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A Biosymtic (Biosymbiotic Robotic) Approach to Human Development and Evolution.

The Echo of the Universe.

Dissertação para obtenção do Grau de Doutor em
Digital Media

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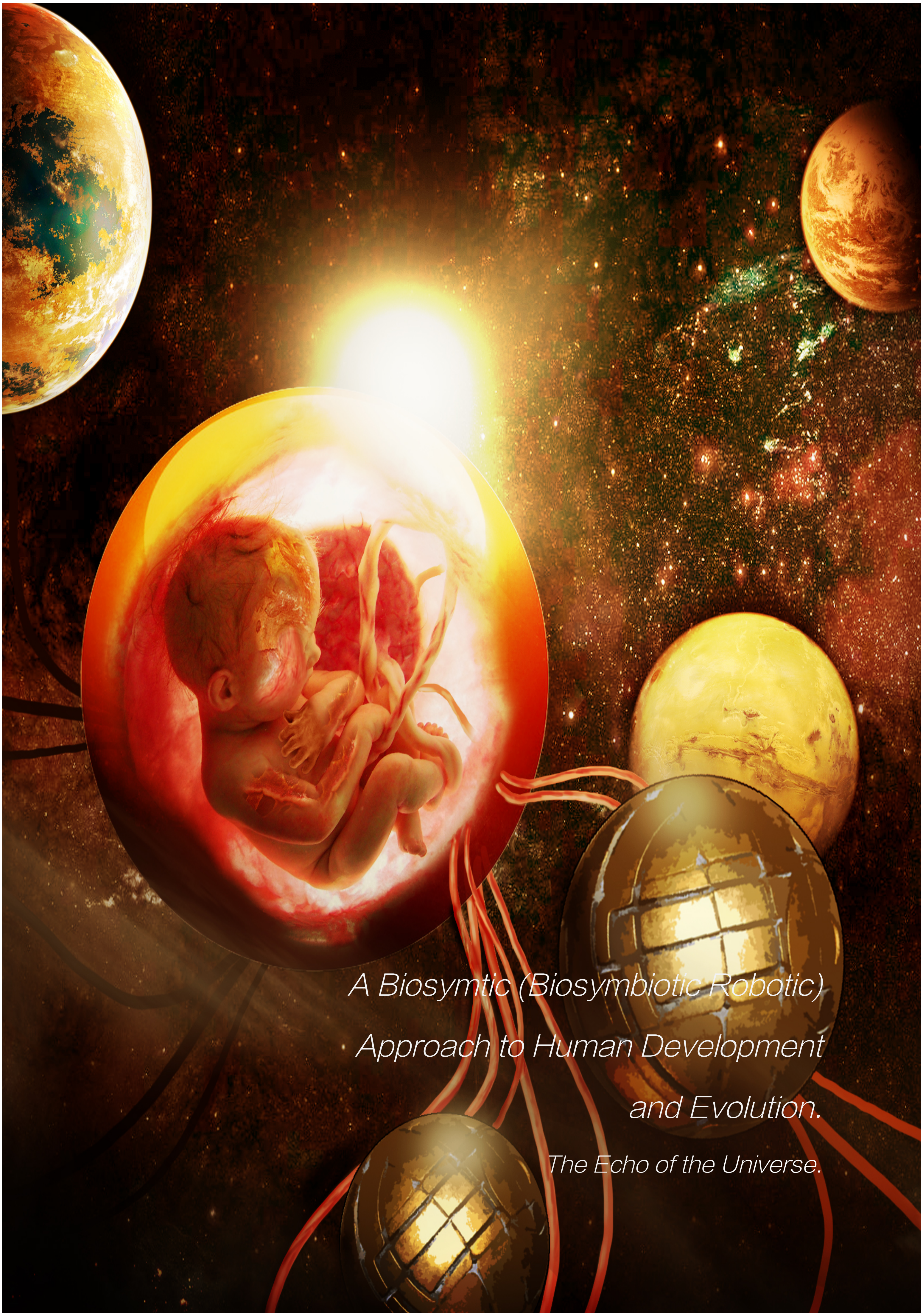
A Biosymtic (Biosymbiotic Robotic) Approach to Human Development and Evolution. The Echo of the Universe. Part I.



A Biosymtic (Biosymbiotic Robotic) Approach to Human Development and Evolution.

The Echo of the Universe.

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This work is dedicated to my father António.

Eugénia Ferraz, Amélia Paiva, São Ferraz.

Children of the Universe. Taking off and landing over cosmic clouds.

ST. Andrew's Episcopal School and education representatives for all the support and shared joyful moments.

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Abstract

In the present work we demonstrate that the current Child-Computer Interaction paradigm is not potentiating human development to its fullest – it is associated with several physical and mental health problems and appears not to be maximizing children's cognitive performance and cognitive development. In order to potentiate children's physical and mental health (including cognitive performance and cognitive development) we have developed a new approach to human development and evolution. This approach proposes a particular synergy between the developing human body, computing machines and natural environments. It emphasizes that children should be encouraged to interact with challenging physical environments offering multiple possibilities for sensory stimulation and increasing physical and mental stress to the organism.

We created and tested a new set of computing devices in order to operationalize our approach – Biosymtic (Biosymbiotic Robotic) devices: "Albert" and "Cratus". In two initial studies we were able to observe that the main goal of our approach is being achieved. We observed that, interaction with the Biosymtic device "Albert", in a natural environment, managed to trigger a different neurophysiological response (increases in sustained attention levels) and tended to optimize episodic memory performance in children, compared to interaction with a sedentary screen-based computing device, in an artificially controlled environment (indoors) - thus a promising solution to promote cognitive performance/development; and that interaction with the Biosymtic device "Cratus", in a natural environment, instilled vigorous physical activity levels in children - thus a promising solution to promote physical and mental health.

Keywords: Child-Computer Interaction, human development and evolution, physical and mental health, cognition, biosymtic robotics, natural environments.

Resumo

No presente trabalho é demonstrado que o paradigma atual na Interação Criança-Computador não está a potenciar desenvolvimento humano na sua totalidade – está associado a uma variedade de problemas físicos e mentais e parece não estar a maximizar o desempenho e desenvolvimento cognitivos em crianças. No presente trabalho foi desenvolvido um novo método para o desenvolvimento e evolução humana de forma a potenciar saúde física e mental nas crianças (incluindo performance cognitiva e desenvolvimento cognitivo). Este método integra um modo particular de conexão entre o corpo em desenvolvimento, máquinas computacionais e ambientes naturais. O último enfatiza que as crianças devem ser encorajadas a interagir com ambientes físicos desafiadores oferecendo múltiplas possibilidades de estimulação sensorial e aumentando o stress físico e mental no organismo.

Criámos um novo conjunto de dispositivos tecnológicos de forma a operacionalizar o nosso método – dispositivos Biosymtic (Biosymbiotic Robotic), "Albert" e "Cratus". De dois estudos realizados constatámos que o objetivo central do nosso método está a ser atingido. Verificámos que a interação com o dispositivo Biosymtic "Albert", num ambiente natural, causou uma resposta neurofisiológica diferente (aumentos nos níveis de atenção sustentada) e tendeu a optimizar a memória episódica em crianças quando comparado com interação com um dispositivo computacional sedentário num ambiente artificialmente controlado (de interior) - daí ser uma solução promissora para promover performance cognitiva e desenvolvimento cognitivo; e que a interação com o dispositivo Biosymtic "Cratus", num ambiente natural, promoveu níveis de atividade física vigorosa em crianças – daí ser uma solução promissora para promover saúde física e mental.

Palavras-chave: Interação Criança Computador, desenvolvimento e evolução humana, saúde física e mental, função cognitiva, biosymtic robotics, ambientes naturais.

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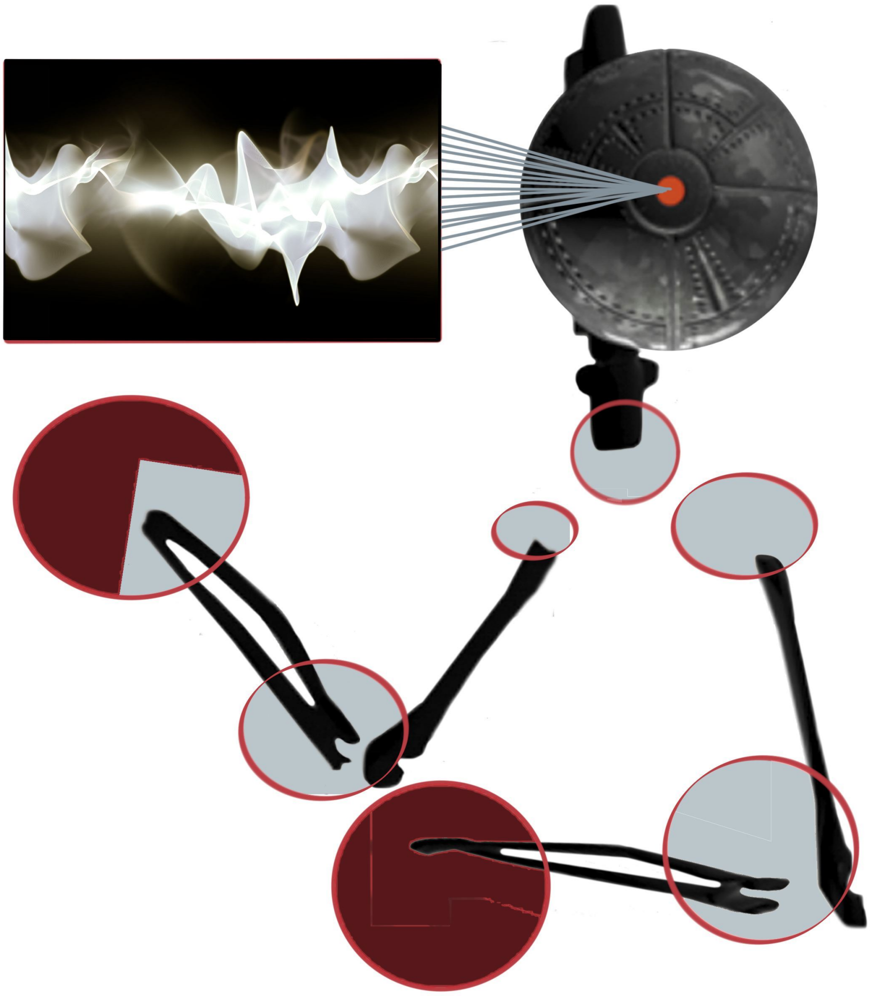
1

Introduction (problem)



"With every tool man is perfecting his own organs, whether motor or sensory, or is removing the limits to their functioning. Motor power places gigantic forces at his disposal, which, like his muscles, he can employ in any direction… Man has, as it were, become a kind of prosthetic god. When he puts on all his auxiliary organs, he is magnificent; but these organs have not grown on him, and they still give him trouble at times."
Freud (1930:37-39)

1.1 In the roots of human evolution

It seems clear that the human body has evolved through space and time as an active organic machine. In fact, during millions of years Hominids needed to move in order to survive.

Hominids are bipedal creatures; they move by means of its two rear limbs. Bipedal creatures evolved from their ape ancestors that moved by using four limbs. Bipedalism occurred due to environmental changes that caused a scarcity of food in the common habitat of apes. It appeared as an advantageous evolutionary adaptation that allowed the survival of our ancestors (by allowing Hominids to search for food in new physical settings).

Bipedalism is considered the major adaptive transformation of the past million years. It allowed for Hominids (namely the genus *Homo*) to become hunter-gatherers approximately two million years ago. Hunter-gatherers had to deal with challenging physical environments while they walked and ran relatively long distances to get food (e.g., escape from and hunt predators; a dangerous river to cross; fight). While hunter-gatherers had to trek "at least 6 kilometers (nearly 4 miles)" a day to gather a variety of food (e.g., fruits, tubers, meat and other foods that represented increased caloric intake), apes had to travel "just 2 to 3 kilometers (about 1 to 2 miles) a day to collect enough food by simply picking the edible fruits and leaves they encounter" (Lieberman, 2013:88).

In order to catch a meat meal, hunter-gatherers developed cautious and calculated strategies to catch their prey. Because preys were usually faster, hunter-gatherers developed a persisting method to hunt. This method consisted of running and chasing a prey strategically to the point of exhaustion - that ended up collapsing by overheating.

Since hunter-gatherers were slower and less agile compared to their quadruped ancestors (who were able to gallop and climb trees) they became efficient long distance runners in order to hunt and gather food (namely *Homo erectus*). Increased efficiency in walking and running in a multitude of challenging environments was accompanied by multiple structural and functional body modifications. For instance, longer legs (to reduce the cost of walking); enlarged hip, knee and ankle joints (to support body weight); developed feet arch and short toes (to support efficient walking and running); long-limbed body-shade supporting sweating mechanisms (to cool down in hot habitats); projected external nose (to humidify the air); short necks (to keep their gaze stable during movement); and enlarged sensory organs for balance.

These body modifications allowed hunter-gatherers not only to walk efficiently but also "to run long distances at moderate speeds in hot conditions" and thus facilitating their quest for food and survival (Lieberman, 2013:84).

Hunter-gatherers developed new communication skills – verbal language. These skills facilitated their quest for survival by allowing better planning and execution of hunting and gathering strategies (collaborative strategies).

Bipedalism allowed for hunter-gatherers to free their hands from quadruped locomotion. Through manipulative actions, hunter-gatherers started to create and use physical tools that facilitated the extraction and processing of food (food in small pieces and cooked was easiest to digest and represented increased caloric intake). Physical tools were also crucial to fight against predators (Darwin, 1871). The use of physical tools has been interpreted as a strong factor for cognitive evolution (Ambrose, 2010; Shubin, 2009, 2013; Stout, 2009, 2010) (see fig.1).

Hunter-gatherer children were physically active creatures. They contributed to group tasks by working during an hour or two per day, "mostly foraging, hunting, fishing, collecting firewood, and helping with domestic tasks such as food processing" (Lieberman, 2013:225). Besides, they had to follow the nomadic lifestyle of their group. These children took extra time to mature compared to ape offspring. This represented and extended juvenile period occurring after weaning and before total growth of the brain - approximately from 3 to 6 years of age. It seems that a prolonged maturation period meant more time to develop bigger brains, and thus, more time to shape a variety of neuronal networks in support of cognitive function (see fig.2).

Hunter-gatherer children spent most of their time actively exploring information from the physical world, particularly from natural physical settings[1]. Researchers point out that real world settings (outside the highly controlled indoor environments) include a variety of sensory information to be processed by the agent - e.g., stimulating the visual, auditory, chemical, cutaneous, proprioceptive and vestibular senses (Calvert et al., 2004; Posner, 2012)[2]. Hence, natural physical settings offered a variety of sensory information to hunter-gatherer children.

Curiously, hunter-gatherers were the only creatures in the history of Hominids to double the size of their brains. This unique event happened during the Ice Age period - an extreme climatic epoch (sharp decline in temperature) occurring approximately 2.5 million years ago. This epoch generated extreme environmental conditions with which Hominids had to interact (Lieberman, 2013).

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1. According to Wilson (2002), cognition is an evolutionary process resultant from voluntary guided action
2. According to Calvert et al. (2004:11), everyday environments, outside the highly controlled indoor environments, engender "a constant influx of sensory information in most of the sensory pathways".

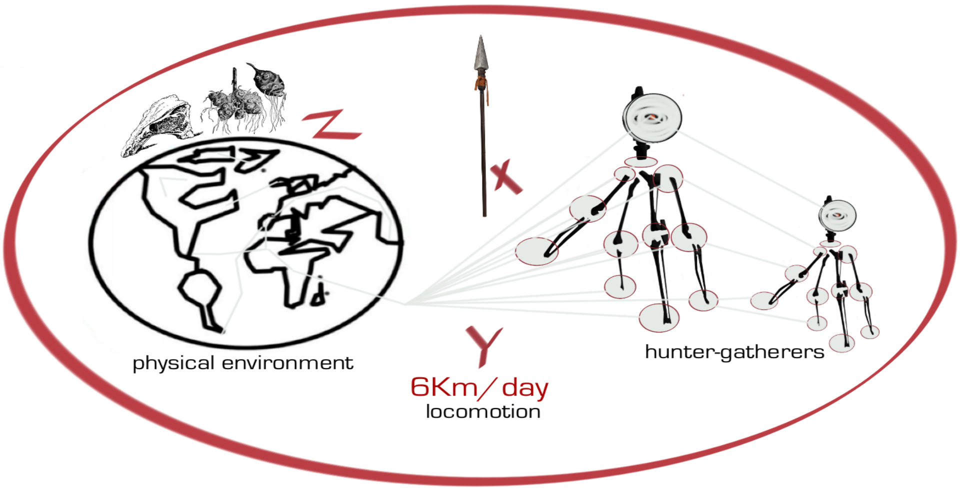

Fig. 1. Hunter-gatherers. During millions of years hunter-gatherers needed to move in the physical environment in order to survive ("Y"). Hunter-gatherers created and used physical tools ("X") to interact with the physical world ("Z").

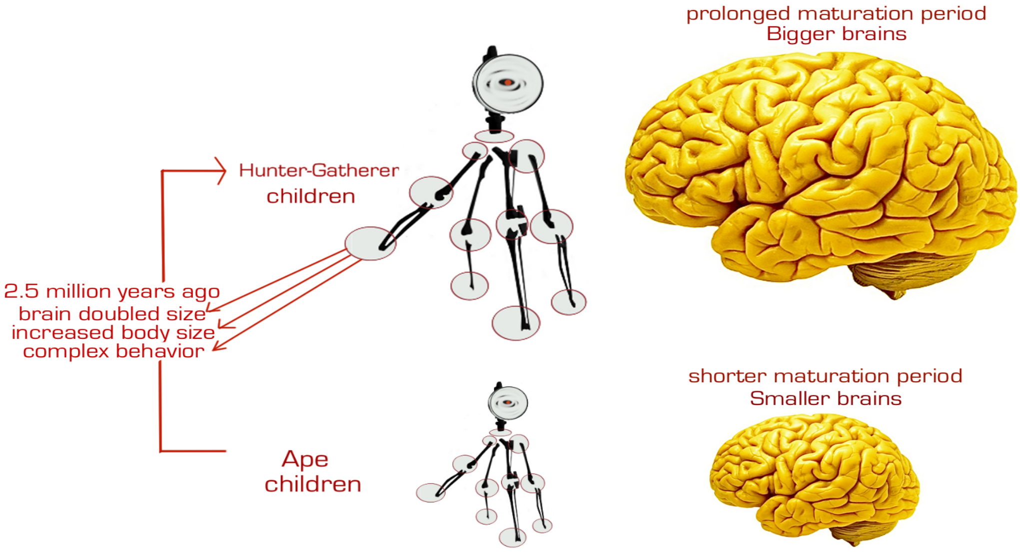

Fig. 2. Comparison between hunter-gatherer and ape children. Hunter-gatherer children had a prolonged maturation period, increased body size, bigger brains and demonstrated more complex forms of behavior when compared to ape children.

