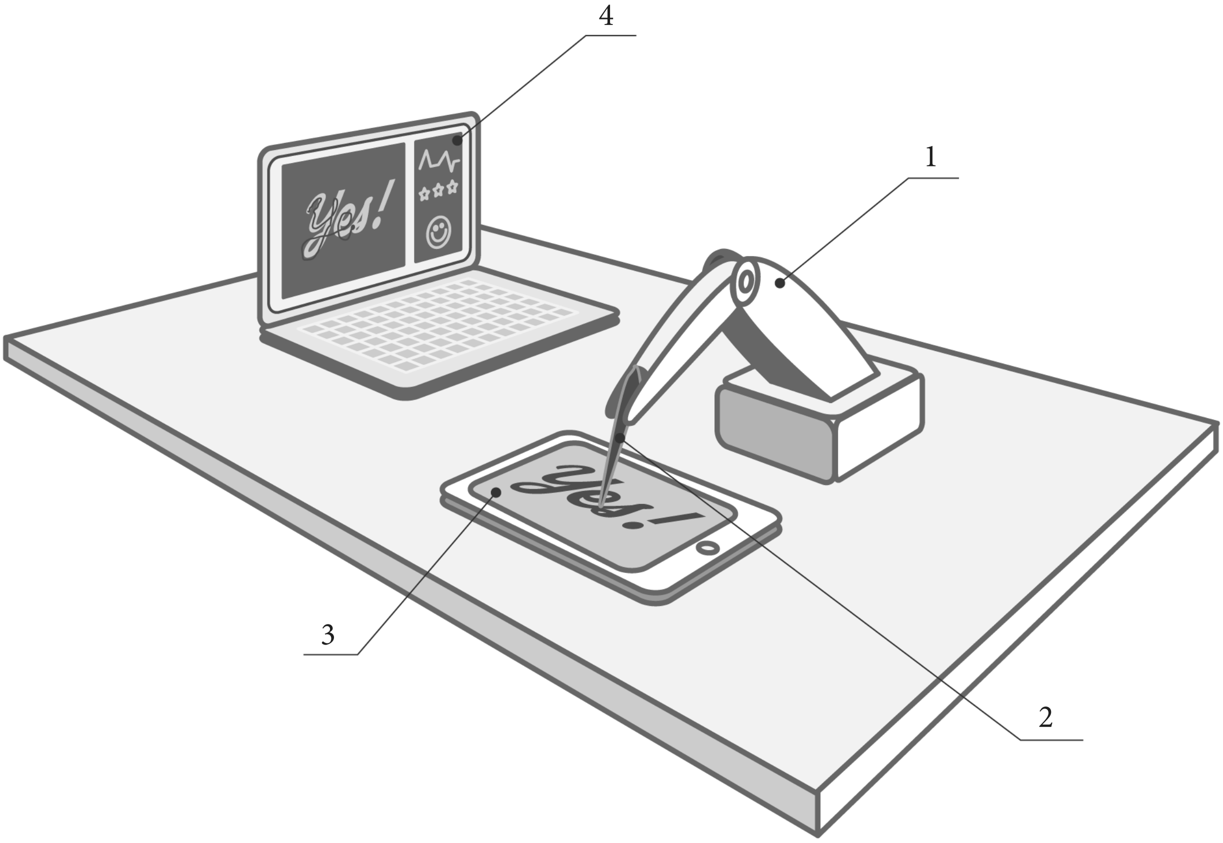


Figure 32 Concept graphic model of Interective Robotic Rehabilitation System for Dysgraphia

Table 6 Description of functioning: System's Hardware and Software interfaces

Physical interface (hardware)
Robotic arm or haptic device with 4 operation modes: - Learning mode (LM) - Guided mode (GM) - Gradual Autonomous mode (AM) - Gradual counteractive mode (CM) Learning Mode (LM) Robotic arm of haptic device "learn" from expert-user(therapist/administrator/developer) the correct writing movement of particular letter/word/track in order to reproduce it in therapeutic modes (GM, AM) with patient as a proper reference movement. Guided mode (GM) Aimed to assist learning understanding and memorising the correct writing movement: patient grips the pen and keeps the hand relaxed, leaving the robotically actuated pen guide him through the writing (or pre-graphic) exercise. Gradual Autonomous mode (AM) Aimed on practicing of previously learned movements (from GM). Patient reproduce the same word (or pre-graphic element) by the force of own hand, with the pen gripped but not powered by robotic assistance. In case of significant motion errors the robotic correction will be applied - resistance feedback reply, oriented towards the correct writing track. Moving forward in rehabilitation game, getting over the difficulty levels of exercises correction feedback force is decreasing gradually up to disappear completely, leaving the total motion freedom to the patient. Gradual Counteractive mode (CM) Activates in the last phase of the rehabilitation process (when the child is already familiar with the pen and has recovered most of the writing skills). A sort of physical exercise to strengthen the muscles of patient's hand. Robotically actuated pen pushes out from the correct path, creating obstacles for writing, the patient have to apply more force to stay within the specified ranges and be able to complete the task.
Interactive game (software)
Rehabilitation engaging game which keeps a child motivated to perform exercises of pre-writing and writing. The game evolves in several levels with increasing difficulty, depending on the progress and achievements of the patient. Factors of interactivity: - Sound and musical accompaniment and feedback during the exercises. - Score points, earning badges, keys, collecting map pieces to accomplish the goals, discover the hidden treasures, gain awards etc.

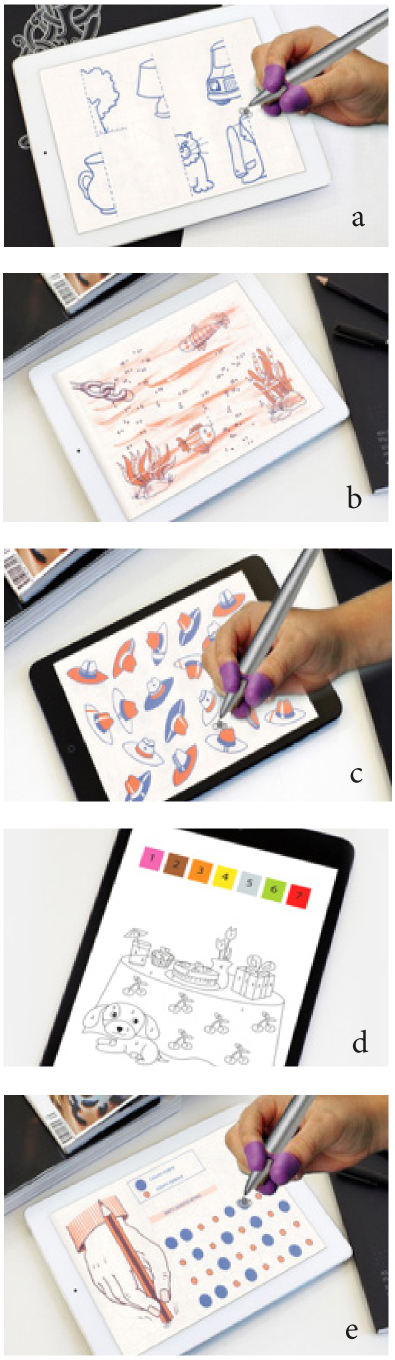


Figure 33 Exercises type to implement into interactive game:
a-b) path tracing, symmetry, dots connection.
c) Shape/size/colour recognition.
d) Colouring pages.
e) Rhythm

- Celebration for successfully passed levels (visual, music, vibration), encouragement for attempts with a low score.
- Possibility to play in the network with friends (competitive factor).