In essence, bipedalism represented major biological and behavioral transformations in Hominids. It was coupled with the emergent abilities to hunt and gather, the development of new communication skills and the creation and use of physical tools. Bipedalism enabled an increased caloric intake in Hominids, who grew bigger bodies and brains (also due to prolonged maturation periods compared to apes). The development of hunting and gathering strategies contributed to the emergence of more complex forms of behavior. All these transformations led to an increase in the complexity of the structural and functional processes of the body, facilitating the survival of the genus *Homo* and supporting reproductive success.

Remarkably, major biological and behavioral changes in Hominids happened due to interactions with challenging physical environments (Ambrose, 2010; Lieberman, 2013; Llinas, 2001; Organ et al., 2011; Potts, 2012; Shubin, 2009; Stout, 2009; Striedter, 2006).

Interestingly, the structural features of the body of hunter-gatherers still have many similarities with those that we, *Homo sapiens sapiens* have nowadays, albeit presenting slight differences. For instance, modern humans have more curved lower backs, smaller teeth and faces, a more spherical head and bigger temporal and parietal lobes compared to Neanderthals.

On the other hand, modern humans seem to have developed new communicative, cooperative and inventive abilities. The emergence of these abilities has been accompanied by a strong decline in physical activity (PA) in modern humans, who tend to be less physically active compared to their ancestors (Cordain et al., 1998; Lieberman, 2013) - particularly with the arrival of the Digital Age. This PA decline has sparked multiple physical and mental health problems in modern humans, namely in children (American Academy of Pediatrics 2001; Anderson et al., 2010; Center for Disease and Prevention Control, 2010, 2012, 2012; Chang et al., 2012; Cleary et al., 2002; Cornwell, 2008; Cranz, 1998; Eong et al., 1993; Ferguson, 2013; FreedHoff, 2012; Gentile, 2009; Griffiths, 2002; Jensen, 2000; Lui et al., 2011; Mazurek & Engelhardt, 2013; Morgan & Rose, 2005; Paavonen et al, 2006; Rajakumar, 2003; Reichhardt, 2003; Rose et al., 2008; Small & Vorgan, 2008; Swing et al., 2010; Tremblay, 2012; Wallace, 2012; Ward, 2013; Wiegman, 1998).

Hunter-gatherer children spent most of their time interacting with natural environments. Conversely, modern children spend most of their time in artificially controlled environments (ACE; indoors) interacting with digital devices instilling sedentary behavior (e.g., Byron Review, 2008; Commomn Sense Media, 2011; Houses of Parliament, 2012; NPD Group, 2011; PEW Research Center 2009; Rideout et al., 2010).

Multiple physical and mental health problems in modern children are in great part associated with maladaptation to sedentary environments (Lieberman, 2013).

1.2 A biologically altered metropolis

> *"Human existence has undergone many profound changes over the last few million years, but never has so much change occurred so rapidly in the last 250 years…a true blink of an eye by the standards of evolutionary time. Industrial Revolution also changed everyone's bodies. It changed what we eat, how we chew, how we work, and we walk and run as well as how we keep cool and warm, give birth, get sick, mature, reproduce, grow old, and socialize."*
>
> *Lieberman (2013:238)*

The Industrial Revolution of the 18th century brought great scientific and technological progress to the world. One of the remarkable achievements refers to the process of generating electrical energy through the combustion of fossil fuels (coal) to power mechanical machines in factories. Those machines supported large-scale production of raw materials that serve the needs of growing populations in urban settings. The "mechanical revolution" of the 18th century profoundly altered the way modern humans coped with their bodies, particularly children.

At the beginning of the Industrial Revolution children's daily activities were directed to work in factories. Children bellow the age of 13 had to perform demanding physical labor approximately 12 to 14 hours a day. Their work activities were confined to the control of mass production mechanisms - operating heavy machinery by using repetitive motor actions (Lieberman, 2013). Children were encouraged to perform more controlled formats of bodily action compared to hunter-gatherer children - who actively and freely explored the physical world.

During the late 20th century - with the advent of personal computers in the 1970s - another major shift occurred regarding children's bodily interactions with the physical world. Personal computing machines have superseded physically demanding labor in factories. Children in the Digital Age are in great part attuned to sedentary activities - wether educative or leisure activities.

Modern children spend most of their time sitting still while interacting with digital devices in ACE. Children also move around the physical space by using transportation machines (e.g., cars, airplanes, fast trains, elevators, escalators). This type of behavior is associated with a sedentary lifestyle and has significantly decreased the possibility for active exploration of the physical environment; that is whole-body interactions with the physical world.

Hunter-gatherer children shared their labor and leisure activities with small groups, used physical tools and presented high levels of mobility in multisensory natural environments. On the other hand, modern children have sedentary lifestyles, use digital devices to share experiences in vast groups (virtual means), live in fixed spaces (urban settings with high-population density rates) and present low levels of mobility in the physical environment. Additionally, there was a huge shift in the diets of modern children compared to hunter-gatherer children - transitioning from low-caloric high-quality food to high-caloric low-quality food (now richer in fat, starch, sugar and salt and lower in fibers) (see fig. 3).

Significant changes in PA and diet formats have lead to a cycle of "dysevolution" in modern children. Daniel Lieberman (2013:192), a renowned paleoanthropologist at Harvard University, developed "the hypothesis of evolutionary mismatch" to explain this cycle of "dysevolution". Accordingly, genes in modern humans that "were selected over the previous few hundreds, thousands, or even millions of generations" and have improved our "ancestor's abilities to survive and reproduce under certain environmental conditions" are now instilling a cycle of noninfectious mismatch diseases due to maladaptation to abrupt changes in environmental conditions.

Sedentary environments, low-quality food and artificially created climatic changes (fast and harmful environmental changes) are linked to noninfectious mismatch diseases in modern humans. For example, neurological disorders[3] (e.g., ADHD, anxiety, depression); cardiovascular disorders[4] (e.g., coronary heart disease); metabolic disorders (e.g., obesity, type 2 diabetes); musculoskeletal disorders (e.g., reduced bone density, lower back pain, rickets); visual disorders (e.g., myopia); allergies; and some types of cancer.

The current human genome has not change significantly over the past 400,000 years; nonetheless, the average energy expenditure per unit of body mass is modern humans is less than 38% compared to that of early Hominids. This significant decrease in energy expenditure correlates with sedentary lifestyles and thus with increased body fat mass levels in modern humans - both detrimental to health. Researchers have been pointing that modern humans have an energetic imbalance – "our bodies are inadequately adapted to cope with restless supplies of excess energy" that we do not spend (Cordain et al., 1998; Lieberman, 2013:283).

Modern medicine has entered a long quest to reduce mortality rates and increase longevity in modern humans (microbiology research); still, "lower rates of mortality have been accompanied by higher rates of morbidity (defined as a state of ill health from any form of disease)" all over the world (Lieberman, 2013:266, 273). High morbidity rates are associated with the emergence of noninfectious mismatch diseases - considered the main cause of disability and death in the 21st century.

Nowadays, modern humans tend to make use of prescriptive drugs to mitigate and treat mismatch diseases rather than adopting a preventive approach. The major problem is that prescriptive drugs contribute to the high-prevalence of noninfectious mismatch diseases from one generation to another. According to Lieberman (2013:330), "when we then fail to prevent the causes of these diseases we allow the pernicious

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3. Schaffer et al. (2014) identified a new genetic disorder in children caused by a gene mutation - CLP1 gene. This disorder is associated with sensory and motor defects, reduced brain size (including signs of neuronal death) and brain malformations (including intellectual disabilities and speech impairments).

4. There are no references to cardiovascular disorders in hunter-gatherers.

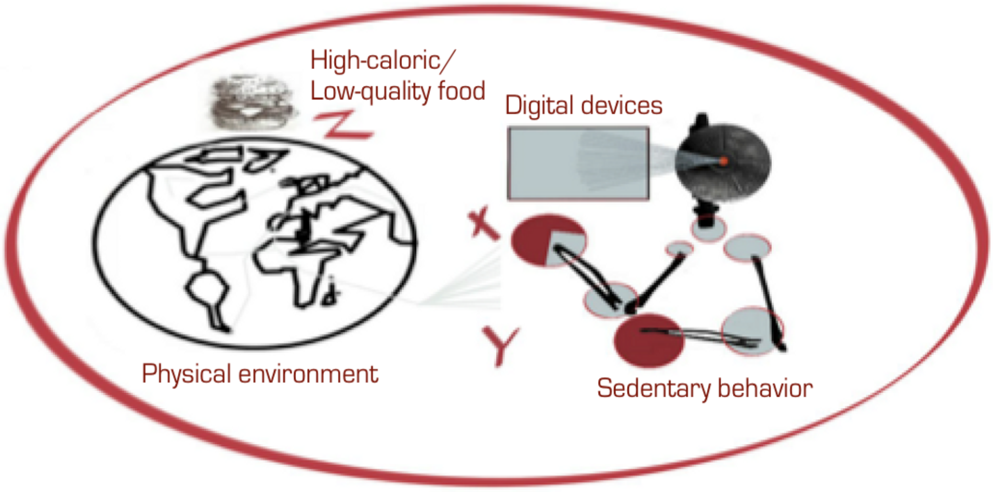

Fig. 3. Digital Age. Modern children spent most of their time interacting with digital devices that instill sedentary behavior ("X"), have reduced contact with the physical environment ("Y") and ingest high-caloric low-quality food ("Z").

feedback loop of dysevolution to occur in which we pass on the same environment to our children, enabling the disease to remain common or grow in prevalence".

In reality, we are passing a cycle of "dysevolution" to our children through our cultural habits translated in low levels of PA, bad nutrition and prescriptive drugs. Instead of preventing noninfectious mismatch diseases we mitigate and treat its symptoms with prescriptive drugs. These drugs don't alter the disease-inducing environmental conditions that our children experience.

PA and a good diet work as preventive medicine by reverting the body's energy imbalance – and thus avoiding the prevalence of noninfectious mismatch diseases. For example, PA and a good diet are twice effective than the most popular drugs (e.g., metformin) in treatment and mitigation of type 2 diabetes symptoms and do not cause nasty side effects (Lieberman, 2013). Further, since noninfectious mismatch diseases originate from multiple causes (e.g., lack of PA, poor diet, emotional stress), and are represented by a variety of genes suffering constant environmental interference, it becomes highly difficult to treat them with prescriptive drugs or gene therapy. In fact, there are no permanent cures yet to noninfectious mismatch diseases.

Moreover, preventive medicine can reduce economic costs all over the world. For instance, the United States spends more than two trillion dollars a year treating noninfectious mismatch diseases with prescriptive drugs. Russo (2011) stated that 70 % of these mismatch diseases are preventable. According to Lieberman (2013:396), “spending $10 per year per person in community-based programs that increase PA, prevent smoking, and improve nutrition would save the United States more than $16 billion per year in health-care costs within five years”.

Sedentary lifestyles plus a huge shift in modern diets and artificially created climatic changes are the main factors contributing to the high-prevalence of noninfectious mismatch diseases in modern children.

Sedentary behavior is associated with the emergence of sedentary (or passive) screen-based computing devices (SBCDs) in the last decades of the 20th century. Furthermore, the emergence of this type of devices represents a profound transformation in the way the human body processes information from the environment. The human body changed from an active organic machine connected to enhanced sensory environments (interactions with natural environments stimulating the body’s multiple sensory systems), to a sedentary organic machine connected to restricted sensory environments (interactions with sedentary SBCDs, in ACE, and stimulating mostly the visual and auditory senses).

The next subchapter describes the mental and physical health problems in children linked to the use of sedentary SBCD’s in ACE. In addition, it will be demonstrated that this type of devices may fail to maximize cognitive development/performance.

1.3 Sedentary screen-based computing devices are associated with several mental and physical health problems in children

In the 21st century children’s daily activities became, to a large extent, digital. Devices such as TVs, laptop computers, tablets, smartphones, among others, are now the favorite toys of young generations. Children in developed countries access media-saturated environments at home and educational settings (Berson & Berson, 2010; Byron Review, 2008; Commomn Sense Media, 2011; Calvert et al., 2005; Houses of Parliament, 2012; Kline, 2004; McDonough, 2009; NPD Group, 2011; PEW Research Center 2009; Rideout et al., 2010; Roberts & Foehr, 2008, Tremblay et al., 2011; Vandewater & Lee, 2009).

Sedentary SBCDs encourage children to experience a multitude of visual-auditory information-gathering scenarios, such as multimedia environments combining still images, video, text and audio. Children may share these multimedia environments with few geographical limitations - through the World Wide Web. Children communicate with sedentary SBCDs through the use of interfaces requiring hand-eye coordination skills (e.g., “keyboard”; “mouse”; “tactile displays”). For example, “tap”, “drag”, “slide”, to control visual contents on a two-dimensional display.

One example that highlights the growing worldwide implementation of sedentary SBCDs in the 21st century is the project "One Laptop Per Child initiative" carried out by the Massachusetts Institute of Technology (MIT). This project aimed at providing a laptop to children aged 6 to 12 years all over the world - involving two million children and teachers. The associated mission was, and still is, to "empower the world's poorest children through education"[5].

Children may also communicate with SBCDs through the use of biofeedback interfaces (e.g., Bonfield et al., 2013; Mandryk et al., 2013). These interfaces capture physiological data from users in order to enhance human-computer experiences. For instance, heart rate, brain electrical activity, galvanic skin response, is used as an input to control visual and auditory data on a two-dimensional display.

Researchers showed that sedentary SBCDs, in ACE, are associated with improvements on children's cognitive function. For instance, sedentary video game play trough the use of "keyboard" and "mouse" interfaces is associated with improvements in attentional control, selective attention (particularly action video games) (e.g., Dye & Bavelier, 2010; Green & Bavelier, 2003, 2009, 2010, 2012), creativity (e.g., Jackson et al., 2012) and virtual social skills in children (e.g., Granic et al., 2014)[6].

Some studies also demonstrate that sedentary video games integrating brain-computer interfaces - biofeedback games - tend to improve children's cognitive function; particularly by reaching the therapeutic goals of decreasing ADHD symptoms (hyperactivity/impulsivity symptoms; improving memory recall) and improving attentional control in children with Fetal Alcohol Spectrum Disorder (Bonfield et al., 2013; Mandryk et al., 2013)[7].

On the other hand, researchers have been demonstrating that the overuse of sedentary SBCDs is associated to a diversity of physical and mental health complications in children (e.g., American Academy of Pediatrics 2001; Anderson et al., 2010; Center for Disease and Prevention Control, 2010; 2011; 2012; Chang et al., 2012; Cleary et al., 2002; Cornwell, 2008; Cranz, 1998; Eong et al., 1993; Ferguson, 2013; FreedHoff, 2012; Gentile, 2009; Griffiths, 2002; Jensen, 2000; Lui et al., 2011; Mazurek & Engelhardt, 2013; Morgan & Rose, 2005; Paavonen et al, 2006; Rajakumar, 2003; Reichhardt, 2003; Rose et al., 2008; Small & Vorgan, 2008; Swing et al., 2010; Wallace, 2012; Ward, 2013; Wiegman, 1998).

According to a recent survey from the Kaiser Foundation (2010), the amount of time children spend with digital media has increased substantially in recent years. U.S children aged 8-18 years are exposed to screen-based technology for an average of approximately 7.5 hours per day - including TV, computer devices, video games and cell

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5. http://one.laptop.org/about/mission
6. More on this topic in http://biosymticrobotics.com/resources/MWPICC_FERRAZ.pdf
7. More on this topic http://biosymticrobotics.com/resources/MWPICC_FERRAZ.pdf

phones (Rideout et al., 2010). Children aged 2 to 5 years spend approximately 32 hours week interacting with TV, DVD, DVR and video game devices[8] (McDonough, 2009).

Children are among the highest users of mobile technologies for information access. Fastest growth has been observed in children aged 2 to 5 years[9]. In addition, video game play became an increasing activity in children's daily lives, particularly sedentary video game play (Fleuriot et al., 2005; NPD Group, 2011; Rideout et al., 2010).

Rideout et al. (2010) performed a gaming survey in cooperation with the Kaiser Family Foundation[10] involving young people in the U.S. Accordingly, 91% of U.S. children (approximately 64 million) aged 2 to 17 years plays video games. As stated by the authors, "In a typical day, 8- to 18-year-olds spend an average of 1:13 playing video games on any of several platforms: console players (:36), handheld players such as a Nintendo DS, a Sony PSP, or an iPod (:21), and other devices such as cell phones (:17). On any given day, 60% of young people play video games, including 47% who play on a handheld player or a cell phone, and 39% who play on a console player. Those who do play spend an average of almost two hours (1:59) at the controller across all platforms."

In the U.K., 5 to 16 year olds play video games an average of 1.5 hours a day. "After the USA and Japan, the UK games market is the third largest in the world" (Houses of Parliament, 2012:3).

Therefore, sedentary SBCDs are nowadays the main tools used by children to access and interact with virtual information. Controversially, in order to avoid health complications, the American Academy of Pediatrics (2010, 2011a, 2011b) recommends no screen media for children under the age of 2, and a maximum of one to two hours a day of screen media in children aged 6 to 18 years.

Sedentary SBCDs are associated with low levels of PA in children - sedentary behavior (Center for Disease and Prevention Control, 2010, 2011, 2012). Sedentary behavior is characterized by diminished or complete lack of PA and is one of the main factors negatively influencing children's health. It correlates with obesity - a chronic disease characterized by excessive body fat accumulation (i.e., when body mass index is equal or higher than percentile 95[11]), resultant from behavioral, genetic, biochemical and cul-

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[8] According to the "Global entertainment and media outlook: 2013-2017", in the next five years sedentary video games will increase at a compound annual growth rate (CAGR) of 6.5%, attaining US$86.9bn in 2017 (surpassing the 2012 US$63.4bn rates). The mobile sector will have the highest predicted growth by 2017: US$8.8bn in 2012 to US$14.4bn in 2017 (Price Waterhouse Coopers, 2013).