Exercises types for basic skills recovery to implement into the game:
- Trace the path, copy the trajectories, complete the symmetrical picture, connecting the dots as in example, unite the numbered points, find the way in the labyrinth; (fig. 33 a,b)
- Recognition of shape, size and colour: find and unite the figures of the same colour/shape/size; Drag the missing figures into the vacant gaps on the picture in order to complete it. (fig. 33 c)
- Colouring pages (numbered colours on the picture in the related areas + specification card “number-colour”). (fig. 33 d)
- Rhythmic exercises (touching, giving taps: strong/weak, slow/fast; directly with finger or a pen aiming the points of a certain colour or size in the line sequence of points maintaining some simple rhythm. (Fig. 33 e)

Each patient has his personal virtual folder that contains all the therapeutic progress information (database shared with their doctors, therapist, parents).
To start the game it is necessary to effectuate authentication by logging into personal account where all the previous results may be found and the game can be resumed exactly where it was left last time.
Performance data collection: accuracy, speed; progress monitoring; calendar of activities, time of play.
Possibility of remote monitoring of rehabilitation activities in real time.

Difficulty groups and levels of the game

Group 1 ☆
Beginners
Robotic Arm mode
GM and AM

Exercises of pre-writing and capital letters writing;
(40 levels)
each level should be performed in two modalities:
1. Guided Mode - Child grasps the pen and holds it with his relaxed hand, letting the robotic arm guide him through the exercise.
2. Gradual Autonomous mode - Patient with the pen tightly grasped in his hand, performs the same movement without being driven by robot (however once the pen exceed the specified mistake ranges, the resistance feedback will be activated in order to correct the wrong movement, pushing back towards the right path).
The speed of guidance increases and feedback correction force gradually decreases with the performance enhancements of patient, and eventually disappears completely, leaving total autonomy of movement.

Continue the game on levels of this difficulty group until the performance of accuracy won't reach the 85% barrier and the speed of exercise accomplishment is fast enough (value to be determined)

Group 2 ☆☆
Intermediate
Robotic Arm mode
AM

Exercises of pre-writing and cursive writing;
(30 levels)
Each level should be performed in a completely autonomous modality.
Pre-writing worksheets with increasingly complex paths to trace, colouring pages with small details, cursive writing (in medium, then smaller size), rhythm exercises.

Continue the game on levels of this difficulty group until the performance of accuracy won't reach the 90% barrier and the speed of exercise accomplishment is fast enough (value to be determined)

Group 3 ☆☆☆
Advanced
Robotic Arm mode
CM

Exercises of pre-writing and cursive writing; (30 levels)
The last phase of the rehabilitation process -strengthening the hand muscles.
Each level should be performed in an counteractive mode:
Robotic arm feedback pushes the pen off the right path creating obstacle for writing or tracing, so the patient will have to apply more force to stay within the specified ranges and be able to complete the task.
The strength of the disturbance increases gradually with the achievements of the patient.
Completing the levels of this difficulty group, patient is supposed not only to recover the missing writing skills but also to reinforce the hand in order to maintain positive results in future.

Figure 34 Sheme: Devision of game levels by difficulty groups and its description

Development of use cases

Definition of the actors and their objectives
Actors interacting with system:
1. Child-patient (Primary Actor)
2. Doctor/therapist/parent (in role of administrator) in some use cases the child himself can perform the role of administrator