[9] https://www.npd.com/wps/portal/npd/us/news/press-releases/pr_111011/

[10] http://files.eric.ed.gov/fulltext/ED527859.pdf

[11] There is a strong correlation between cardiovascular diseases, obesity and mortality rates. When body mass index is greater than or equal to 30 kg/m2, mortality rates increase from 50% to 100% (Rowland & Bar-Or, 2004). Obesity has been linked to poor academic achievement in children (e.g., Taras & Potts-Datema, 2005).

tural factors (Cole, 2000). There is a high correlation between sedentary behavior and the increasing rates of overweightness and obesity in children (Nieman, 1999; Rowland & Bar-Or, 2004; World Health Organization, 2010).

According to the World Health Organization (2010), more than 40 million children under the age of five are overweight - 35 million living in developing countries (urban settings in low-income and middle-income countries are the ones majorly affected). Obesity is now considered a worldwide epidemic. Current statistics suggest that in the next decades the number of deaths in younger generations caused by obesity will outnumber the number of deaths caused by starvation worldwide (Rowan, 2010). Younger generations that engage in sedentary behavior may not live longer than their parents (Fontaine et al., 2003).

In 2004, the Center for Disease Control and Prevention (CDC) demonstrated that 16% of U.S children aged between 6 and 19 years were overweight or obese due to nutritional habits and sedentary behavior (tripling since 1980) - a value that rose 17% in 2012[12][13]. The CDC associates sedentary behavior and bad nutrition to the increased use of screen-based computing devices (Center for Disease and Prevention Control, 2010, 2011, 2012).

Sedentary behavior is related with developmental delays (Hamilton, 2006; Zimmerman, 2007). It correlates with mental disorders (e.g., ADHD; anxiety; depression); musculoskeletal disorders (e.g., osteoporosis; mobility and postural problems); metabolic disorders (obesity; type 2 diabetes); cardiovascular disorders (high cholesterol; hypertension); cardiorespiratory disorders (breathing difficulties); sleep disorders (e.g., sleep apnea); and digestive disorders (e.g., gastro-esophageal reflux). This type of behavior has also been linked to increased cancer risk (e.g., colorectal, endometrial, ovarian and prostate cancer) and premature death (American Medical Association, 2013; Center for Disease and Prevention Control, 2012; WHO, 2010).

In fact, overuse of sedentary SBCDs is associated with obesity; incorrect body posture; tendonitis; hand-arm vibration syndrome (video games including vibration interfaces); reduction of physical and emotional awareness; physical fatigue; visual problems (e.g., photosensitive epilepsy); motion sickness; poor fitness; attention problems; hyperactivity; addictive and aggressive behaviors; anxiety and greater risk for depression; poor self-esteem; sleep disorders; and attachment and obsessive-compulsive disorders (e.g., American Academy of Pediatrics 2001; Anderson et al., 2010; Chang et al., 2012; Cleary et al., 2002; Cranz, 1998; Cornwell, 2008; Ferguson, 2013; Gentile, 2009; Griffiths, 2002; Lui et al., 2011; Paavonen et al, 2006; Reichhardt,

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[12] http://www.cdc.gov/nchs/data/hus/hus04trend.pdf

[13] According to the American Medical Association (2013), childhood obesity in the U.S grew extra than the threefold in the last 30 years.

2003; Small & Vorgan, 2008; Swing et al., 2010; Tremblay et al., 2011; Wallace, 2012; Wiegman, 1998). According to Ward (2013), children under the age of 4 are becoming so addicted to smartphones and "iPads" that necessitate mental therapy.

While interacting with sedentary SBCDs children are encouraged to remain seated for long periods of time. Sitting in chairs for more than ten minutes is associated with reduced body awareness and physical fatigue (Cranz, 1998). Prolonged sitting relates to deficits in breathing, spinal and lower back dysfunction, muscle's deterioration and poor vision (Zacharkow, 1988).

Swing et al. (2010) showed that children who exceeded 2-hours day of screen time (TV or video game play) were 1.5 to 2 times more likely to develop attention problems (reports from parents, children and teachers). This study integrated 1323 children in fourth, fifth and six grades. Wallace (2012) investigated the impact of video game play habits in attentional functioning in a group of 105 children (third and six grades). A significant correlation was found between the number of hours playing action video games and symptoms of inattention and hyperactivity.

A recent study demonstrated that boys with ADHD (n= 44) or autism (n=56) tend to exhibit increased signals of addictive video game behavior compared to neurotypical boys (n= 41). Boys with ADHD played video games for an average of 1.7 hours a day; boys with autism for an average of 2.1 hours a day; and neurotypical boys for an average of 1.2 hours a day (Mazurek & Engelhardt, 2013).

Multitasking computer programs in sedentary SBCDs have been linked to aggressive behaviors in children. Aggressive behaviors have been explained through the "Techno-brain burnout" hypothesis developed by Small & Vorgan (2008). Accordingly, while using multitasking computer programs children engage in a continuous state of partial attention that causes high levels of stress in the brain - translated in high levels of cortisol and adrenaline production on the adrenal gland. The authors refer that high levels of cortisol and adrenaline can "actually impair cognition" and "lead to depression". High levels of cortisol and adrenaline can impair "the neural circuitry in the hippocampus, amygdala, and PFC[14] that control mood and thought, and can even reshape brain structure".

Small & Vorgan (2008) also refer that by using multitasking computer programs "children are now prone to instant gratification that leads them to trouble when thinking ahead to the future". Children "have shorter attention spans, specially if we put them in front of a teacher".

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14. Prefrontal cortex.

Sedentary SBCDs are also linked to the reduction in number of facial expressions due to increased focus on 2D displays - facial muscle work drops after 30 minutes of interaction with these devices (Small & Vorgan, 2008). Facial expressions clarify emotional states and optimize human communication (including whole body communication) (Dael et al., 2012; Nummenmaa et al., 2013). Furthermore, face-to-face and body-to-body interaction (physical contact) tends to be impaired by continuous attention on a 2D display - weakening the channels of bodily communication. Children who lack human physical contact are more prone to developing anxiety, depression and aggressive behaviors (Montagu, 1972).

Furthermore, children who become restricted to the use of hand-eye coordination skills - fine motor skills: small muscular groups and precise actions - to interact with SBCDs, may compromise motor development in its entirety. These devices do not encourage gross motor skills practice - large muscular groups and less precise actions; e.g., walking, running, jumping. Motor development relates to the ability to control and direct voluntary muscle movement (e.g., Gallahue & Ozmun, 2005; Payne, 1995).

While interacting with sedentary SBCDs children are encouraged to continuously focus their gaze on a two-dimensional display. This type of behavior compromises the eye's ability to perform distant light focus. While focusing on nearby images during long periods of time the lens in the eyes become more convex in order to send information into the retina. In turn, the retina sends electric signals to the brain. On the other hand, if the eyes need to focus on distant images the lens becomes more flattened. Repetitive focusing on nearby images makes the eyeballs grow longer, making the lens fall short from the retina - what makes distant focus a difficult task (namely beyond 2 meters). This repetitive motor behavior of the eyes is related to chronic visual problems such as myopia, cataracts and retinal degeneration. In fact, children who spend many hours focusing on nearby objects tend to elongate their eyeballs permanently and thus to become myopic (Grosvenor, 2007).

Due to the increased use of sedentary SBCDs children's play activities turned from largely physical in natural settings to largely sedentary in indoor settings (Louv, 2006).

Natural bright light in outdoor environments helps children to develop their visual system (structure and function). Donald Mutti (2007) concluded that children (n=514; third grade) who spend great amounts of time in indoor environments are likely to become nearsighted compared to children that spend great amounts of time outdoors. Nearsightedness is a chronic disease with increasing prevalence in the last decades.

In outdoor environments, sun light exposure offers 32,000 to 130,000 lux of light intensity to the human eye - uniformly distributing light in the human eye. Indoor environments offer approximately 1000 lux of light intensity - sometimes 50 lux in focused and unfocused peripheral images. Low intensity of light in indoor environments relates to passive motor behavior in the structure of the eyes and thus to visual developmental problems. In fact, children who live in urban areas tend to have more visual problems throughout development than rural children. In the U.S and Europe, approximately 1/3 of children aged between 7 and 17 years are becoming nearsighted. This rate rises in some Asian countries (Eong et al., 1993; Lieberman, 2013).

Researchers point out that genetic factors have small influence in visual developmental problems – associated with behavioral factors (i.e., continuous focus on nearby events and interactions with indoor environments) (Grosvenor, 2007; Lieberman, 2013; Morgan & Rose, 2005; Rose et al., 2008).

In addition, children who interact with SBCDs, in ACE, lose benefits from natural ultraviolet radiation (B UVB) - vitamin D for blood level normalization, increased bone mineral density and autoimmune disease prevention (FreedHoff, 2012; Tremblay, 2012). Lack of B UVB may result in significant vitamin D deficits leading to "Rickets" - a condition associated with bone deformities and fractures (Rajakumar, 2003).

Additionally, ACE reduce children's contact with germs, diminishing stress on their immune system, which requires contact with germs to properly mature. ACE are also associated with a diminished production of antibodies that protect children from life-threatening pathogens (Lieberman, 2013).

Figure 4 resumes the physical and mental health problems associated with sedentary SBCDs in ACE.

We also suggest that sedentary SBCDs, in ACE, may fail to maximize children's cognitive development and cognitive performance.

Aerobic-based PA and physical exercise (PE), at moderate-intense levels, tend to optimize cognitive function (including academic achievement) and boost cognitive structure in children (post-activity benefits), compared to sedentary conditions (Brown, 1967; Chaddock et al., 2010ab; Davis et al., 2007, 2011; Ellemberg & St-Louis-Deschênes, 2010; Gabbard & Barton, 1979; Grissom, 2005; Hillman et al., 2005, 2008, 2009ab, 2011; Pesce et al., 2009; Sibley & Etnier, 2003; Tomporowski et al., 2003, 2006, 2008).

Preadolescent children who engage in chronic PA/PE demonstrate improvements in IQ, social maturity, cognitive function and academic achievement. For instance, researchers found a positive association between aerobic-based physical fitness and cognitive function - attention functions (e.g., Hillman et al., 2005; 2009a; 2011); a positive association between overall physical fitness and academic achievement (Grissom, 2005); a positive association between vigorous aerobic-based PA requiring complex combination of cognitive skills (e.g., team games, running

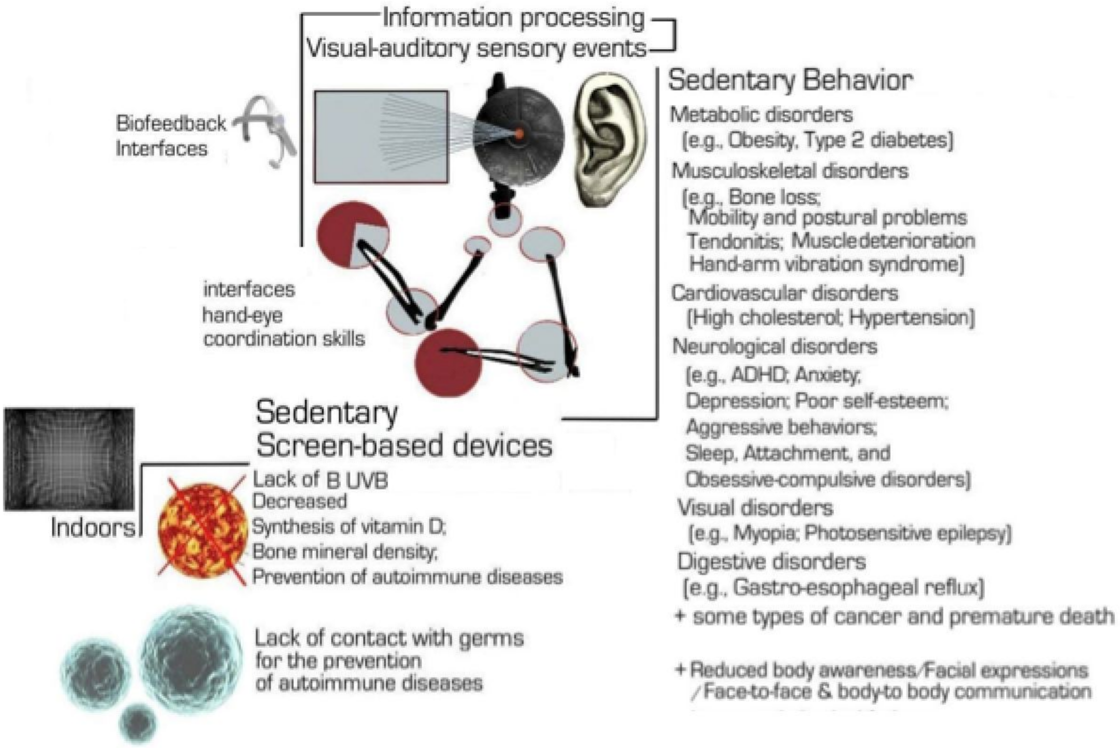

Fig. 4. Physical and mental health problems in children associated with the use of sedentary screen-based computing devices in artificially controlled environments.

games, jump rope) and cognitive function (e.g., planning) and academic achievement (math competence) (Davis et al., 2007, 2011).

Preadolescent children who engage in acute PA/PE demonstrate improvements in cognitive function and academic achievement. For example, improvements in attention, memory and reasoning (Ellemberg & St-Louis-Deschênes, 2010; Gabbard & Barton, 1979; Hillman et al., 2009b, 2011; Pesce et al., 2009)[15].

PA impacts multiple systems in the child's body: sensorimotor system; vestibular system[16]; pleasure-and-reward system; attention and memory systems; sympathetic stress response system; circulatory and neurovascular systems (stressing arteries and veins); and immune system. PA allows the immune system to send white blood cells and antibodies through the body at a faster rate; increases body temperature thus pre-

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[15] More on this topic in http://biosymticrobotics.com/resources/PAECC_FERRAZ.pdf

[16] "encodes self-motion information by detecting the motion of the head in space (…) it provides us with our subjective sense of self-motion and orientation thereby playing a vital role in the stabilization of gaze, control of balance and posture" (Cullen, 2012:185).

venting bacterial growth; may increase the expelling rate of carcinogens (e.g., Jeannerod, 1997; Jensen, 2000).

PA benefits the development of the sensorimotor system by stimulating the proprioceptive, vestibular and visual channels (e.g., improves postural and balance control; coordination between body movement and the visual system; optimizes the development of binocular vision and spatial learning); increases motivation and reduces anxiety and depression by raising the levels of serotonin (5-HT), norepinephrine (NE) and dopamine (DA); boosts self-esteem (raising levels of 5-HT and DA); it is associated with the reduction of ADHD symptoms; benefits cognitive function in children with cerebral palsy (Braswell & Rine, 2006; Gallaue & Ozmun, 2005; Jensen, 2000; May-Benson & Cermark, 2007; Montagu, 1972; Neto, 2003; Payne, 1995; Pellegrini & Smith, 1993, 1998; Rowan, 2010; Tantillo et al., 2002; Taylor et al., 1985; Sachs et al., 1984; Verschuren et al., 2007).

Furthermore, aerobic PA/PE increase the levels of protein-molecules known as neurotrophins (growth factors) in the child's brain - contributing to development of cognitive structure (e.g., Black et al., 1990, 1998; Chaddock et al., 2010ab; Gied et al., 1999; Greenough et al., 2002). For instance, Chaddock et al. (2010ab) demonstrated that high levels of aerobic fitness are associated with improvements in cognitive structure and function in preadolescent children - particularly by increasing hippocampal (improvements in relational memory) and basal ganglia (improvements in cognitive control and response resolution) volumes.

From the arguments set out above, we may conclude that PA has multiple benefits for children's cognitive development/performance – which go beyond the benefits associated with the use of sedentary SBCDs.

Cognitive function and academic achievement are also affected by the nature of sensorimotor experiences in the environment (e.g., Broaders et al., 2007; Casasanto & Henetz, 2012; Church et al., 1986; Engelen et al. 2011; Gibson and Pick, 2000; Goldin-Meadow, 2003; Goldin-Meadow & Butcher, 2003; Goldin-Meadow et al., 2001, 2007; Graf et al., 2003; James & Maouene, 2009; Johnson, 1987; Krinzinger et al., 2011; Pesce et al., 2009; Piaget, 1952, 1954, 1969; Piek et al., 2008; Poore & Barlow, 2009; Pullvermuller, 2005; Smith et al., 1999; Smith & Thelen, 2003; Thelen et al., 1994, 2001; Westendorp et al., 2011).

Researchers demonstrated that cognition in children is embodied - grounded in perception and action and thus extended to sensorimotor experiences in the physical world (e.g., Gibson and Pick, 2000; Johnson, 1987; Piaget, 1952, 1954, 1969; Smith 2009; Smith et al., 1999; Smith & Thelen, 2003; Thelen et al., 1994, 2001).

Embodied Cognition is a recent theoretical field in philosophy and cognitive psychology that characterizes cognition as grounded in perception and action. According to this theory, cognition results from dynamic interactions between the body's sensorimotor mechanisms and the surrounding physical world (Barsalou, 1999, 2003, 2008;

Barsalou et al., 2007; Barsalou & Wiemer-Hastings, 2005; Cahil et al., 1994; Chemero, 2009; Clark, 1997, 1999, 2000, 2008; Conway, 2001; Damasio, 1994, 1999; Eich et al., 2000; Esopenko et al., 2012; Gallese & Lakoff, 2005; Gibbs 2006; Glenberg, 1997; Goldberg et al., 2006; Johnson, 1987; Lakoff & Johnson's, 1980, 1999; Mahon & Caramazza, 2008; Niedenthal, 2007; Pulvermüller, 2005; Shapiro, 2011; Simmons et al., 2007; Simmons & Barsalou, 2003; Varela et al., 1991; Wilson, 2002; Willems & Francken, 2012)[17].

Embodied cognition theory in children has been scientifically validated through both multimodal simulation systems (e.g., James & Maouene, 2009; Krinzinger et al., 2011) and dynamic systems theory (Clark, 2000, 2008; Smith, 2009; Smith et al., 1999; Smith & Thelen, 2003; Thelen et al., 1994, 2001).

According to multimodal simulation systems, mental representations are generated through simulation processes in the brain (brain computations) – reactivation of neural circuits that were activated during previous perceptual, motor and introspective experiences (Barsalou, 2008). Multimodal representations regarding perceptual, motor and introspective states are stored in the brain's memory system and later recalled during conceptual processing - supporting higher-order cognitive abilities such as higher-order perception, implicit memory, working memory, long-term memory and conceptual knowledge (Barsalou, 1999, 2003, 2008; Barsalou & Wiemer-Hastings, 2005).

Researchers demonstrated that, perceptual and motor experiences activate neural networks in the child's brain that are later reactivated in support of cognitive function (e.g., supporting cognitive numerical abilities) (e.g., James & Maouene, 2009; Krinzinger et al., 2011); the development of language is grounded in perception and action (e.g., Engelen et al. 2011; James & Maouene, 2009; Pullvermuller, 2005).

Embodied cognition emphasizes that animal behavior emerges over time coupled with the environment: cognition is a situated process (Barsalou, 2008; Chemero, 2009; Clark, 1997, 1999, 2000, 2008). Dynamic systems theory gives support to this argument. This theory is applied to explain organism-environment couplings over time: agent and environment interact continuously as interdependent self-organized systems that affect each other over time (e.g., Chemero, 2009; Clark, 2000, 2008).

Gibson & Pick (2000), Smith (2009), Smith et al. (1999), Smith & Thelen (2003) and Thelen et al. (1994, 2001) suggest that cognition in children emerges throughout development according to real-time dynamics between organism and environment. These authors argue that the development of higher-order cognition - e.g., reasoning, memory, language, decision-making, planning - is supported by perception and action mechanisms in connection with the environment.

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17. More on this topic in http://biosymticrobotics.com/resources/ECC_FERRAZ.pdf

Gibson & Pick (2000) argue that perception in children is as a process extended to the structural characteristics of the body and environment where action evolves.

Smith (2009), Smith et al. (1999), Smith & Thelen (2003) and Thelen et al. (1994, 2001) employ the dynamic systems theory to demonstrate that cognition in children is dependent on organism-environment couplings. These authors demonstrated that changes in organism-environment parameters – e.g., body posture, waiting time, salience of targets - cause different behavior formats to emerge in infants (affecting how children represent and act in the environment). For example, sitting versus standing influences object retrieval in infants (Smith & Thelen, 2003:345). According to Smith, (2009:80), "By the dynamic field account, objects and locations are bound together - and internally represented - via motor plans, which are themselves tightly tied to the current position of the body. These are dynamic representations, a kind of sensorimotor object concept, that provide a means of keeping track of nonpresent things and events over time".

Although scarce, recent studies in motor development, experimental psychology and neuroscience have been demonstrating how sensorimotor experiences affect children's cognitive development/performance. It was verified that the development of motor skills - particularly gross motor skills - improves the development of cognitive function and optimizes academic achievement in children (Graf et al., 2003; Piek et al., 2008; Poore & Barlow, 2009; Westendorp et al., 2011); and that gesturing reduces mental effort (cognitive load) and facilitates memory retrieval during mathematical problem solving (optimizing cognitive processing in children) (Broaders et al., 2007; Church et al., 1996; Goldin-Meadow, 2003; Goldin-Meadow & Butcher, 2003).

Recent studies have demonstrated that differences in physical affordances (possibilities for action; Gibson, 1979), provided by different types of manipulative user interfaces, tend to affect cognitive function in children in distinctive ways (Antle, 2009; Antle et al., 2008, 2009ab; Fails et al., 2005; Glenberg et al., 2004; Manches et al., 2010; Martin & Schwartz, 2005; Melendez et al., 1993, 1995). For instance, manipulation of physical objects optimizes numerical learning (Manches et al., 2010), problem solving (Antle et al., 2009b) and memory recall (Fails et al., 2005) in children compared with manipulation of virtual objects on SBCDs through peripheral "mouse" and "keyboard" interfaces[18].

Although scarce, studies have investigated the effects of manipulative versus whole-body motion interfaces (based on computer vision methods) on children's cognitive function (e.g., Best, 2010, 012; Buching et al., 2009; Malinverni et al., 2010).

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[18] More on this topic in http://biosymticrobotics.com/resources/MWPICC_FERRAZ.pdf

Malinverni et al. (2010) demonstrated that a whole-body motion interface benefited the construction of abstract concepts in children compared to a peripheral "mouse" interface. Best (2012) observed that exergames (video games that require physical effort) optimized visuospatial conflict resolution in children compared to sedentary video games ("gamepad" interface). On the other hand, Buching et al. (2009) demonstrated that a peripheral "mouse" interface benefited the construction of abstract concepts in children compared to a whole-body motion interface.

Studies regarding the effects of manipulative versus whole-body motion interfaces on children's cognitive function are still scarce and results inconclusive.

Moreover, it is known that the physical environment offers a variety of sensory opportunities for children. For example, natural physical environments bring together a set of variables, such as, temperature, humidity and wind. These variables constitute multiple sources of sensory information to be processed by the human organism.

Multisensory integration (or multimodal integration) regards the integration of multisensory information in the nervous system in order to generate coherent percepts from the environment and to facilitate goal-directed behavior within it (Goldstein, 2010; King & Lewkowicz, 2012; Stein, 2012a). Perception concerns the identification, interpretation and organization of sensory information in order to represent and understand the environment (Schacter et al., 2011).

As previously mentioned, Hominids evolved during millions of years to actively explore information in the surrounding physical environment. Hence, it seems no coincidence that animals are better at encoding multisensory events than unisensory events - e.g., faster reaction times to multisensory stimuli (e.g., Hughes et al., 1994; Pallas & Mao, 2012; Wallace, 2004). In fact, perception is made easier when combining information from multiple sensory modalities (e.g., Gottfried & Dolan, 2003; Gutfreund & King, 2012; King & Lewkowicz, 2012).

It's not an accident that, throughout development, children's ability to generate coherent percepts from the environment and to direct behavior within it, benefits from multisensory experiences in the physical world - also affected by the continuous maturation of the body structure (Bremner et al., 2012; Gibson & Pick, 2000; King et al., 2004; King & Lewkowicz, 2012; Lewkowicz, 2012; Lewkowicz & Kraebel, 2004; Lewkowicz & Roder, 2012; Piaget, 1952, 1954; Stein, 2012b; Thelen & Smith, 1994; Wallace, 2004). For instance, King et al. (2004: 599) refer that "experience plays a critical role in matching the neural representation of spatial information provided by different sensory systems"[19].

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[19] More on this topic in http://biosymticrobotics.com/resources/MAMC_FERRAZ.pdf

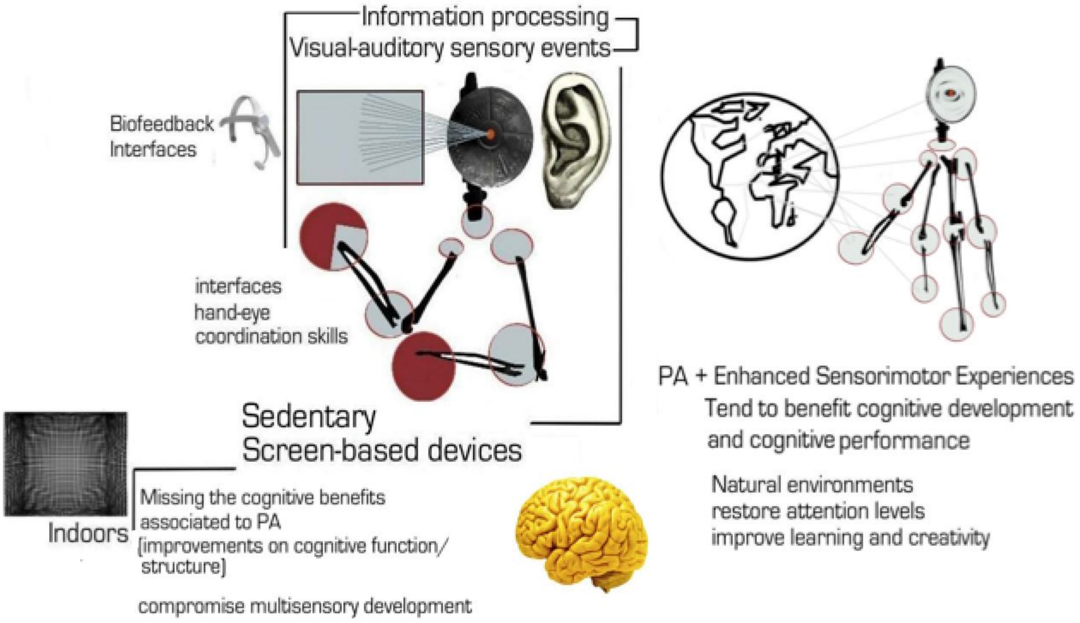

Fig. 5. The use of sedentary screen-based computing devices in artificially controlled environments may fail to maximize children's cognitive development and cognitive performance.

The ability to integrate information from different sensory modalities varies throughout development. The somatosensory senses[20] develop first (e.g., locating the mother's nipple), followed by the chemical senses (smell and taste) and auditory and visual and senses. The ability to integrate multisensory information is already present in the postnatal period (e.g., integration of visual and audio cues to locate objects after 8 months), continues during childhood and expands to adolescence (Bremner et al., 2012; Gallagher, 2005; Gottlieb, 1971; King & Lewkowicz, 2012; Larson & Stein, 1984; Lickliter & Bahrick, 2004; Turkewitz, 1994).

Depriving the child from interactions with multisensory environments throughout development may delay or eliminate "the maturation of the integrative capacity" of multisensory neurons in the brain - gross deficits in the sensory systems - for the processing of information (Lewkowicz & Roder, 2012; Wallace, 2004).

Throughout childhood the ability to process multisensory information starts to narrow in order to generate specific formats of perceptual expertise. This process, known as perceptual narrowing, happens in great part due to environmental experi-

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[20] Tactile sensory impairment is associated with learning disabilities in children (May-Benson & Cermark, 2007).

ences that instill pruning effects in the brain: reduction of overall number of neurons and synapses in order to instill efficient neural configurations in the brain. Rehearsed experiences strengthen certain neural circuits and make them more efficient - these circuits are maintained. Neuronal circuits that aren't used regularly become less efficient and are eliminated (e.g., Chechik et al., 1999; King & Lewkowicz, 2012; Lewkowicz & Kraebel, 2004). Chechik et al. (1999:2061) state that "Human and animal studies show that mammalian brains undergoes massive synaptic pruning during childhood, removing about half of the synapses until puberty"[21].

While using sedentary SBCDs, in ACE, the child loses her possibility to interact with a variety of sensory information that, e.g., natural physical environments offer. SBCDs restrict the child's perceptual process (identification, interpretation and organization of sensory information) to auditory and visual events. For instance, variation of visual stimulus intensity tends to be very low - usually observing visual images on a two-dimensional display with much the same light intensity. In addition, "Keyboard", "mouse" and "tactile displays" interfaces integrate similar materials and textures (e.g., plastic, glass materials with flat surfaces), limiting the child's tactile experiences.

Moreover, while frequently interacting with sedentary SBCDs, in ACE, children lose most of the benefits from natural bright light - contributing to the regulation of melatonin and cortisol hormones. These hormones optimize cognitive function by increasing levels of alertness and reducing stress levels. Insufficient daylight increases the levels of cortisol excessively, resulting in increased negative expectations (Harmon, 1951; Jensen, 2000).

Natural environments reduce aggressive behaviors and improve children's learning and creativity (Dannenmaier, 1998; Kellert, 2002; Louv, 2006). Children tend to feel less anxious while exploring natural environments (Fjortoft & Sageie, 2000). Kuo & Faber (1997) found that natural environments restore attention levels in children[22]. Unfortunately, in the current decades there has been a significant reduction in informal PA in natural settings due to security issues - namely in urban settings (Clementes, 2004).

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21. Perception of spatial events improves during childhood and becomes fully developed during adolescence: improvements in the ability to integrate proprioceptive and vestibular information (coordinating balance, locomotion, spatial orientation and navigation). Around 5 to 6 years of age, multisensory integration of somatosensory information (tactile, proprioceptive and vestibular information) becomes essential to generate controlled spatial behavior (not only visual information). Before the age of 8 children are still developing their ability to integrate somatosensory and visual information (Gori et al., 2008; Nardini & Cowie, 2012). Children increase their capacity to integrate somatosensory and visual information between 4 to 12 years of age (Bair et al., 2007; Sparto et al., 2006). Ross et al. (2008) argue that the ability to integrate visual and audio information in noisy environments increases as function of age. Brandwein et al. (2011) emphasize that the peak maturation of multisensory visual-audio integration occurs by the age of 14.

22 . The integration of plants and animals (e.g., dogs) in classroom settings optimizes attention levels and social skills and decreases levels of stress and aggression in children (Han, 2009; Kotrschal & Ortbauer, 2003).

The previous set out arguments demonstrate that both physical activity and enhanced sensorimotor experiences tend to benefit cognitive development and cognitive function in children. Therefore, sedentary SBCDs (including devices that make use of biofeedback interfaces), in ACE, may fail to maximize children's cognitive development/performance (see fig.5).

To avoid physical and mental health complications and optimize children's cognitive function, SBCDs have been integrated with user interfaces supporting whole-body motion (WBM) experiences in ACE. WBM devices have improved the Child-Computer Interaction (CCI) field, given the opportunity they provide for enhanced sensorimotor experiences compared to sedentary SBCDs. Nonetheless, it seems that WBM devices are not promoting children's physical and mental health and may fail to maximize their cognitive development/performance. This will be the topic of the next subchapter.

1.4 Whole-body motion screen-based computing devices in artificially controlled environments

Whole-body interfaces capture and process physical, physiological, cognitive and emotional data from users in order to support interactions with digital environments (England, 2011). For example, visual and audio data control in virtual environments can be accomplished through the use of WBM interfaces such as gesture-based (e.g., computer vision) and/or sensor-based (e.g., infrared sensing) interfaces (Noble, 2009).

Computer interfaces that instill physical effort in users are termed exertion interfaces. This type of interfaces aim to improve physical and mental health and social skills in users and are, so far, usually related to the practice of sports (Mueller & Agamanolis, 2008; Mueller et al., 2002, 2008). In line with Mueller et al. (2008:265), “We define exertion as the act of exerting, involving skeletal muscles, which results in physical fatigue, often associated with physical sport”.

Computer games that require physical effort are characterized as exergames, e.g., active video games (AVGs) combining physical exertion with gaming experiences (Mueller et al., 2008). As stated by Mueller et al. (2008:265), “An exertion game has an input mechanism in which the user is intentionally investing physical exertion. Such an exertion interface has been previously defined as being physically exhausting and requiring intense physical effort”.

Exergames were introduced in the world market in the early 21st century. Video game consoles like the “SonyPlayStation®[23], “Nintendo®Wii[24] and “Xbox” from Mi-

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23. http://us.playstation.com/ps3/accessories/playstation-eye-camera-ps3.html
24. http://www.nintendo.com/wii/what-is-wii/

crosoft®[25] were developed to encourage physical effort in users through active video game play formats (AVGs). These systems allow users to practice PA inside their homes (especially targeting urban niches). Visual and audio data control, in these systems, is accomplished through gesture-based (e.g., computer vision; e.g., "Xbox") and/or sensor-based (e.g., infrared sensing; e.g., "Nintendo®Wii") interfacing techniques.

Researchers in the CCI field investigated how exertion interfaces improve children's physical health, namely, by evaluating levels of PA caused by exergames in indoor settings (e.g., Baranowski et al., 2012; Ferraz, 2008; Haddock et al., 2010; LeBlanc et al., 2013; Maloney et al., 2008; Penko & Barkley, 2010; Tremblay, 2012; Whitehead et al., 2010)[26].

AVGs in indoor settings have been related to the development of simple and complex motor skills (e.g., Höysniem et al., 2004) and increased energy expenditure levels in children (e.g., Haddock et al., 2010; Maloney et al., 2008; Penko & Barkley, 2010); however, researchers point out that these systems are not promoting the recommended 60 minutes of moderate to vigorous levels of PA (MVPA) that benefit children's physical and mental health. In addition, researchers have been arguing that AVGs are not a substitute for PA in natural environments (Baranowski et al., 2012; LeBlanc et al., 2013; Tremblay, 2012; Whitehead et al., 2010).

The organization Active Healthy Kids Canada performed a meta-analysis of the long-term effects of AVGs in health and behavior in children (aged 3 to 17 years) (LeBlanc et al., 2013). This meta-analysis comprised 1367 published papers dated from 2006 to 2012 (Cochrane Central Database and MEDLINE, EMBASE, psycINFO, and SPORTDiscus databases). Reviewed papers included 1992 participants from 8 countries. It concluded that AVGs did not promote the 60 minutes of MVPA necessary to benefit children's health. On the other hand, it was verified that AVGs increased energy expenditure levels - above rest - in children compared to playing sedentary video games; however, heart rate values did not represent moderate to vigorous intensity levels for most of the analyzed studies. In addition, there was a lack of evidence suggesting for long-term spontaneous adherence to AVGs. According to the authors, "Kids find active video games appealing, but the appeal wears off over time and many don't stick with them"[27]. Moreover, the researchers emphasize that AVGs are not a replacement for PA in natural environments. Accordingly, AVGs "don't offer the fresh air, vitamin D, connection with nature and social interactions that come with outdoor active play".

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[25] http://www.xbox.com/en-US/xbox-one/innovation

[26] More on this topic in http://biosymticrobotics.com/resources/MFCEI_FERRAZ.pdf

[27] http://www.activehealthykids.ca/active-video-games-position.aspx

Moreover, while interacting with WBM devices, in ACE, children lose the opportunity for face-to-face and body-to-body interaction, the benefits from B UVB and contact with germs. Lack of exposure to natural bright light may also compromise the development of the visual system.

Hence, WBM devices, in ACE, do not seem to be promoting children's physical and mental health.

Already in 1986, Bill Buxton observed that SBCDs didn't exploit the full potential of human sensorimotor capabilities (Buxton, 1986). Dourish (2001) continued this line of thought and claimed a body-centric, situated and social approach to the design of interactive systems. According to this approach, interactive systems should be designed in order to facilitate communication between the user's body actions and the physical and social worlds. Dourish termed this approach *Embodied Interaction.* More recently, Fogtman et al. (2008) developed the concept of *Kinesthetic Interaction.* In line with these authors, Kinesthetic Interaction involves potentiation of the user's kinesthetic skills through the use of whole-body interactive systems.

Researchers in the CCI field have been exploring the concept of Embodied Interaction - the effects of WBM interfaces on children's cognitive function. For example, a few studies demonstrated that video game play, in ACE, through the use of WBM interfaces (computer vision methods), is associated with benefits on children's cognitive function: construction of conceptual knowledge (Kynigos et al., 2010); conflict resolution (Best, 2012) and selective and sustained attention in autistic children (Bartoli et al., 2013). Nonetheless, we suggest that this type of devices may fail to maximize children's cognitive development/performance.

Because WBM devices, in ACE, are not promoting moderate-intense PA levels, then they may also be failing to benefit children's cognitive function/structure.