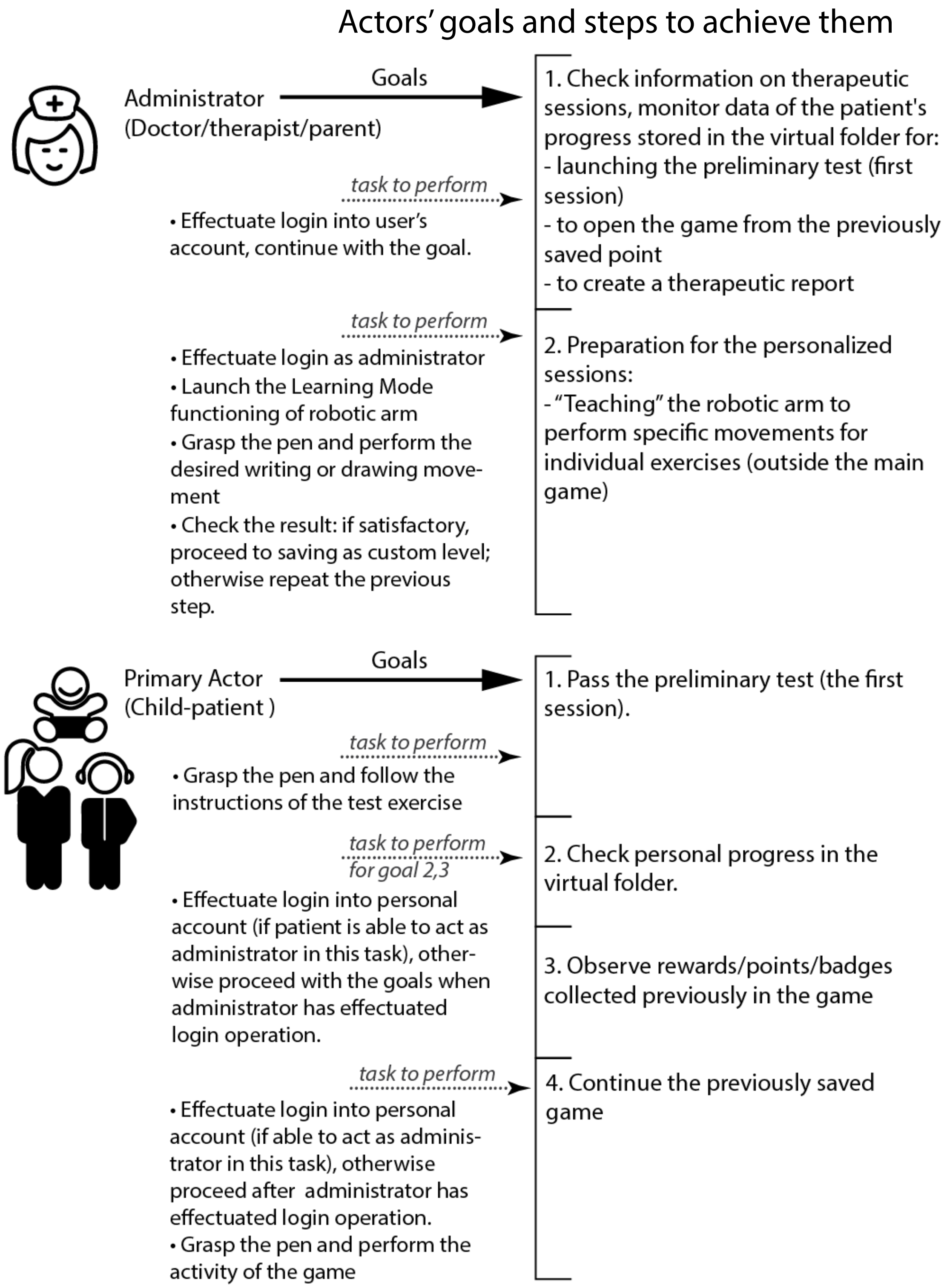


Figure 35 Diagram: Actors' goals and steps to achieve them

Use Case Diagram

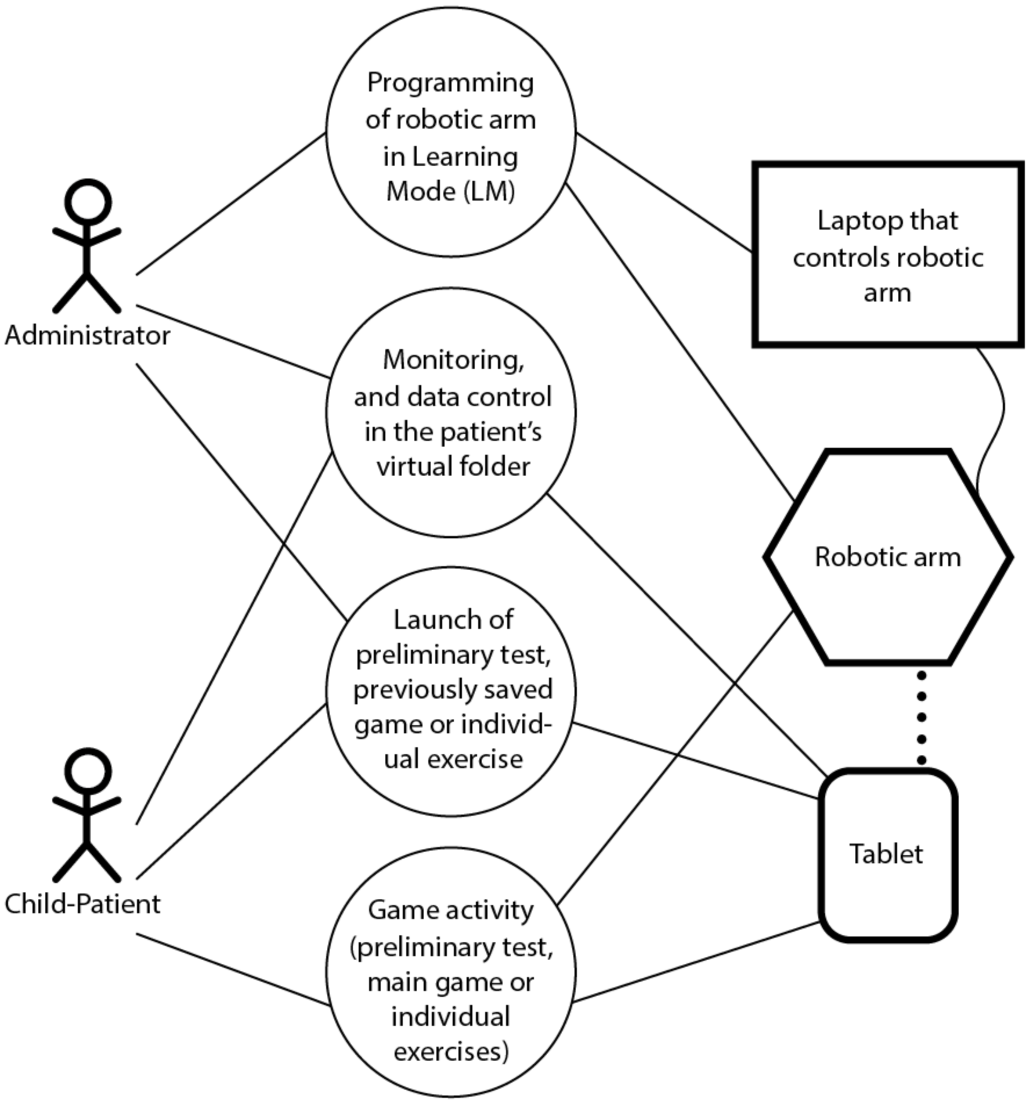


Figure 36 Use case diagram of Interective Robotic Rehabilitation System for Dysgraphia

Use cases scenarios

Use case 1:

Programming of robotic arm in Learning Mode (LM)

Actor: Administrator (Doctor/therapist/parent)

Goal: Teach robotic arm to perform specific writing or drawing movements, in order to create personalised exercises for individual therapeutic sessions.

Scenario:

1. Administrator: Logging into administrator's account from the lap-

top which controls the robotic arm (insert user name and password).
2. Administrator: Launches the Learning Mode.
3. Administrator: Grasps the pen.
4. Administrator: Performs the desired movement.
5. Administrator: Controls the result (if satisfactory, proceeds with the next step, otherwise turns a step back).
6. Administrator: Saves the movement and introduces it in the context of custom exercise.
7. Administrator: Loads the custom level into the virtual folder of related patient.

Priority: Essential

Use case 2:
Game activity (preliminary test, main game, personalised exercises)
Actors: Administrator (doctor/therapist/parent); Child-Patient
Goal: Patient has to perform the game activity
Scenario:
1. Administrator (or patient if able to): Effectuates login into patient's account (insert user name and password).
2. Administrator (or patient if able to): Launches preliminary test, or previously saved game, or personalised level.
3. Child-Patient: Grasps the pen.
4. Child-patient: Performs the game activity in one of tree difficulty groups, passing from one to another when reaching the required conditions.
5. Child-patient: Accomplishes the level - performance data is automatically saved into virtual personal folder; Next level unlocks and becomes available for further playing.
6. Child-patient: Finishes the game, all the performance data from the therapeutic session is being automatically saved into the patient's virtual folder.
7. Administrator: Effectuates log out from patient's account, closes the application on tablet, switches off the robotic arm and laptop (if necessary).

Perspectives of rehabilitation platform development:

"Home" and "Clinic" versions

For home-based exercises the "light" version of rehabilitation system can be provided (the costly robotic arm may be replaced by stylus pen). So by it will be necessary just to install the game app on the tablet, and the therapeutic gaming may be continued at home, but exclusively in "Autonomous Mode".

Another possibility for the future development is a creation of a particular social network focused on neurological rehabilitation (Participants: children with similar disorders, parents, doctors, researchers, developers, designers);
Network should be live, collaborative, freely updated: participants should be able to contribute new exercises, therapeutic worksheets, methodologies and games (published with the approval of the experts' team). Forum aria for socialization among members, search for therapeutic partner (for multiple player rehabilitation games), communication, exchange experiences, tips, information, links; consultation with medical experts, researchers etc.