Moreover, WBM devices, in ACE, restrict children's sensorimotor experiences. While moving, children are encouraged to center attention on a two-dimensional display, depriving them from a variety of motor experiences (proprioceptive and vestibular stimuli) available in three-dimensional space (missing out on several possibilities to coordinate lower and upper limbs, head and eyes in the three-dimensional axis). Sensor-based interfaces integrate similar materials and textures (e.g., plastic or rubber), limiting tactile experiences (see fig. 6). There is also a lack of variation in stimuli to the nerve network at the bottom of the feet as ACE integrate surfaces of similar material consistencies and textures. Hence, this type of interactive environment confines the child's perceptual process to restricted proprioceptive, vestibular and tactile events.

As previously mentioned, enhanced sensorimotor experiences tend to improve children's cognitive development/performance, whilst restricted experiences may delay or eliminate their capacity to integrate multiple sources of sensory information throughout development.

Fig. 6. Sensor-based controllers.

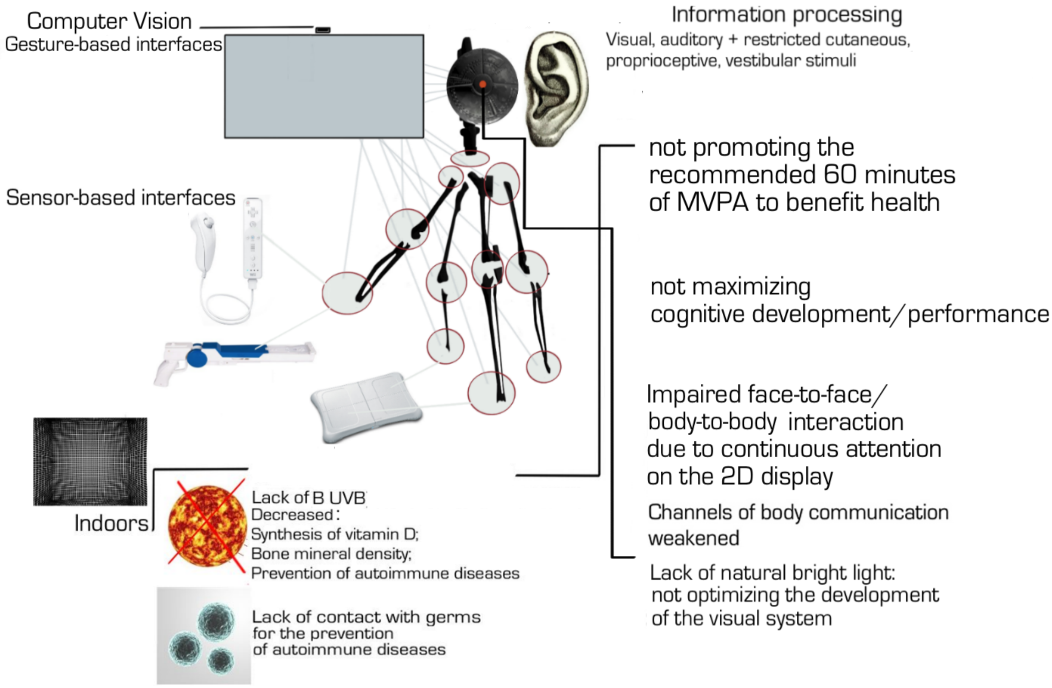

Fig. 7. Whole-body motion screen-based computing devices in artificially controlled environments are not promoting children's physical and mental health and may fail to maximize cognitive development/performance.

Paradoxically, AVGs are being implemented in physical education classes (Hansen & Sanders, 2010).

Figure 7 resumes the effects of WBM devices, in ACE, on children's physical and mental health and cognitive development/function.

To promote children's physical and mental health and maximize their cognitive performance/development, SBCDs have been connected to real world settings - Pervasive Computing. Pervasive Computing, namely through the use mobile computing devices, was an improvement in CCI given the opportunity for increased contact with the physical world. However, we suggest that these devices may be associated with physical health problems in children and may not be maximizing their cognitive performance. This will be the topic of the next subchapter.

1.5 Mobile screen-based computing devices in real world settings

Pervasive Computing (or ubiquitous computing) unobtrusively connects users and digital worlds (e.g., embedding microprocessors in real world settings) (Benford et al., 2005; Magerkurth et al., 2005). Devices such as PDAs, smartphones, tablets, augmented toys and wearables have been used to connect children with real world settings (e.g., Badawi et al., 2012; Bekker & Eggen, 2010; Chipman et al., 2006; Daanen et al., 2007; Fitzpatrick et al., 2004; Kamarainen et al., 2013; Macvean & Robertson, 2013; Magielse & Markopoulos, 2009; Misund et al., 2009; Nilsson et al., 2012; Rosales et al., 2011; Silva et al., 2008).

Mobile devices such as PDAs, smartphones and tablets have been encouraging children to engage in collaborative learning in real world settings (e.g., Chipman et al., 2006; Druin, 2009; Fleuriot et al., 2005; Fritzpatrick et al., 2004; Marshall, 2007; Nilsson et al., 2012; Silva et al., 2008; Spikol & Milrad, 2008).

Children communicate with mobile computing devices through the use of hand-eye coordination skills, e.g., "tap", "drag", "slide", to control virtual contents on a two-dimensional display.

PDAs, smartphones and tablets, in real world settings, are associated with cognitive benefits in children, e.g., instilling engagement, motivation and concentration and favoring the construction of abstract concepts (Fitzpatrick et al., 2004) and creativity (e.g., Chipman et al., 2006; Silva et al., 2008; Williams et al., 2006). Mobile devices combined with augmented reality techniques, in real world settings, seem to encourage learning in children (e.g., Kamarainen et al., 2013; Nilsson et al., 2012)[28].

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28. More on this topic in http://biosymticrobotics.com/resources/MWPICC_FERRAZ.pdf

Children may also be encouraged to move in the physical space while using mobile computing devices - whole-body motion in the physical world (e.g., Chipman et al., 2006; Fitzpatrick et al., 2004; Fleuriot et al., 2005; Kamarainen et al., 2013; Nilsson et al., 2012; Silva et al., 2008; Spikol & Milrad, 2008).

Mobile devices (e.g., Abreu et al., 2013; Kiili & Merilampi, 2010; Macvean & Robertson, 2013; Misund et al., 2009) and wearable computers (e.g., Badawi et al., 2012; Bekker & Eggen, 2010; Daanen et al., 2007; Magielse & Markopoulos, 2009; Rosales et al., 2011) have been persuading children to engage in PA in real world settings - mobile exergames. Mobile exergames make use of motion sensors and GPS techniques to increase children's PA levels (e.g., Abreu et al., 2013; Kiili & Merilampi, 2010; Macvean & Robertson, 2013; Misund et al., 2009; Mustafin et al., 2012).

According to Rogers & Price (2006:329), mobile devices can be used "to enhance and support learning in novel ways, moving it away from the computer screen to other foci of interest (…) in doing so, students can interact with digital information in the physical world in quite different ways other than when interacting solely with digital information at a PC or solely with the physical world. The physical world can be digitally augmented, for example, through embedding the environment with information contextually relevant to an ongoing activity, but not otherwise available in the physical world". Hence, mobile devices allow users to process information from both physical and digital worlds.

Prolonged interaction with SBCDs placed lower or higher than the child's gaze has been linked to body posture distortions - overburdening upper limbs and neck (Cordes & Miller, 2002). Likewise, mobile computing devices encouraging the child to continuously center attention on a two-dimensional display - placed lower than the child's gaze - may overstrain upper limbs and neck. This type of motor behavior becomes even more problematic in situations that require physical displacement on the terrain, e.g., walking or running while focusing on the two-dimensional display (e.g., Koivisto et al., 2011; Macvean & Robertson, 2013; Magielse & Markopoulos, 2009; Misund et al., 2009; Spikol & Milrad, 2008).

In fact, human beings evolved to move in three-dimensional space by maintaining an efficient body posture: neck straight in an upright position while moving (Lieberman, 2013). We alert for possible postural problems associated with the use mobile devices encouraging children to move while centering attention on a 2D display. Also, by hand holding these devices, children restrict upper limb motor actions - unable to interact with the physical world (see fig. 8).

Moreover, mobile devices encourage children to either center attention on the device or the physical world (alternating the focus of attention) – split-attention effect (e.g., Chipman et al., 2006; Fitzpatrick et al., 2004; Fleuriot et al., 2005; Kamarainen et al., 2013; Nilsson et al., 2012; Silva et al., 2008). On the other hand, it has been emphasized that external information sources, combined in space and synchronized in time,

Fig. 8. While centering attention on mobile computing devices children overburden the upper limbs and neck (increased neck strain). These devices restrict the motor actions of the upper limbs, making it harder to move and interact with the physical world.

tend to optimize cognitive processing: facilitating perceptual integration and optimizing learning (e.g., Liu et al., 2012; Sweller, 1999; Tarmizi & Sweller, 1988).

The split-attention effect results from sources of information separated in space and time - impairs perceptual and learning processes (Tarmizi & Sweller, 1988). For example, instructional strategies imposing a split in the focus of attention of the learner - involving at least two sources of information. Extraneous cognitive load tends to increase when sources of information appear separated in space and time. For instance, separating diagrams from text in multimedia environments (spatial configuration) tends to increase extraneous cognitive load and compromise learning. On the other hand, if these sources of information overlap in space, extraneous cognitive load tends to diminish and learning is favored (Sweller, 1999)[29]. Hence, mobile devices may fail to maximize children's cognitive performance.

The scientific arguments delineated in the previous subchapters demonstrate that the current Child-Computer Interaction paradigm is not potentiating human development to its fullest. It is linked to several physical and mental health problems and appears not to be maximizing children's cognitive development and performance.

To potentiate children's physical and mental health (including cognitive development and performance) we conceived a new approach to human development and evolution. This approach proposes a particular synergy between the developing human body, computing/robotic machines and natural environments. It emphasizes that children should be encouraged to interact with challenging physical environments offering multiple possibilities for sensory stimulation and increasing physical and mental stress to the organism. We created and tested a new set of robotic devices to operationalize our approach – Biosymtic (Biosymbiotic Robotic) devices.

In the next chapter (2), we will describe our approach (including the nature of Biosymtic devices). In chapters 3 and 4, we present two initial studies in order to validate our approach: a study in Child-Computer Interaction and Neuroscience (sustained attention and episodic memory); a study in Child-Robot Interaction and Physiology (physical activity levels). Chapter 5 describes general conclusions and future work.

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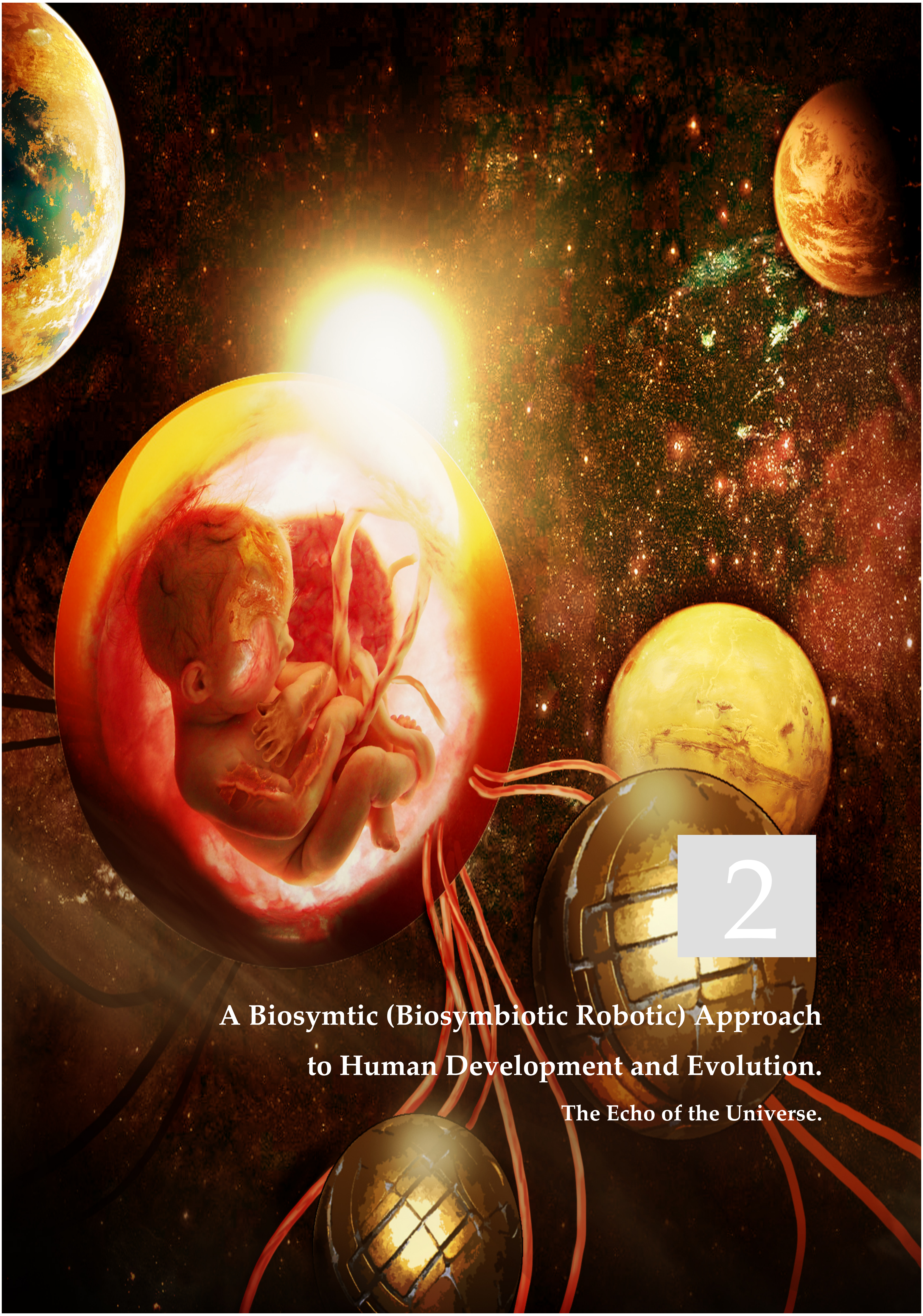
29. More on this topic in http://biosymticrobotics.com/resources/MAMC_FERRAZ.pdf



2

A Biosymtic (Biosymbiotic Robotic) Approach to Human Development and Evolution.

The Echo of the Universe.

2.1 The foundations: connecting human body, computing machines and natural physical environments

We will now describe how to potentiate cognitive development, cognitive performance and physical and mental health in children through the use of computing machines. We propose a particular combination between the human body, computing machines (enhanced sensorimotor user-interfaces) and natural physical environments (enhanced sensorimotor environments) in order to potentiate human development and evolution. This combination represents the foundation of our approach.

We will first demonstrate how to potentiate children's cognitive development, particularly perceptual abilities, through the use of computing machines.

2.1.1 Potentiating cognitive development – perceptual abilities - in children through computing machines

As previously mentioned, throughout development, the ability in modern children to generate coherent percepts from the environment and to direct behavior within it, benefits from multisensory experiences in the surrounding physical world.

Perceptual expertise is linked to the development of higher-order cognitive abilities in children: *attention shifting*, or the ability to engage and disengage from environmental stimuli (or from internal stimuli); *working memory* (WM), or the ability to store, control and update information; and *inhibition*, or the ability to inhibit autonomic (e.g., heart rate and blood pressure), dominant and proponent responses (the ability to maintain focus while inhibiting distracting information) (Baddeley, 1996, 2000, 2002; Baddeley & Hitch, 1974; Lehto et al., 2003; Miyake et al., 2000; Posner & Rothbart, 2009).

Attention shifting, WM and inhibition undergo major transformations from infancy to late adolescence. They develop at a faster rate during childhood and at slower rate during adolescence (Center on the Developing Child, 2011; Garon et al., 2008; Huizinga et al., 2006; Waber et al., 2007). Advances in these higher-order cognitive abilities result in increased capacity to control behavior (Bezrukikh et al., 2009).

Attention shifting, WM and inhibition follow distinct developmental pathways. This desynchronized phenomenon happens due to genetic and environmental factors. Cognitive function and structure in children suffer a strong influence from environmental experiences compared to adults. Environmental experiences are associated with a multitude of structural and functional transformations in the child's brain throughout development (Black et al., 1998; Fuster, 2002; Fuster & Bressler, 2012; Gied et al., 1999; Greenough et al., 2002; Hensch, 2004; Huttenlocher, 1979; Huttenlocher & Dabholkar, 1997; Klingberg, 2013; Nelson, 1999; Nelson et al., 2006; Waber et al., 2007).

Research indicates that low-level feature binding processes (bottom-up sensory mechanisms) are the foundation of higher-order cognition in children (e.g., Edin et al., 2007; Fabiani & Wee, 2001; French et al., 2004; Klingberg, 2013; Luciana, 2003; Paus, 2005; Moscovitch et al., 2007). For example, authors suggest that WM performance, in children, is mostly dependent on low-level feature binding processes (Edin et al., 2007; Fabiani & Wee, 2001; Klingberg, 2013; Luciana, 2003; Paus, 2005; Moscovitch et al., 2007). This happens due to the ongoing maturation of the PFC and the frontoparietal neuronal circuitry. Only in later developmental stages does WM performance becomes largely influenced by top-down mechanisms (Anderson et al., 2001; Chugani & Phelps, 1986; Edin et al., 2007; Fabiani & Wee, 2001; Fuster, 2002; Johnson & Hann, 2011; Klingberg, 2013; Klingberg et al., 2002; Kwon et al., 2002; Luciana, 2003; Nagy et al., 2004; Nelson et al., 2006; Ofen et al., 2007; Olesen et al., 2003; Paus, 2005; Raj & Bell, 2010; Shaw et al., 2008; Sluzenski et al., 2004; Wetzel et al., 2009; Yeager & Yeager, 2013; Zelazo & Muller, 2002). Interestingly, Sweller et al. (2011) refer that while novices mostly use thinking skills in WM performance, experts use knowledge.

In this way, environmental experiences determine, in great part, how cognition emerges in children: the development of higher-order cognitive processes (attention, WM, inhibition processes) is influenced by environmental experiences based on low-level feature binding processes (sensory driven). More specifically, perceptual expertise develops from low-level feature binding processes and is associated with the development of higher-order cognitive abilities.

In fact (as previously mentioned), cognition in children is embodied, grounded in perception and action and thus extended to sensorimotor experiences in the physical world.

As early as 1966 and 1979, James Gibson argued that perception evolves from action: a process extended to the structural characteristics of the organism and the environment where action evolves. Gibson stated that "Head movements, ear movements, hand movements, nose and mouth movements, and eye movements are part and parcel of the perceptual systems they serve (…) to explore the information available in sound, mechanical contact, chemical contact, and light" (Gibson, 1966:58). This illustrates that perception and action do not work in isolation.

Gibson defined the concept of "affordances" as representing environmental possibilities for action. According to the author, the environment integrates objective features that tend to be perceived according to possibilities for motor action, e.g., a chair to sit, a knife to cut. For instance, it is expected for a human to perceive a chair differently from a crocodile (Crocodylinae) because these species present different body structures. A chair suggests the action of "seating" for most humans. A crocodile will probably not notice it or destroy it with its sharp teeth (see also Barsalou, 1999, 2003, 2008; Chemero, 2009; Clark, 1997, 2000, 2008).

In fact, Gibson visualizes the perceiver as a "self-tuning" system that "resonates" relevant sensory stimuli from the surrounding physical world. Likewise, Shubin (2013:85) stated that "Virtually every part of the world we experience is influenced by our size, even how we visualize size itself. The size and shape of our pupils, eyeballs and lenses influence our visual acuity just as the shape and structure of the different components of our ears affect the sound and frequencies we hear".

Gibson & Pick (2000) adopted Gibson's (1979) "Ecological approach to visual perception" to demonstrate that perception, in children, is a process extended to the structural characteristics of the body and environment where action evolves.

Gibson & Pick used Gibson's definition of "affordances" to demonstrate how perception emerges in children. According to Gibson & Pick (2000), affordances represent "the fit between an animal's capabilities and the environmental supports and opportunities (both good and bad) that make possible a given activity" (Gibson & Pick, 2000:14). The authors refer that the environment integrates objective features, which tend to be perceived according to possibilities for motor action ("a chair affords sitting for creatures possessing a flexible torso and hip joints") (Gibson & Pick, 2000:14). For instance, one would expect a baby to perceive the physical world differently from an adult because they possess different body structures (e.g., body height conditions the field of vision in three-dimensional space).

According to Gibson & Pick (2000), "affordances" work as primitives to generate abstract knowledge in children. For example, interacting with liquid filled containers, using different motor actions, provides babies with "a basis for forming concepts of liquidity, of pouring, of containers, and more" (Gibson & Pick, 2000:177-188). These authors refer that "affordances" support the development of higher-order cognitive processes in children (e.g., memory, reasoning, imagining). Thelen et al. (2001:1) also refer that cognition, in children, "depends on the kinds of experiences that come from having a body with particular perceptual and motor capabilities that are inseparably linked and together form the matrix within which reasoning, memory, emotion, language, and all other aspects of mental life are meshed" (see also Smith, 2009).

In effect, it is known that the ability to combine sensory sources of information from the environment throughout development is influenced by the maturation of the body's structure (Gibson & Pick, 2000; King et al., 2004; Lewkowicz & Kraebel, 2004; Thelen & Smith, 1994). For instance, shape, size and relative location of sense organs "change during the course of development" (King et al., 2004: 602). The size of the, e.g., limbs, head, generates a specific layout in the body that determines how perception emerges in relation to space. Lewkowicz & Kraebel (2004: 658) emphasize that different motor experiences in infants (e.g., passage from crawling to standing) provide novel sensory opportunities that "force reorganization" of sensory integration in the nervous system.

In this way, changes in the structural features of the human body, and associated possibilities for action throughout development, influence the way perception is generated - how children identify, interpret and organize multiple sources of sensory information from the environment.

As previously mentioned, depriving a child from interacting with multisensory environments may delay or eliminate her capacity to identify, interpret and organize multiple sources of sensory information from the environment.

We therefore suggest that computing machines should encourage children to be exposed to multiple and novel bodily action possibilities in enhanced sensorimotor environments (natural physical environments; stimulating the visual, auditory, chemical, cutaneous, proprioceptive and vestibular senses) - so as to develop multisensory integration abilities, in order to generate coherent percepts from the environment and to facilitate goal-directed behavior within it.

We suggest two formats of interaction with computing machines in order to potentiate the development of perceptual abilities in children:

1) Whole-body motion interfaces allowing for multiple bodily action possibilities in the natural environment (the human body as an interface)

As stated by Gibson (1966), perception evolves from action. For instance, the combination of vision, motion and environmental features allows perceiving objects and surfaces in the physical world. Visual perception of objects (substances/matter) in the physical world is dependent on continuous changes in light diffusion and reflection of to objects and their surfaces (energy in the environment[30]) and the motion of the perceiver (active search for visual information; e.g., locomotion).

Motion in a dynamic three-dimensional environment enables new information about the object to be accessed by the observer (visual sensing mechanism). In fact, multiple possibilities for action (movement) generate multiple ways of exploring a variety of environmental sources of sensory information.

Because perceptual representations of the environment are influenced by the continuous maturation of the body, multiple bodily action possibilities, throughout development, may facilitate the formation of coherent percepts from the environment. Multiple corporeal action possibilities allow the child access to different properties of the environment.

For instance, observing a tree while walking provides the child with a particular perceptual representation of that same tree: an object with a specific geometrical form and coloring. On the other hand, if the child climbs the tree, she will have access to other properties that compose the tree: trunk and branches textures and scent of the leaves. Therefore, the child may create a perceptual representation of the three based on multiple sources of sensory information. The resulting multisensory representation may facilitate, for instance, recognition processes – matching information from stimuli with information retrieved from memory (e.g., identify a tree in the dark through textures and scents) – and thus goal-directed behavior in the environment (e.g., climb the tree to avoid a wild pig).

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30. Light diffusion and reflection depend on the properties of substances. For instance, shape, texture, color, orientation.

Hence, computing machines should encourage children to be exposed to multiple bodily action possibilities (movement; combining fine and gross motor skills) in enhanced sensory environments in order to potentiate the development of perceptual abilities. To that end, computing machines should combined with whole-body motion interfaces: the child is encouraged to perform a variety of movements (e.g., walking, running, jumping, climbing, throwing, grasping – the human body as an interface) to interact with virtual of information (visual and/or audio) on computing machines, while experiencing the natural physical environment.

2) Whole-body motion interfaces that extend the bodily action possibilities in the natural environment (extending physical interfaces)

> *"One morning, as Gregor Samsa was waking up from anxious dreams, he discovered that in bed he had been changed into a monstrous verminous bug. He lay on his armor-hard back and saw, as he lifted his head up a little, his brown, arched abdomen divided up into rigid bow-like sections. From this height the blanket, just about ready to slide off completely, could hardly stay in place. His numerous legs, pitifully thin in comparison to the rest of his circumference, flickered helplessly before his eyes"*
>
> *Kafka (1915:3)*

The above excerpt is from the novel "Metamorphosis", written by Franz Kafka in 1915. Kafka tells the story of Gregor Samsa, who wakes up one morning metamorphosed into a gigantic insect-like creature. This metamorphosis meant that Gregor Samsa could interact with the physical world in new ways.

Kafka's novel is an analogy to our suggestion on how to potentiate the development of children's perceptual abilities.

Since the structural features of the human body, and associated action possibilities, affect the way perception is generated, we suggest that by by structurally augmenting the human body, through extending physical interfaces offering new action possibilities (new body structure layout), the child may generate perceptual representations of the environment, throughout development, beyond those the standard human body has to offer. We defined this augmentation as *Motoric-Metamorphosis* ("Motoric" concerns motor capabilities, "Metamorphosis" transformation in form) - a transformation through which the child may generate novel ways of representing and understanding the environment.

The human body has a structural configuration that determines action possibilities in three-dimensional space. For example, locomotion through walking, running, jumping and swimming. By extending the feet with wheels (e.g., rollerblades) new action possibilities arise. These extending physical interfaces provide a different form of locomotion, e.g., rolling from a vertical position of the body. This sort of "artificial" movement may generate new perceptual representations of the environment.

Rolling from a vertical position at a certain speed - faster than the speed that is naturally permitted by the human body – allows the child to have access, for example, to new visual configurations of the surrounding environment (e.g., rolling at a faster speed while observing a tree blurs its textures - providing to the child a more abstract representation of the environment). Furthermore, by connecting additional upper limbs in the upper part of the child's body, e.g., four articulated mechanical octopus arms, other forms of manipulating and perceiving objects arise. For instance, by grabbing an object with four octopus arms (two octopus arms on each side of the body) the child may access new configurations of that same object (e.g., weight of the object distributed through the four octopus arms). This experience generates new possibilities for mental self-image because it provides the child with new proprioceptive/vestibular experiences (learning to control an object through a new body structure layout) (see fig. 9).

In order for the child to generate new perceptual representations of the environment (or novel ways to represent and understand the environment) throughout development, she should have access to a variety of *Motoric-Metamorphosis* experiences provided by a diversity of extending physical interfaces in enhanced sensorimotor environments.

Hence, we should encourage children to experience new action possibilities in enhanced sensory environments, in order to potentiate the development of perceptual abilities. To that end, computing machines should be combined with whole-body motion extending physical interfaces: the child is encouraged to perform new types of bodily action through extending physical interfaces (e.g., moving horizontally in a vertical position, grabbing an object with three arms), which in turn control virtual information on computing machines, while experiencing the natural physical environment.

We suggest that whole-body motion interfaces, allowing for multiple and new bodily action possibilities, in enhanced sensorimotor environments, may contribute to the shaping of a variety of synaptic configurations in the brain throughout development, which support multiple and novel ways to identify, interpret and organize a variety of sensory information from the environment.

In the next subchapter, we will demonstrate how to potentiate cognitive performance in children - how to optimize the process of virtual information on computing machines.

2.1.2 Potentiating cognitive performance – optimizing processing of virtual information in children through computing machines

As previously mentioned, mobile computing devices may be linked to health problems (distortions in body posture) and may not maximize children's information processing capabilities. These devices have been encouraging children to either center their attention on the device or on the surrounding physical world – split-attention effect (e.g., Chipman et al., 2006; Fitzpatrick et al., 2004; Fleuriot et al., 2005; Kamarainen et al., 2013; Nilsson et al., 2012; Silva et al., 2008).

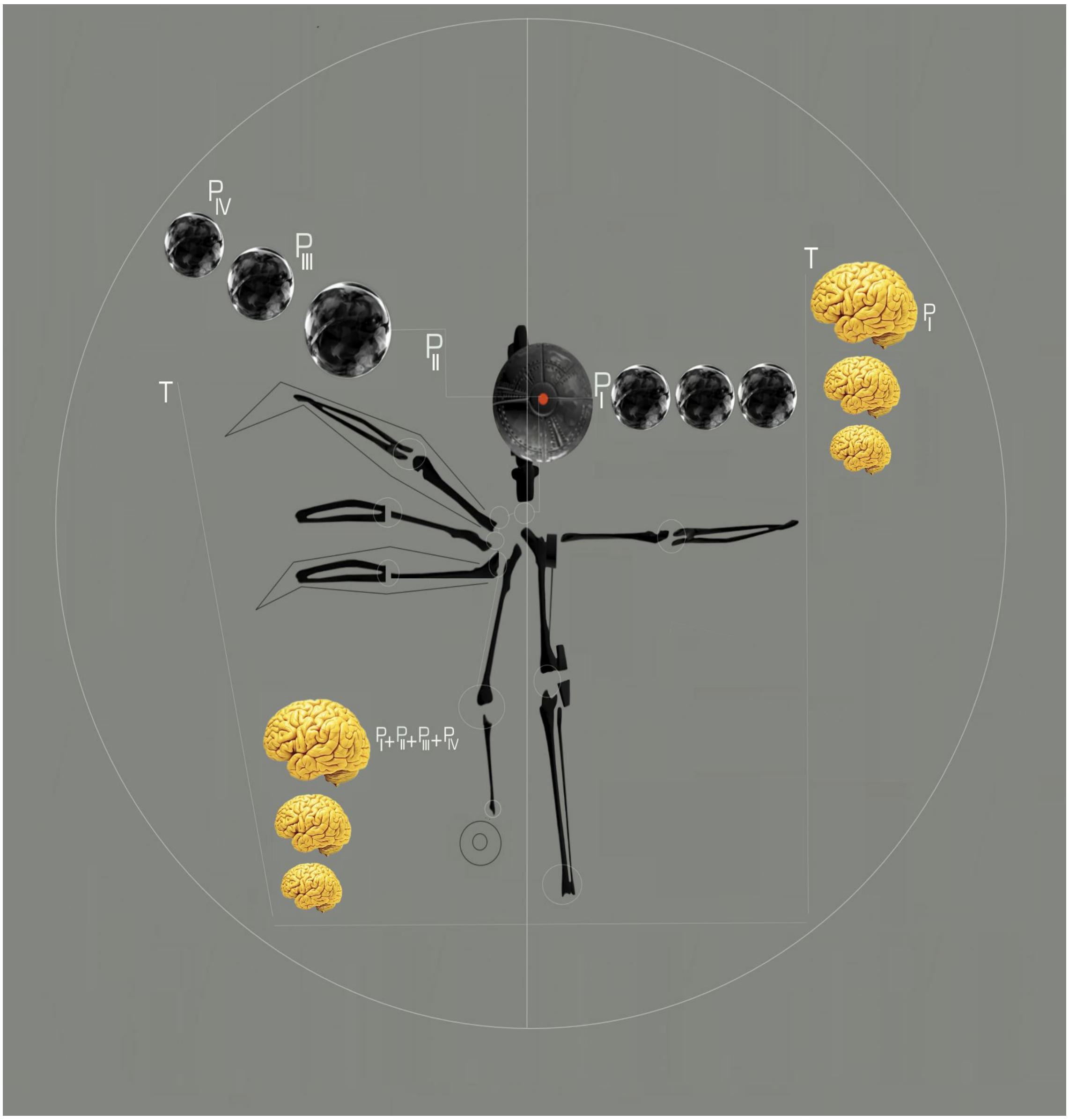

Fig. 9.

Motoric-Metamorphosis

Extending the structural components of the human body through whole-body motion extending physical interfaces that offer new bodily action possibilities in the physical world.

P_{I} (Perceptual representation$_{I}$); P_{II} (Perceptual representation$_{II}$); P_{III} (Perceptual representation$_{III}$); P_{IV} (Perceptual representation$_{IV}$); T (time).

Right side: standard structural configuration of the human body (comprising a head, neck, trunk, and upper and lower limbs). The standard structural configuration of the human body generates specific perceptual representations of the physical world (three similar size spheres): P_{I} (Perceptual representation$_{I}$).

Left side: extended structural configuration of the human body through *Motoric-Metamorphosis* (a wheel and two octopus arms). By extending the structural components of the human body through whole-body motion extending physical interfaces (new layout of the body structure), which offer new bodily action possibilities (e.g., feet resting on a base connected to a wheel or two octopus arms), the child has access to novel perceptual representations of the physical world (three different size spheres): P_{II} (Perceptual representation$_{II}$), P_{III} (Perceptual representation$_{III}$), and P_{IV} (Perceptual representation$_{IV}$).

Humans evolved to move in three-dimensional space by maintaining an efficient body posture (e.g., neck straight in an upright position while moving). External sources of information, combined in space and synchronized in time, optimize the processing of information (optimizing perceptual integration/learning)[31]. Hence, we suggest an adequate combination between technological devices, which display virtual formats of information (visual and/or audio), and the anatomical structure of the human body (sensory organs) so as to avoid postural problems and split-attention effects in children.

For example, visual virtual information should be directly aligned with the visual system (e.g., see-through head-mounted displays). In addition, the combination between virtual information and the human body should enable free body movement in the physical world - to freely interact with multiple sources of sensory information (enhanced sensorimotor experiences tend to improve cognitive function in children). We describe this combination as *Virtual-Sensorimotor Alignment* (VSMA) (see fig.10).

In fact, we submit that VSMA allows the child to generate a variety of perceptual and motor states (multimodal representations) in support of cognitive performance – optimizing the processing of virtual information through enhanced sensorimotor experiences (as we will explain in subchapter 3, experiment I).

The human-technological combination that we propose here – VSMA - is not far removed from the human-technological combination used by hunter-gatherer children. Hunter-gatherer children used physical tools to interact with the natural environment, e.g., to forage, hunt, fish. Physical tools and the natural environment offered a variety of sensorimotor experiences to hunter-gatherer children. For example, physical tools increased stress to the proprioceptive and vestibular senses by offering multiple bodily action possibilities: throwing a spear towards an animal requires a combination of fine and gross motor skills (holding and throwing), at the same time it demands balance and postural control (the same for manipulating, e.g., a hand axe or a fishing rod). Balance and postural control could be affected, e.g., by differences in wind speed.

Moreover, physical tools comprised different physical materials and sizes and thus fostered a variety of tactile, proprioceptive and vestibular experiences (e.g., wood and stone materials with distinctive sizes imply different effort and movement control). Through the use of physical tools, hunter-gatherer children extended their action and perception possibilities in the physical world.

In addition to the VSMA, we suggest that enhanced sensorimotor environments may optimize cognitive performance in children, particularly the processing of virtual information on computing machines.

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31. Liu et al., 2012; Sweller, 1999; Tarmizi & Sweller, 1988.