Robot-assisted exercises of handwriting

(Collaboration with engineers from NeuroLab of DIBRIS, University of Genoa)

Engineers from Genoa NeuroLab had independently and simultaneously with us reached very similar technological solution of writing assistant system, but applying it for inter-manual writing skill transfer (Left hand writing).
Our collaboration is now leading to sharing and uniting our results in order to produce more effective and useful product for the rehabilitation of writing disorders.

In 2012 the research team of DIBRIS published an article[133] on Robot-assisted intermanual transfer of handwriting skills. It is noticed in their article that handwriting acquisition is generally difficult and slow, and young children need several years of formal training to master it properly.[134] Subjects must learn the shape of the letter and the movement associated to that shape. Robots may mediate some form of physical interaction, which can be exploited as a task-dependent 'aid' – often referred as 'virtual fixture'. In this way, users' motion is driven by robots along desired directions (guiding virtual fixtures), or motion in undesired directions or regions of the workspace may be prevented.
Research question of NeuroLab team was: Can haptic devices facilitate the acquisition of fine motor skills, in general, and of handwriting skills, in particular?

In pre-school children, haptic interaction with physical models of handwritten letters may speed up handwriting acquisition.[134] Using a robot to increase pen inertia and viscosity resulted in an improved handwriting quality in school-aged children.[135] Palluel-Germain[136] used a visuo-haptic device to train pre-school children in writing isolated cursive letters. In comparison to children trained through simple visual demonstration of the letters, those trained through haptic guidance could write more fluently, with a greater average velocity and a smaller

[133] Basteris A. et al. / *Human Movement Science* 31 (2012) 1175–1190.

[134] Bara, F., & Gentaz, E. (2011). *Haptics in teaching handwriting: The role of perceptual and visuo-motor skills.* Human Movement Science, 30, 745–759.

[135] Ben-Pazi, H., Ishihara, A., Kukke, S., & Sanger, T. D. (2010). *Increasing viscosity and inertia using a robotically controlled pen improves handwriting in children.* Journal of Child Neurology, 25, 674–680.

[136] Palluel-Germain, R. (2008). *A visuo-haptic device (Telemaque) increases the kindergarten children's handwriting acquisition.* International Journal of Psychology, 43, 715.

number of velocity peaks.

Handwriting movements are typically performed with the dominant hand, and most people exhibit poor performance in writing with their non-dominant hand. Researchers of NeuroLab DIBRIS were focused on intermanual transfer of handwriting skills in order to improve the rehabilitation experience of cerebrovascular accidents survivors or patients with amputation involving the dominant hand. For them transfer of their handwriting skills to their non-dominant hand is the only solution (injury-induced hand dominance transfer, I-IHDT). This typically takes several months of training by occupational therapists[137], and the overall success is highly subject-dependent.[138, 139]

Although drawing geometric shapes is often used with children as part of learning programs aimed at cursive handwriting skills, the individual components (strokes) of geometric shapes and those of cursive writing are peculiar in size, curvature, complexity, and in the way they are connected.[140] These aspects make writing quite distinctive in comparison to reproduction of complex spatial patterns, and may possibly affect the modalities of intermanual transfer.

NeuroLab DIBRIS team decides to investigate whether haptic guidance could promote the intermanual transfer of writing skills. They addressed a simplified scenario as in Palluel-Germain[136] and focused on isolated cursive letters, but their required size was comparable to that used in writing on a blackboard. Therefore, the task mostly involved shoulder and elbow movements.

Writing may be seen as a redundant task, in the sense that multiple movements satisfy the task requirements; e.g., many different trajectories may correspond to a legible 'e'.[141] It is unclear how to provide assistance in these situations, but it would seem that weaker constraints might allow the trainee to fully explore (and exploit) task redundancy. With this in mind, NeuroLab researchers compared different assistance modalities to understand what scheme of assistance is more effective.

The experimental setup (Fig. 37) was based on planar manipulandum with two degrees of freedom – PhysioAssistant. (Celin srl, Follo, Italy)[142]. It was used to record hand positions and to generate assistive forces. Subjects sat on a chair, with their torso restrained by means of suitable holders. They grasped the handle of the manipulandum with their dominant hand. Their forearm was placed over a support, so that its movements were restricted to the horizontal plane, with no influence of gravity. A vertical 19" LCD computer screen placed at eye level in front of the subject displayed a virtual environment resembling the top view of a notepad (with 8 cm squares), and a small red cursor (5 mm diameter) continuously displayed the position of the robot handle, which was used as the virtual 'pen'. The software application was based on

137 Harada, T., Okajima, Y., & Takahashi, H. (2010). *Three-dimensional movement analysis of handwriting in subjects with mild hemiparesis.* Archives of Physical Medicine and Rehabilitation, 91, 1210–1217.

138 Pereira, E. A., Raja, K., & Gangavalli, R. (2011). *Effect of training on interlimb transfer of dexterity skills in healthy adults.* American Journal of Physical Medicine and Rehabilitation, 90, 25–34.

139 Yancosek, K. E., & Mullineaux, D. R. (2011). *Stability of handwriting performance following injury-induced hand-dominance transfer in adults: A pilot study.* Journal of Rehabilitation Research and Development, 48, 59–68.

140 Teulings, H.-L., Thomassen, A. J. W. M., van Galen, G. P., Henry, S.R., Kao, G. P. v. G., & Rumjahn, H. (1986). *Invariants in handwriting: The information contained in a motor program.* Advances in psychology (Vol. 37, pp. 305–315). North-Holland.

141 Latash, M. L., Danion, F., Scholz, J. F., Zatsiorsky, V. M., & Schöner, G. (2003). *Approaches to analysis of handwriting as a task of coordinating a redundant motor system.* Human Movement Science, 22, 153–171.

142 Casadio, M., Sanguineti, V., Morasso, P. G., & Arrichiello, V. (2006). *Braccio di Ferro: A new haptic workstation for neuromotor rehabilitation.* Technol Health Care, 14, 123–142.

the open-source platform H3DAPI (SenseGraphics, Kipsta, Sweden).

One letter was displayed (in a typed-print font) on the left side of the screen, and subjects were required to reproduce it by approximately fitting letter height into one or two notepad squares (in-line letters, and ascending/descending letters, respectively); The 'pen' (i.e., the cursor) started to leave a trace on the screen once it was placed inside a start area (displayed in green, and visible only before movement start). Numeric score was displayed on the screen, calculated in terms of the shape 'error'. The same quantity was used to provide an audio feedback on performance, consisting of a voice pronouncing the written letter, whose pitch frequency was modulated by the shape error.

Different assistance modalities were tested in different groups of subjects. In one subject group (control group, C), assistance was purely visual, and consisted of displaying the reference template in the background, as a grey line to trace over.