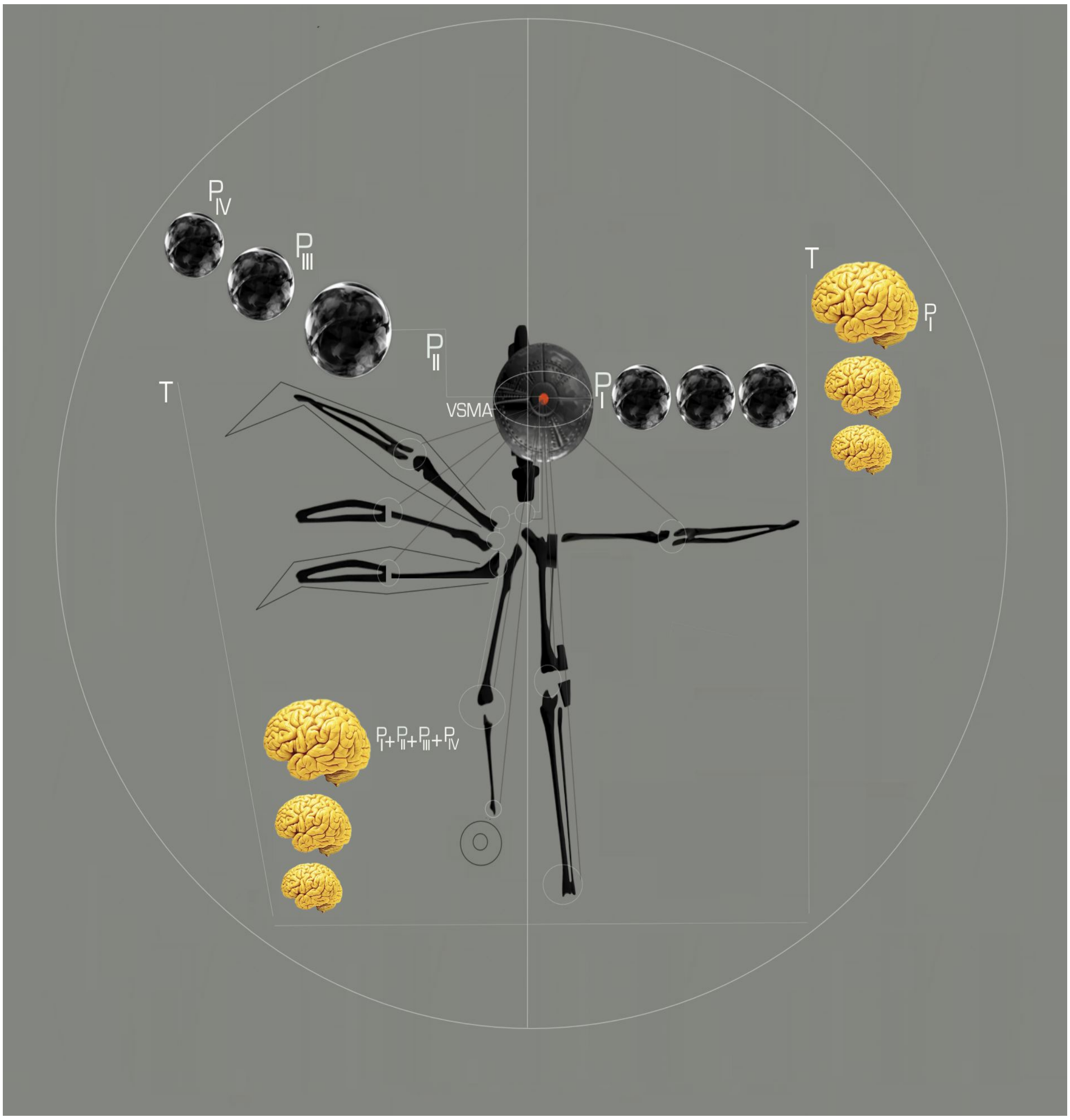

Fig. 10.

Virtual-Sensorimotor Alignment (VSMA)

The proper combination (alignment) between virtual information and the human body (sensory organs; e.g., visual information directly aligned with the visual system – ellipse surrounding the visual system), at the same time enabling a variety of motor bodily actions in the physical world (black lines) to optimize information processing.

Combining sources of virtual information and multiple sources of sensory information from the physical world.

As previously mentioned, studies have investigated how different types of interfaces (manipulative, whole-body motion) affect children's cognitive function. Accordingly, differences in physical affordances, provided by different types of manipulative interfaces, tend to affect children's cognitive function in distinctive ways (conceptual categorization; problem solving; memory recall; numerical learning; and reading comprehension) (Antle et al., 2009; Fails et al., 2005; Glenberg et al., 2004; Manches et al., 2010; Martin & Schwartz, 2005; Melendez et al., 1993, 1995). Manipulative and whole-body motion interfaces affect construction of abstract concepts in children in distinctive ways, albeit revealing contradictory results (Buching et al., 2009; Malinverni et al., 2010).

The previous studies suggest that different sensorimotor experiences seem to affect children's cognitive function in different ways.

So far, researchers have been centered on investigating the effects of different types of physical affordances, provided by different types of manipulative interfaces, on children's cognitive function; the effects of manipulative versus whole-body motion interfaces on children's cognitive function. These studies have been performed in indoor settings.

Peripheral "mouse" versus toy "objects" interfaces require the use of distinct fine motor skills (e.g., tapping on a "mouse" interface versus gripping a physical toy). In addition, peripheral "mouse" interfaces (requiring the use fine motor skills - small muscular groups and precise actions) require the use of physical actions that distinct from whole-body motion interfaces based on computer vision methods (requiring the use of gross motor skills: large muscular groups and less precise actions).

Curiously, we have no knowledge about studies investigating the effects of different types of sensory stimulation offered by manipulative interfaces (e.g., textures) or different environmental settings (interactions with SBCDs in indoor versus outdoor settings) on children's cognitive function.

According to Nelson et al. (2006), even the same task used in different ways, in laboratorial settings, could "Impose different task demands on the subject and reflect different underlying neural circuitry"[32]. Moreover, it is of our understanding that everyday environments (outside of the highly controlled laboratory environments) are noisy environments. They include a variety of sensory information (sensory stimuli) to be processed by the agent (Calvert et al., 2004:11, Posner, 2012).

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32. https://books.google.pt/books?id=aVmrJ2EGZOgC&pg=PT73&lpg=PT73&dq=Impose+different+task+demands+on+the+subject+and+reflect+different+underlying+neural+circuitry&source=bl&ots=l8t44IijyL&sig=qncs8ugUQTsU9H4mQwYe3omTiNo&hl=en&sa=X&ved=0ahUKEwjj5Maikd3MAhVFiRoKHdS2BOUQ6AEIGzAA#v=onepage&q=Impose%20different%20task%20demands%20on%20the%20subject%20and%20reflect%20different%20underlying%20neural%20circuitry&f=false

In effect, and as previously mentioned, sedentary SBCDs, in indoor settings, mostly restrict the child to the processing of visual and auditory information. Thus, one might expect that the use of SBCDs, in everyday environments (e.g., natural environments; also stimulating the cutaneous, proprioceptive and vestibular senses for information processing), may affect children's cognitive function in distinctive ways compared to sedentary SBCDs in indoor settings (stimulating mostly the visual and auditory senses).

We submit that enhanced sensorimotor environments (stimulating the multiple sensory systems in the human body) may cause different levels of stress in the child's neurophysiological system – increases in alertness or sustained attention levels over time (high neuroexcitatory activity) – compared to restricted sensorimotor environments (stimulating mostly the visual and auditory senses). In turn, increases in sustained attention levels over time may optimize children's cognitive performance in virtual settings (e.g., working memory, learning, problem solving, decision-making).

The previous proposition has an evolutionary foundation.

Children evolved to process information in enhanced sensorimotor environments - information processing occurred in a fast changing multisensory world (Lieberman, 2013).

Hunter-gatherer children had to self-attend and self-select a multitude of sensory information in the environment in order to sustain task goals. Attention involves high-competitive perceptual processes: multiple features, from various items, converge and compete to be codified in the same receptive field of neurons at the same time distracting items are filtered (Berger, 2011; Berger et al., 2012; Desimone & Duncan, 1995; Parasuraman, 2000; Posner, 2012; Posner and Petersen, 1990). It is likely that hunter-gatherer children had to develop a proper attentional response in order to self-attend and self-select a host of sensory information from the physical world – e.g., staying alert.

Alertness (also known as attentional arousal) concerns the maintenance of wake-states during a certain event. It prepares the brain for incoming stimuli and influences information processing – enables a fast and efficient response to sensory stimuli. It is essential for the encoding of sensory information (e.g., Parasuraman et al., 1998; Posner, 2004, 2008; Sturm & Willmes, 2001). According to Caine & Caine (1990:66), "The brain absorbs the information of which is directly aware".

Alertness activates the brain-stem-thalamo-cortical networks associated with the regulation of the sleep-wake spectrum (Steriade, 1996, 1999; Posner & Petersen, 1990). The sleep-wake spectrum is linked to variations in neuroexcitatory activity levels: sleep states represent low neuroexcitatory activity; wake-states represent high neuroexcitatory activity (de Lecea et al., 1998; Steriade, 2000). Low levels of alertness are usually identified as "drowsiness" or "distraction" (Berka et al., 2005ab, 2007; Makeig & Jung, 1996). Researchers have emphasized that wake-states rely on afferent sensory stimuli (bottom-up sensory input) (Berka et al. 2007; Moruzzi and Magoun, 1949; Oken et al., 2006).

The process of alertness increases the production of the neuromodulator norepinephrine (NE) - wake states are associated with increases in the production of the neuromodulator NE[33] (or, the presence of NE raises alertness levels in individuals) (Aston & Cohen, 2005; Marroco & Davinson, 1998; Posner, 1975). NE modulation occurs in the frontal and parietal (dorsal areas) lobes in the brain (Lewin et al., 1996). NE is also involved in executive control of attention - involving also dopamine for executive regulation during conflicting tasks (Parasuraman et al., 2005). Interestingly, researchers have demonstrated that PA - particularly aerobic PA - raises the levels of NE in the brain (e.g., Gligoroska & Manchevska, 2012; Jensen, 2000; Ratey & Hagerman, 2013; Sachs & Buffone, 1984; Tantillo et al., 2002; Taylor et al., 1985).

Alertness can be subdivided into phasic (extrinsic) and tonic alertness (intrinsic). Here, we will refer to tonic alertness.

Tonic alertness (sustained attention) concerns the attentional ability to respond to events in the environment and is characterized as a sustained function - maintaining focus during a task in the presence of distracting stimuli. This type of alertness is related to perceptual functions (Posner, 2008; Sadaghiani et al., 2010; Sarter et al., 2001; Valdez et al., 2008).

Sadaghiani et al. (2010:10249) refer that tonic alertness "involves a generalized 'windshield wiper' mechanism and that alpha oscillations serve this purpose by rhythmically and synchronously clearing the flood of sensory information on a rapid time scale to reduce distraction and hence enhance detection of novel and relevant sensory information". These authors demonstrated that tonic alertness is related to upper alpha (10-12Hz) and lower beta oscillations in adults (see also Yan et al., 2010).

Since wake-states rely on afferent sensory stimuli (bottom-up sensory input), we suggest that enhanced sensorimotor environments (stimulating the multiple sensory systems in the human body) may induce increases in wake-states (sustained attention) in children over time compared to restricted sensorimotor environments (stimulating mostly the visual and auditory senses) - causing a different response in the child's neurophysiological system. In addition, we suggest that increases in sustained attention over time may benefit children's cognitive performance in virtual settings (e.g., working memory, learning, problem solving, decision-making).

Valdez et al. (2008:14) refer that "tonic alertness (arousal, general alertness), the more primitive process, is affected first and produces interference with other basic

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33. Glutamate and endorphins are also released during the process of alertness (Pace-Schott & Hobson, 2002).

cognitive processes (…) Therefore, as somnolence and fatigue increase, other components of attention, working memory, and executive functions are affected, producing more frequent and more serious errors that may compromise decision making, learning, and problem solving" (see also Posner, 2008; Sarter et al., 2001). According to Sarter et al. (2001:147), "Sustained attention" represents a basic attentional function that determines the efficacy of 'higher' aspects of attention (selective attention, divided attention) and of cognitive capacity in general".

Sustained attention is related to memory processes in adults. Vogt et al. (1998:167) demonstrated that upper alpha (10-12 HZ) is related to memory performance in adults (memorizing of words) – "the upper alpha band of approximately 10-12 Hz is related to memory performance. Only within this frequency range did we obtain significant positive correlations between memory performance and EEG power". Research also showed that increased alpha power is linked to the inhibition of certain brain regions that may compromise WM maintenance (e.g., Klimesch et al., 2007; Scheeringa et al., 2008).

It has been referenced that sustained functions allow the maintenance of representations of sensory information in the WM system (Carruthers, 2013). Carruthers (2013:10372) states that "Information sustained in WM will be lost if subjects are distracted". Klimesch (1999:181-182) reviewed neuroscientific studies demonstrating that lower alpha power correlates with "difficulties to inhibit distracting environmental stimuli" and difficulties in "maintaining a state of alert wakefulness".

A few studies examined the relation between sustained attention and memory function in children. A recent developmental study (psychology) demonstrated that executive functions such as inhibition, switching, working memory and sustained attention, show improvements between 5 until 8 years of age. Moreover, processes such as inhibition, switching, working memory and sustained attention present small to moderate correlation throughout development (Loher & Roebers, 2013). On the other hand, Magimairaj & Montgomery (2013:3) reviewed studies (psychology) demonstrating that "Developmental improvement in sustained attention has been found to be related to early learning skills, IQ, language, and academic skills".

In chapter 3 (Experiment I), we demonstrate that sustained attention functions benefit episodic memory in children.

Rueda et al. (2004ab) showed that alertness abilities develop until 10 years of age; however results are controversial. Lin et al. (1999) refer that alertness continues to develop after 10 years of age (see also Ridderinkhof et al., 1997). According to Morrison (1982), differences in alertness abilities throughout development can be explained by differences in processing speed: younger children (aged 5 years) seem to react slower to alerting tasks compared to older children (aged 8 years) and adults (e.g., higher reaction-times in visual computerized tasks).

Recent studies evaluating orienting and executive control networks have reported that, from 8 to 10 years of age, the ability to relocate visual attention is very similar to that of adults, nonetheless, the ability to ignore distractive elements is not yet matured by age 10 (Goldberg et al., 2001; Trick & Enns, 1998). Children aged 6 to 8 years have increased difficulty inhibiting irrelevant stimuli (distracting sources) in highly controlled laboratory environments compared to adults (Enns & Brodeur, 1989; Wainwright & Bryson, 2002). Distracting elements activate processes of voluntary executive control of attention (e.g., decision-making processes; activating the frontal brain areas). These processes allow avoiding distractive elements during a certain event. Mental effort is higher in the presence of distractors due to the need to maintain increased focus on the ongoing task. Increased mental effort, in turn, may overload the agent's capacity to process information (Baars, 2007; Duncan & Owen, 2000; Lavie, 2005; Lavie et al., 2005).

Recent studies demonstrate that the ability to avoid distractive elements is dependent on the maturation of the prefrontal cortex (PFC), the brain area related to executive control of attention that matures until adulthood (Fuster, 2002; Wetzel et al., 2009). Conflict resolution mechanisms are already active in early infancy, namely at 7 months (Berger et al., 2006). Recently, Waszak et al. (2010) demonstrated that conflict resolution abilities develop gradually until early adulthood, reaching similar levels to adults by the age of 16 (females maturing fast) (see also Buchman et al., 2011; Davies et al., 2004). Waszak et al. (2010) also demonstrated that children aged 7 show a significant increase in conflict resolution abilities compared to children aged 6.

The previous scientific arguments emphasize that children have less efficient alertness and executive control mechanisms of attention compared to adults - seem to react slower to alerting tasks and have increased difficulty in disengaging from distracting sources. These conclusions were reached in controlled laboratory environments – child interacting mostly with computing devices producing visual and auditory stimuli, in artificially controlled environments.

We do not contradict the idea that young children seem to present less efficient attentional mechanisms compared with older children and adults in controlled laboratory environments. We suggest that children may demonstrate improvements in attentional functions in enhanced sensorimotor environments compared to restricted sensorimotor environments. Our argument has an evolutionary foundation - children evolved to process multiple sources of sensory information in natural environments for millions of years.

Children may demonstrate improvements in alertness functions in enhanced sensorimotor environments - staying alert and thus facilitating processing of information. We suggest that these environments allow the child to maintain focus over time in the presence of distracting stimuli and thus facilitating executive control attention functions. On the other hand, restricted sensorimotor environments may hamper the child's capacity to stay alert, and thus, not optimize information processing. For example, children may have to sustain alertness levels during virtual tasks in order to better memorize events of that same task - accurate representation of virtual events. As referenced by Lewkowicz & Kraebel (2004:656), “adult humans and many nonhuman species perform more efficiently and accurately on various attentional, discriminative, and learning tasks when multiple sources of sensory information are available”.

In fact, we speculate that hunter-gatherer children may have needed to maintain attentional focus in challenging physical environments to survive. Since children had to, for instance, escape from predators, cross a dangerous river, while they walked and ran relatively long distances to forage (Lieberman, 2013), maintaining focus over time was probably synonym to survival: allowing children to better self-attend and self-select information in the surrounding environment to sustain task goals.

Children’s attention mechanisms evolved in connection with enhanced sensorimotor environments. Hence, it may be the case that enhanced sensorimotor environments still optimize attentional functions in modern children, improving sustained attention functions and thus facilitating information processing. Children may have to sustain attention during a virtual task, e.g., to better encode (memorize) episodic events within that same task - accurate representation of episodic events.

The previous described arguments suggest that both the nature of the interactive technological device (e.g., VSMA) and of the environment (enhanced versus restricted) can influence the processing of virtual information in children.

In the previous subchapters we made a suggestion on how to potentiate cognition in children through the use of computing machines. We suggested a particular combination between the human body, computing machines (enhanced sensorimotor user-interfaces) and natural physical environments (enhanced sensorimotor environments) in order to potentiate children’s cognitive development and cognitive performance.

In the next subchapter we will demonstrate how to potentiate children’s physical and mental health through the use of computing machines.

2.1.3 Potentiating physical and mental health in children through computing machines

It is crucial to include PA in children’s daily lives so as to promote healthier lifestyles. PA is defined as any bodily activity, produced by the skeletal muscles, requiring levels of energy expenditure superior to those when resting (Caspersen et al., 1985; National Institutes of Health, 2013; Welk, 2002; World Health Organization, 2013).

Moderate to vigorous PA (MVPA) benefits children’s physical health (Rowland & Bar-Or, 2004; WHO, 2013; Center for Disease Control and Prevention, 2011). The “Surgeon General’s Report on Physical Activity and Health” recommends a daily practice of PA - providing expenditure rates at least of 150 kCalories in order to confer health benefits (US Department of Health and Human Services, 1996). The World

Health Organization (2013) recommends at least 60 minutes of daily MVPA for children aged 5 to 17 years. Accordingly, "Most of the daily physical activity should be aerobic. Vigorous-intensity activities should be incorporated, including those that strengthen muscle and bone, at least 3 times per week"[34].

MVPA optimizes the development of the cardiovascular system[35] and musculoskeletal tissues (contributes to neuromuscular awareness and a healthy body weight[36]). MVPA increases the efficiency of oxygen transfer to the muscles, which, in turn, can metabolize fat resources in addition to carbohydrates; hence, MVPA is a gold standard for preventing children from being overweight and obese (Rowland & Bar-Or, 2004; Spear et al., 2007).

As previously mentioned, MVPA seems to be the gold standard for optimizing cognitive function (including academic achievement) and boost cognitive structure in children (Brown, 1967; Chaddock et al., 2010a, 2010b; Davis et al., 2007, 2011; Ellemberg & St-Louis-Deschênes, 2010; Gabbard & Barton, 1979; Grissom, 2005; Hillman et al., 2005; 2009ab, 2011; Pesce et al., 2009; Tomporowski et al., 2008).