In the other subjects' groups, in addition to visual assistance the robot generated assistive forces. In two different subject groups, we tested two variants of robot assistance. In the trajectory guidance (T) modality, a proportional-derivative motion controller attracted the subjects' hand toward the ongoing position of the reference trajectory.
In the path guidance (P) modality, assistive force was always directed toward the closest point of the template trajectory. At every time, given the current hand position, and the robot closest point of the reference template.

Subjects were required to reproduce samples of their own (dominant hand) handwriting, by using their non-dominant hand. The training protocol consisted of three 1-h sessions in consecutive days, plus one additional test on day four to assess retention. During training, all three assistance modalities resulted in a gradual reduction of the shape difference between handwritten letters and the corresponding reference templates. A similar reduction was observed in the timing with the exclusion of the trajectory guidance modality in which time is explicitly regulated by assistance. Likewise, in all modalities letters gradually became more reproducible (lower shape variability and lower duration variability).

These effects transferred only partially to test (free hand) conditions. In fact, transfer was only significant in trajectory guidance and, to a lesser extent, visual guidance. Subjects undergoing trajectory guidance exhibited an average 34% decrease in the shape error; more than twice that observed in visual guidance subjects (13%). Subjects in the path guidance group did not show statistically significant changes.

In summary, trajectory guidance reduces shape error and shape variability much more than visual guidance, but provides no additio-

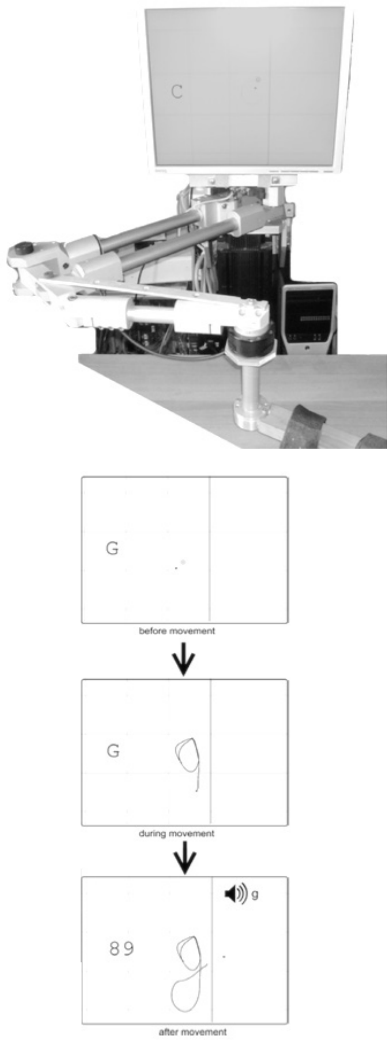


Figure 37 Experimental setup PhysioAssistant intermanual transfer of handwriting skills and screenshots of the visual display during the different phases of the experiment.

nal benefit on duration and its variability. Nevertheless, the benefit on shape error is remarkable, as it would allow to greatly reduce the time needed for achieving intermanual transfer of cursive writing.

One major limitation of this study is that the required movements are very different from actual handwriting, which raises the question of whether the results are somehow applicable to hand-writing skills.

First point is - experiment was focuses on arm movements, whereas actual handwriting movements mostly involve the hand and the wrist, and the degree of intermanual transfer has been reported to depend on the muscle groups involved.

Second, subjects used a power grasp on the robot manipulandum instead of dynamic tripod grasp which is typical of writing with a pen. This may have reduced the need for multi-finger coordination, which is a requirement of handwriting.[143]

Third, although there is evidence of end-effector independence in handwriting, when writing relatively large letters their shapes are altered,[144] and the need for position accuracy is also reduced.

On the other hand, in the present task the inertia involved (arm, robot) is much greater than that found in pen-based handwriting (hand, pen). And, a greater inertia can make dynamics control and intermanual transfer of a complex skill more challenging and difficult to achieve.

The NeuroLab team concludes at the end of this experiment that significant reductions of error observed in the trajectory guidance group with respect to controls suggest that robot-assisted haptic devices that incorporate a dynamical model of handwriting movements may play a role in intermanual transfer protocols.

Next step of their research was to proceed experimentation with smaller and more precise robotic devices in order to discover effectiveness of haptic assistance writing performed actually by hand and wrist with a normal-size pen instead of arm as in previous experiment.

Design of new robotic system:

Novint Falcon a little robot - 3D touch controller (One of haptic manipulation device from lower-cost segment) was used to create a new experimentation setup (Fig.38).Falcon was programmed to register the hand position during the exercise performance and to generate assistive haptic forces.

The endpoint of Falcon was equipped with a pen purposely designed for this experiment.

The inclination of the pen may be adjusted for each subject at the beginning and maintains the constant angle for the whole task.

Computer screen is positioned horizontally under the pen and shows

[143] Dooijes, E. H. (1983). *Analysis of handwriting movements.* Acta Psychologica, 54, 99–114.

[144] Marquis, R., Taroni, F., Bozza, S., & Schmittbuhl, M. (2007). *Size influence on shape of handwritten characters loops.* Forensic Science International, 172, 10–16.

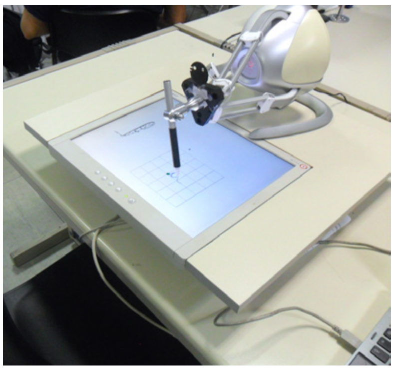


Figure 38 Prototype of robotic system for assisted hand-writing exercises based on Haptic 3D touch controller Novint Falcon

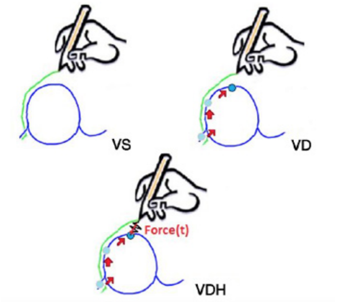


Figure 39 Three modalities of robotic assistence during hand-writing exercises

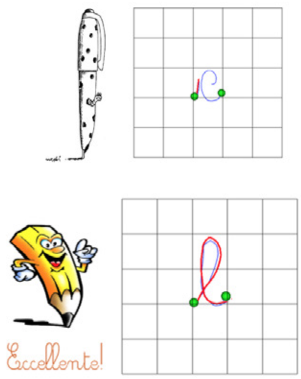


Figure 40 Screenshots from the exercise of cursive letters robot assisted hand-writing

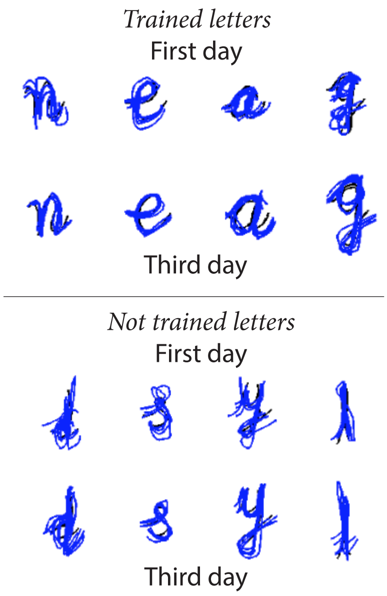


Figure 41 Qualitative results of a tipical subject

the top view of a notebook page. All the movements of the pen tip, if in contact with the screen are shown continuously as a red trace.
Three modalities of robotic assistance are(Fig. 39):

Visual-Static Mode (VS)

Subject can see the reference template to trace over.

Visual-Dynamic Mode (VD)

Target-point moves along the track with the reference speed.

Visual-Dynamic and Haptic Mode (VDH)

In addition to Visual-Dynamic mode haptic device Falcon generates forces towards the target-point moving along the track. (Fig. 40)

Subjects were asked to write 8 cursive letters (a,d,e,g,l,n,s,y) of different level of complexity (Complexity is based on number of strokes every particular letter contains) (Fig. 41)
At the beginning of every session one letter was shown and subjects were supposed to reproduce it on their own. At the end of every performed writing movement exercise the numeric score was announced (0-100 points, based on tracking error). The result was presented in a form of visual message.
After confronting our prototype description (developed together with doctors and therapists from Infant Neuropsychiatry Department of Mondino National Neurological Institute of Pavia) with engineers-researcher from NeuroLab DIBRIS we were all convinced that sharing our results may significantly improve their already existing hardware prototype and will lead to promising collaborative results.

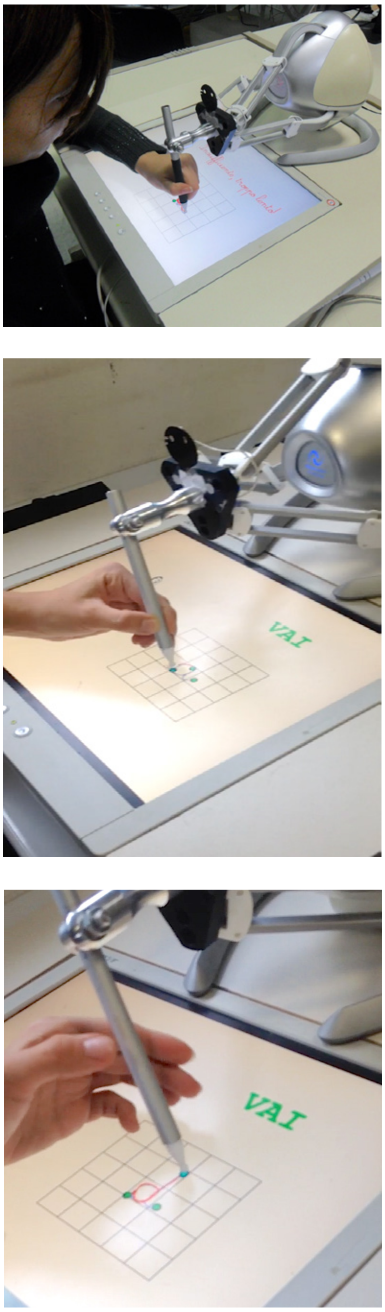


Fig.ure 42 Prototype demonstration at NeuroLab DIBRIS, University of Genoa

First meeting with NeuroLab DIBRIS team at University of Genoa

First visit to the robotic laboratory DIBRIS of University of Genoa was organized by prof. Antonucci as an informal introductory meeting.
Ph.D. student Irene Tamagnone and prof. Vittorio Sanguineti explained and demonstrated to us their prototype; (Fig.42) the results of our researches, eventual ideas, intentions and plans for future collaboration were shared and discussed.
The decision to organize the next appointment at Mondino Neurological Institute, Pavia was taken.

This meeting was arranged in order to bring together all components of multidisciplinary team for the development of rehabilitation program. Doctors and therapists from Mondino were expected to try and evaluate the prototype suggesting consequently ideas of improvement and proposing possible therapeutic protocol for the first try with dysgraphic children.

Second Meeting, multidisciplinary team, Pavia

On January 18, 2014 the agreed meeting was held at Mondino Neurological Institute of Pavia. The following participants were present: prof. U. Balottin, Dr. L. Capone, professors R. Antonucci and V. Sanguineti and Ph.D. students I. Tamagnone and A. Kozlova (author).
The portable prototype designed by NeuroLab DIBRIS was brought and installed in the office of prof. Ballotin, the Head of Infant Neuropsychiatric Department to be presented and demonstrated in practice by engineers. (Fig. 43)

While testing the prototype and discussing perspectives, several ideas for the joint research project emerged:

1. The device could be used not only for therapeutic exercises but as a *Diagnostic Tool* for dysgraphia screening as well. For that purpose the prototype is already sufficient as it is, because the requirements for diagnostic tools are much less demanding than for rehabilitation once. The diagnostic test duration is relatively short (not more than 10 min) and only one single session is needed, so for this goal the factors of engagement, motivation, age appropriate interface design etc., became less significant.

Doctors confirmed to have contacts with several local schools in Pavia area and the idea is to organize 2 or 3 days of diagnostic screening at one of these schools in order to individuate children with writing issues for the further participation in experimental project and to try the prototype for the first time on children, to see their reaction and the way

Fig. 43 Multidisciplinary meeting at Infant Neuropsychiatric Departmet of Mondino National Neurological Institute, Pavia. Working moments.

they manage the device for eventual design corrections.
Doctors suggested to prepare a test sessions 5-10 minutes long and apply them for screening of at least 50 children in 3rd to 5th grade of elementary school.
(Scheduled by the end of March).

In order to speed up the study it was agreed to choose children who have already participated in previous similar tests (held by researchers from University of Pavia with another diagnostic tool) and were already diagnosed as related to learning difficulties issue.
As for the exercisers to present at diagnostic test, the conversation in multidisciplinary team produced two solutions, where one of them was a new and very appreciated idea of dr. Capone:

- Assessment of the ability to write.

The child will be asked to perform some movements of pre-writing and/or hand-writing without any active haptic assistance from robotic device.

Second brand-new idea of this meeting was:

- Evaluation of the perception ability.

The child will be asked to grasp the pen passively (with the hand relaxed) and to close his eyes. Robotic device is supposed to perform a letter or a simple shape (like circle, square, heart) and once the movement has been completed, child will be suggested to recognized the performed letter or shape.

This new diagnostic feature will reveal the validity of the hypothesis that dysgraphic patients has also difficulty in visual imagination of physically percept shapes (performed by someone else with his own hand or e.g. “drown” by someone with finger or stick on the skin of his different parts of body)

In the meantime before screening, at least one more meeting should be organised in Pavia or Genoa, for a general inspection of the system and the exercises implemented.

2. Application of the robotic device for the *rehabilitation treatment* of writing disorders.

It was agreed to proceed first of all with the first point, in order to achieve immediate and less demanding results.
However for the further development of rehabilitation branch of project the following protocol was preliminarily suggested:
Therapeutic sessions of 30 minutes each, 2-3 times a week for about 10 weeks with 8-12 children.
In each session patient is supposed to exercises his pre-writing and/or writing skills (print letters and/or cursive) in different robotic assistive

modes.
In the beginning and in the end of treatment period patient's writing skills and/or fine motor skills should be evaluated with specific tests in order to assess any improvements due to the therapy.
It would be advantageous to involve also an age-matched control group.
Details of the study have yet to be designed. It will be essential further exchange of ideas among all employees, so make the best possible individual scientific skills.

3. Changes in hardware of the system (Interventions of engineers and designer)

- Before the start of experiments it is expected to replace the current LCD monitor with a graphics tablet, in order to enable the recording of pen pressure and to increase the precision of movements control.
- Further changes are expected also in the pen grip in order to render it more handy and easy-managable (though this adjustment is not essential for the beginning of experiment)
- It was suggested to implement the possibility of external design personalization of robotic device, like e.g. animal-shaped cover, so younger children will appreciate it more, playing with funny and friendly personage (it was noted as well that as for boys the actual robotic exterior seems to be quiet attractive due to its futuristic, spaceship forms).

5. Changes in user interface (Intervention of Designer, Engineers and Doctors)

It was admitted that therapeutic exercises have to be age-appropriate, motivating and engaging, with the great variety of game activity.
For the success of the treatment it is crucial to be able to get attention, interest and commitment of child in performing exercises. So the development of attractive game design is a must

To this purpose it was suggested to divide the exercises into levels with increasing difficulty. Each exercise will be a level of a video game, which can be passed only if the child has obtained a satisfactory result.
Implementation of multi-player competitive mode in the network of friends is a great involving factor as well.
Therapeutic exercises of pre-writing and hand-writing should be designed under the doctor's supervising. Another interesting feature of haptic device Falcon, came out to be potentially convenient in game design. Since the system is capable of performing feedback simulations of different materials' surfaces as well as simulation of different materials of endpoint grip (pen in our case), so why not to add options of surface

and pen material choice while performing the exercises (e.g. tracing on water surface with a wooden pen, or tracing on the stone with a feather pen etc.)
In conclusion, to experimental Part 3, and particulary to Case Study 2 "Dysgraphia" it would be relevant to underline that the project keeps moving foreward after the accomplishing of present doctoral thesis.

Hopefully in March some first results of prototype testing in school will be available for alalysis, meanwhile the plans of hard- and software improvmet are in an active phase of realization.

2 | Conclusions, Recommendations

The purpose of this research was to identify the role of designer in project development of children's rehabilitation programs and to verify the contributes that can be brought into this area by application of proper design approaches, dedicated design research and evidence based design solutions.

Critically disputing it would be appropriate to conclude that the purpose is mostly achieved by demonstrating the role of Designer-Researcher and its contribute into project, firstly based on theoretical studies and then confirmed by experimental results in case studies.

Thus the answer to the essential question of this doctoral thesis and probably generalizing also of many other branches of design sciences: "What is the role of designer in in project development of rehabilitation programs?" will be the following:

Designer plays the conductive role between different groups of specialists of various competences and frames of reference (e.g. engineers, software developers, doctors, therapists etc.), and communities of individuals with particular characteristics (potential users or customers: patients, children, parents etc.), uniting them together as a productive multidisciplinary team and contributing knowledge of his own competence (product design, graphic design, interface design, user experience design, ergonomics etc.) (See the diagram Fig. 44)

In order to be able to organize, manage and be the valuable part of the project developing team, designer should inevitably become a multidisciplinary researcher as well.

Answering the main research questions:

How design can contribute to children's neurological rehabilitation?

Present research exposed the example of successfully developing multidisciplinary project on robotic rehabilitation system for Dysgraphia. In our case the therapeutic equipment for curtain neurological disorder in a curtain infant neuropsychiatric department is being brought to a new quality level.

Consequently patient's therapeutic experience is to become more pleasant and exciting, so the efficiency of rehabilitation process is being improved. Moreover our suggestion is that using our general guidelines of project development in this field would bring to similar positive results.

It turned out that the type of research I have managed to accomplish in this work could be categorized as an Action Research.

Action Research - is either research initiated to solve an immediate problem or a reflective process of progressive problem solving led by individuals working with others in teams or as part of a "community of practice" to improve the way they address issues and solve problems. There are two types of action research: participatory action research

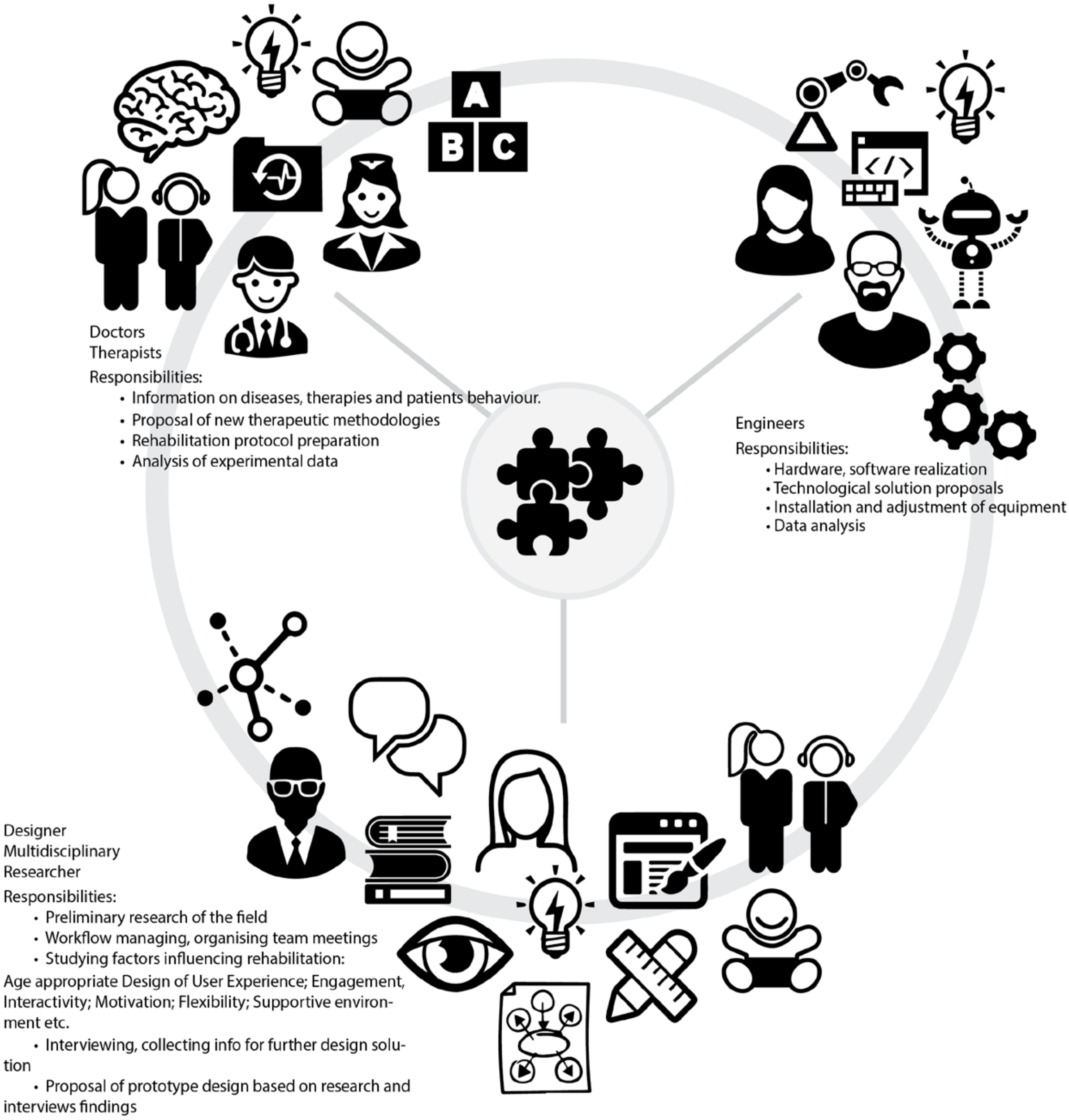


Figure 44 Schematic diagram of project development team participants and their responsibilities. Co-designing robotic rehabilitation program for children with dysgraphia

and practical action research. Denscombe writes that an action research strategy's purpose is to solve a particular problem and to produce guidelines for best practice.[145]

Action research involves actively participating in a change situation, often via an existing organization, whilst simultaneously conducting research. Action research can also be undertaken by larger organizations or institutions, assisted or guided by professional researchers, with the aim of improving their strategies, practices and knowledge of the environments within which they practice. As designers and stakeholders, researchers work with others to propose a new course of action to help their community improve its work practices.

Present research surprisingly followed the Action Research template in a truly unconscious way and as a coherent completion - generalization of my results in particular field of expertise (children's neurological rehabilitation) are supposed to lead to more or less universal advantageous guidelines for similar projects development.

[145] Denscombe M. 2010. *Good Research Guide : For small-scale social research projects* (4th Edition). Open University Press. Berkshire, GBR.

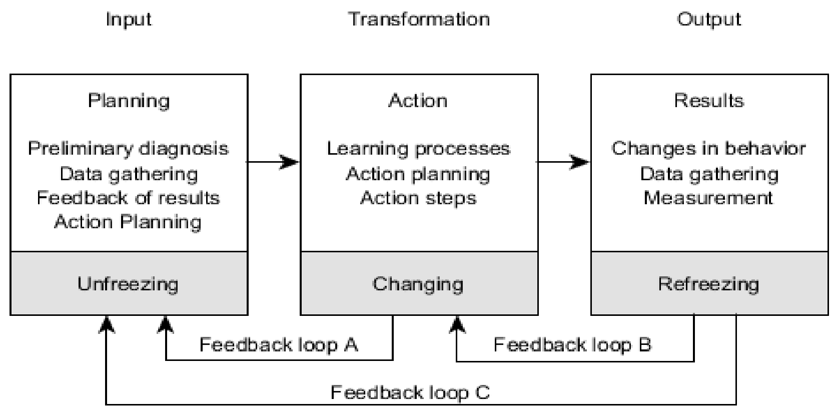


Figure 45 Systems Model of Action - Research Process

Recommendations

Research Design

A research design is a systematic plan to study a scientific problem. The design of a study defines the study type (e.g. descriptive, correlational, semi-experimental, experimental, review, meta-analytic) and sub-type (e.g., descriptive-longitudinal case study), research question, hypotheses, independent and dependent variables, experimental design, and, if applicable, data collection methods and a statistical analysis plan. Research design is the framework that has been created to seek answers to research questions.

Research Design of my accomplished theoretical and experimental study is recognized as an Action Research with the following generalized research questions:

How design can contribute to the field of isseu?

Generalized conducting questions:

- *What are the factors influencing the object of issue in the respective field?*
- *What are the main benefits and drawbacks of existing solutions?*
- *How the drawbacks can be eliminated or reduced?*
- *How the benefits can be forced?*
- *Which technologies can be applied for the eventual improvement of object at issue?*
- *Which design methodological approaches can be applied in order to improve the project development process?*
- *What is the role of designer in the project development?*

The diagram Figure 46 shows four main generalized steps of my study.

Obviously it is a very general, flexible and incomplete model of research design, participants on every step may vary, for example it is always advantageous to consider user's opinion right from the very first step and through the whole project's lifecycle.

The most important research methods applied are: Literature review, Analysis, Field research, Observation and Participatory observation, Participatory action research, Interview, Creative participation, co-design.

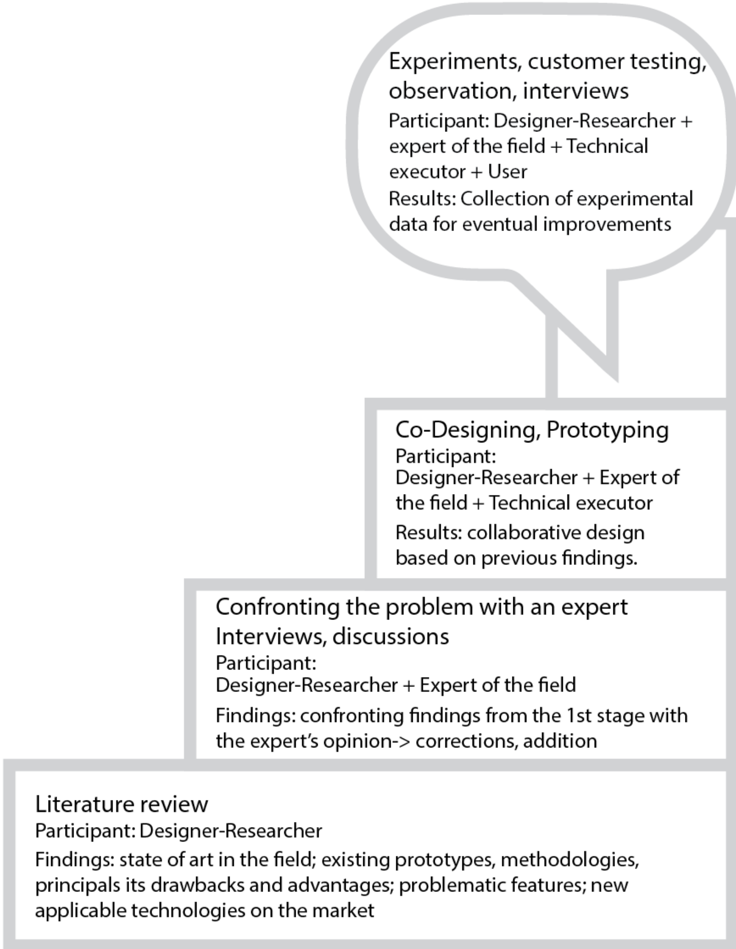


Figure 46 Diagram: Generalized steps of accomplished action research

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