Moderate values of heart rate (HR) are recommended in order to benefit children's health. HR values should target 140 to 160 beats per minute (Rowland & Bar-Or, 2004). A high HR frequency correlates with high levels of PA; a low HR frequency correlates with low levels of PA (Armstrong & Welsman, 2000). HR frequency may vary due to emotional states or excitement levels (Rowland & Bar-Or, 2004). Children's HR values increase in situations of excitability or fear: may increase 20-40 beats per minute (BPM) above the actual resting value (even in situations of moderate intensity) (Lumley et al., 1993). PA in hot or humid climates tends to increase HR values (15 to 20 BPM higher than in neutral climates). HR values also tend to be higher if the produced mechanical work includes gross motor skills (Rowland & Bar-Or, 2004). The use of equipment and larger spatial areas increases children's PA levels (Ridgers et al., 2010; Verstraete et al., 2006).

Hence, to increase PA levels, children should be encouraged to perform activities in large spatial areas, such as NPE, offering climatic variation (to increase HR values).

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[34] http://www.who.int/dietphysicalactivity/factsheet_young_people/en/

[35] A healthy cardiorespiratory system is associated with multiple health benefits in children, namely, improvements in cardiac output in rest or exercise states and myocardium contraction; improvements in resting heart rate and respiratory rates (become lower in submaximal exercise) (Center for Disease Control and Prevention, 2010; Nottin et al., 2002; Rowland et al., 1998; WHO, 2013).

[36] PA is associated with the development of motor skills and improves muscular strength (including muscular endurance and flexibility) in children (Braswell & Rine, 2006; Gallaue & Ozmun, 2005; Jensen, 2000; May-Benson & Cermark, 2007; Montagu, 1972; Neto, 2003; Payne, 1995; Pellegrini & Smith, 1998; Rowan, 2010; Taylor et al., 1985; Sachs et al., 1984). Strengh training aims to induce morphological and functional changes in body tissues and systems (affecting muscles, bones, ligaments and tendons; e.g., preventing obesity and postural problems in children) (Rowland & Bar-Or, 2004; Willmore & Costill, 1999). Strength training increases children's self-esteem through improved body image (WHO, 2013).

As the use of equipment may increase levels of PA, children should also be encouraged to interact with a variety of physical tools (user interfaces) fostering the use of gross motor skills. Because children's HR values may increase in situations of excitability or fear, video game play may be an optimal solution to produce this effect. In fact, children refer to video games as engaging mainly due to the opportunity of experiencing challenging fantasy worlds (Hamlen, 2011).

In this way, computing machines should encourage whole-body motion (use of gross motor skills) in natural environments (large spatial areas offering variation of climatic conditions) in order to increase children's PA levels – to attain the MVPA levels that benefit physical and mental health.

Moreover, computing machines should promote body-to-body and face-to-face interaction to avoid anxiety, depression and aggressive behaviors and improve bodily communication in children. This objective can be achieved through technological configurations encouraging children to have direct human physical interaction. The VSMA allows the child to perform face-to-face and body-to-body interaction, while at the same time, virtual information is visualized, e.g., on a head-mounted see-through display (auditory displays may also serve this goal).

Computing machines should also encourage interaction with natural environments, as natural bright light improves the development of the visual system (structure and function; e.g., improving the eyes ability to perform near and distant focus) (e.g., Morgan & Rose, 2005; Mutti, 2007; Rose et al., 2008). Natural environments are associated with vitamin D synthesis for blood level normalization, increased bone mineral density and autoimmune disease prevention; stress to the immune system (contact with germs); reduce stress levels and aggressive behaviors and improve cognition in children (e.g., restore attention levels) (Dannenmaier, 1998; Fjortoft & Sageie, 2000; Harmon, 1951; Jensen, 2000; Kellert, 2002; Kuo & Faber, 1997; Lieberman, 2013; Louv, 2006) (see fig. 11).

We have now described how to potentiate cognitive development/performance and physical and mental health in children through the use of computing machines. We proposed a particular synergy between the human body, computing machines and natural environments. This combination represents the foundation of the Biosymtic (Biosymbiotic Robotic) Approach to Human Development and Evolution.

A Biosymtic Approach to Human Development and Evolution is operationalized through a new form of computing devices that we have termed Biosymtic (Biosymbiotic Robotic) devices. This will be the topic of the next subchapter.

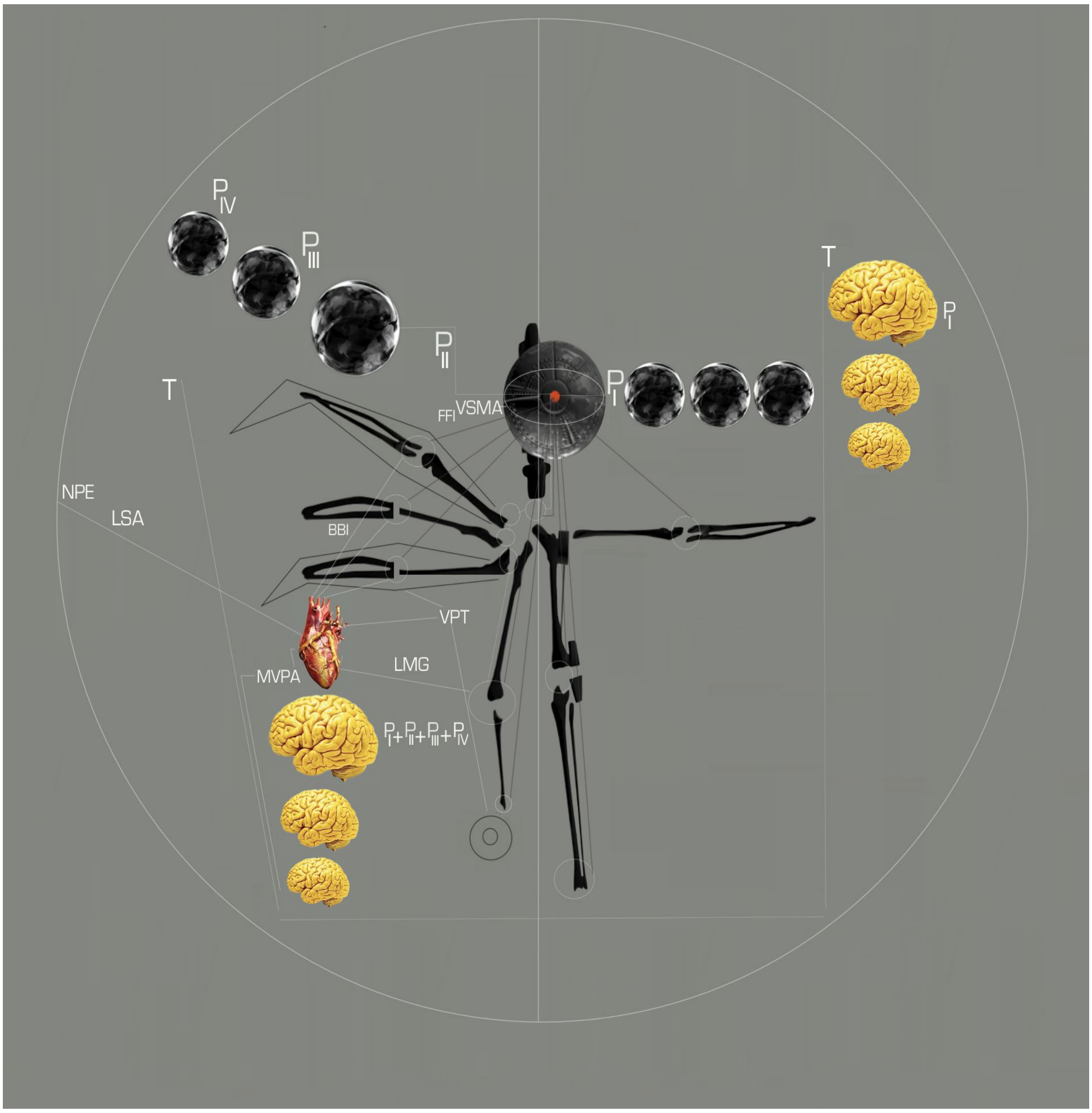

Fig. 11.

Potentiating physical and mental health

In order to increase PA levels, children should be encourage to perform PA in Large Spatial Areas (LSA) such as Natural Physical Environments (NPE) that offer variation on climatic conditions. Activities should involve Large Muscular Groups (LMG) and thus gross motor skills performance. Children should be encouraged to interact with a variety of physical tools (VPT) encouraging for gross motor skills practice (e.g., extending physical interfaces).

Computing machines should encourage body-to-body interaction (BBI) and face-to-face interaction (FFI) in order to avoid anxiety, depression and aggressive behaviors and improve bodily communication in children (e.g., allowed through VSMA).

Computing machines should encourage children to interact with natural physical environments (NPE) in order to benefit physical and mental health (improving the development of the visual system; optimizing cognitive function; reducing stress levels and aggressive behaviors; synthesis of vitamin D for normalization of blood levels, increased bone mineral density and prevention of autoimmune diseases; stress to the immune system that requires contact with germs to mature properly).

2.2 Biosymtic (Biosymbiotic Robotic) Devices

2.2.1 Autonomous, semi-autonomous and manual robots

Robots[37] may be classified as *autonomous*, *semi-autonomous* or *manual*.

An *autonomous robot* refers to a self-operating machine (extending from physical robots to virtual software agents) guided by automatic controls - or a "machine designed to follow automatically a predetermined sequence of operations or respond to encoded instructions" (Cooper, 1983:22). An autonomous robot is able to sense the environment and act within it, demonstrating adaptive behavior - "endowed with the capacity to interpret and to reason about a task and about its execution, by intelligently relating perception to action" (Giralt, 2008:10). An autonomous robot is able to perform various complex tasks without human control (e.g., speech/gesture production and recognition; navigation; social interaction). A *semi-autonomous robot* implies some degree of autonomy combined with human control (human operator controlling the robot's actions; autonomy to help the user). A manual robot is totally controlled by a human operator (Bar-Coehn & Hanson, 2009; Brooks, 1985; Cooper, 1983; Giralt, 2008; Menzel & D'Aluisio, 2000; Murphy, 2000; Neimeyer et al., 2008; Shinozawa & Yamato, 2007; Siciliano & Khatib, 2008).

Modern autonomous robots evolved from automated machines - machines endowed with automatic mechanisms (e.g., Heppenheimer, 1985; Siciliano & Khatib, 2008).

The first automated machine appeared in 1400 BC, the Babylonian' clepsydra water clock, which made use of liquid flow regulation to measure time[38]. Much later, around 1620, Cornelis Drebbel developed an automated control system to regulate the temperature of a furnace that was part of an incubator. Franklin et al. (2009:10) describe this system as follows, "The furnace consists of a box to contain the fire, with a flue at the top fitted with a damper. Inside the fire box is the double-walled incubator box, the hollow walls of which are filled with water to transfer the heat evenly to the incubator. The temperature sensor is a glass vessel filled with alcohol and mercury and placed in the water jacket around the incubator box. As the fire heats the box and water, the alcohol expands and the riser floats up, lowering the damper on the flue. If the box is too cold, the alcohol contracts, the damper is opened, and the fire burns hotter.

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[37] The word "robotics" derives from the word "robot". The Czech writer Karel Capek used the word "robot" for the first time in 1920 in a play called "Rossum's Universal Robots" (R.U.R). This play portrayed the creation of "artificial people" or "robots" (created in a factory), whose goal was to relieve humans from the burden of work. The term "Robot" comes from the Czech word "robota", which means *labor* or *work* (Khemani, 2013).

[38] http://en.wikipedia.org/wiki/Water_clock

The desired temperature is set by the length of the riser, which sets the opening of the damper for a given expansion of the alcohol".

Automated controlled systems turned out to be used by many inventors, namely by those whose goal was to create artificial machines similar to animals (in appearance and functional abilities) - ranging from ducks to humans beings.

The first humanoid automated machines were developed by Al-Jazari in 1200 (e.g., drink-serving waitress and a music band controlled by a an automated water mechanism)[39] followed by the humanoid automated machines of Leonardo Da Vinci in 1500 (Rosheim, 2006; Siciliano & Khatib, 2008).

According to Rosheim (2006), renowned NASA roboticist, Leonardo da Vinci designed the first mobile programmable mechanical computer - automated controlled automaton - while serving the Medici in 1478. This automaton consisted of a mechanical wood cart with differential gears, cables and wheels. Rosheim (2006:21) refers that "This automaton was a precursor to mobile robots and was perhaps the earliest computer in western civilization". The author speculates that Leonardo could have used this automaton as a platform for a self-propelled mechanical Lion - "a mechanical lion that walked a few steps and then rose on its hindquarters, opening its breast to show it was full of fleur-de-lis".

Leonardo da Vinci also developed a humanoid automaton: the armored "Robot Knight" made of wood, bronze and leather. This automaton resembled a human: it could move its arms (raise and lower its arms) and move its head (included a flexible neck)[40]. Da Vinci created and developed automated machines that resembled birds and that could fly. Interestingly, most of the Leonardo's inventions were inspired in biologic creatures.

Leonardo da Vinci influenced many inventors in the following centuries. For instance, in the 18th century, Jacques de Vaucanson (1737) developed three automated mechanical machines: "The Flute Player" (played the flute; air pressure propelled mechanism); "The Tambourine Player" (played the tambourine; air pressure propelled mechanism); and "The Digesting Duck" (could digest grain, drink water, defecate and flap its wings)[41]. Jacquet-Droz developed the mechanical programmable "Writer" (presented to the public in 1772): a mechanical wood carved structure resembling a young boy that dipped a feather into an inkwell to write on a blank page (the eyes of the machine followed the action of the arms)[42] (Heppenheimer, 1985; Khemani, 2013; Siciliano & Khatib, 2008).

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39. http://en.wikipedia.org/wiki/Al-Jazari
40. http://historycomputer.com/Dreamers/LeonardoAutomata.html
41. http://history-computer.com/Dreamers/Vaucanson.html
42. https://www.youtube.com/watch?v=bY_wfKVjuJM

These automated machines made use of mechanical combinations (e.g., elaborated springs and clockwork mechanisms) and, in some cases, natural energy resources to operate (e.g., water, air). As stated by Heppenheimer (1985:42), “they executed accurately and repetitively a detailed sequence of motions, controlled by a program”.

In line with Heppenheimer (1985:42), “Artists, from ancient times to the Renaissance, had mastered the technique of simulating human form – the art of sculpture (…) builders of automata had created a new art – reproducing human motions – and developed its techniques to a high degree. But to go further, to advance beyond blind preprogramming, it would be necessary to give a machine the power to make decisions. That mean it would have to store and handle information, and to loop and branch among possible alternative paths within a program (…) As early as 1788, James Watt devised a flyball governor, featuring two whirling balls able to swing outward by centrifugal force. It was linked to a steam engine, and the outward swing of the flyballs measured the engine speed. It was, in short, a simple feedback control mechanism – the world’s first (…) which would be essential in devising the robots of the twentieth century”.

Automated controlled systems (or feedback control mechanisms) emerged, in great part, around 1922 and had its apogee during World War II (e.g., self-guiding mechanisms; jet aircrafts; V-2 rocket[43]). One example is the V-2 rocket, it had an inertial guidance system based on a gyroscope “to measure its velocity and cut off fuel engine at the proper moment” (Heppenheimer, 1985:54). In essence, automated controlled systems follow a central idea, “a system’s output can be measured and fed back to a controller of some kind and used to effect the control” (Franklin et al., 2009:1).

Automated controlled systems along with programmable computers came to support the development of modern artificial machines.

The first attempts to assign biological functions to artificial machines started in the mid-20th century, with the arrival of Artificial Intelligence (AI) as a scientific field. AI is the science of making machines act intelligently[44].

The emergence of the AI scientific field results from a combination between mechanics, electronics and computing control. One of the central goals of AI is the development of artificial machines that display humanlike mental abilities (Khemani, 2013; McCarthy et al. 1955; McCarthy & Hayes, 1969; Minsky, 1961; 1985; Murphy, 2000; Neumann, 1958, 1966; Shannon, 1950; Turing, 1944, 1950). According to Khemani (2013:50), “The study of Artificial Intelligence is concerned not so much with defining intelligence, but the study of the different kinds of reasoning processes that would

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[43] http://en.wikipedia.org/wiki/V-2_rocket

[44] The percursors of AI associate intelligence to the ability to solve problems.

come together to create an intelligent system. And an intelligent system would be one that can represent its domain of activity, perceive the state of the domain, and reason in a manner to achieve its goals".

AI is the foundation of modern Robotics, or as Siciliano & Khatib (2008:1) put it, "the science and technology of robots". Roboticists are working on artificial machines aiming to emulate physical and cognitive features of a variety of biological organisms (e.g., insects, reptiles, birds, humans). Robots are now being integrated in human contexts - *human-centered robotics*. Autonomous, semi-autonomous and manual robots have been used in industrial manufacturing (e.g., competitive manufacturing), space exploration (e.g., explore remote planets), hazardous settings (e.g., manipulate radioactive materials), rescue (e.g., natural disasters), medical systems (surgery), rehabilitation and health care (e.g., to help disabled people; automated health care monitoring and care) and education (e.g., Hägele et al., 2008; Krebs et al., 1998; Lum et al., 2002; Van der Loos & Reinkensmeyer, 2008; Ortmaier et al., 2007; Siciliano & Khatib, 2008; Yoshida & Wilcox, 2008).

Autonomous robots make use of predefined computational models (based on algorithms) to demonstrate autonomous control - independent of any sort of direct human intervention. Autonomous robots are able to sense, and act in, the environment without real-time human control (e.g., speech/gesture recognition and production; navigation; mimic human behavior; social interaction). In turn, the ability to sense/act in the environment (including adaptive behavior) has been linked to a certain degree of intelligence in autonomous robotic machines (Bar-Coehn & Hanson, 2009; Brooks, 1985, 1991; Khemani, 2013; Menzel & D'Aluisio, 2000; Murphy, 2000; Shinozawa & Yamato, 2007; Siciliano & Khatib, 2008).

Roboticists have been developing predefined computational models, inspired in the modus operandi of biological systems, to implement autonomous control in robotic systems[45] (e.g., Bar-Cohen & Breazeal, 2003; Delcomyn, 2007; Featherstone & Orin, 2008; Floreano et al., 2008; Franceschini et al., 1992; Mataric, 1998; Meyer & Guillot, 2008; Russel & Wijaya, 2003; Webb & Consi, 2001). In some cases, computational models are combined with physical robotic structures that mimic the structure of biological organisms (e.g., Franceschini et al., 1992; Russel & Wijaya, 2003).

Biologists have been cooperating with roboticists in order to develop Biologically Inspired Robots.

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45. Pioneering AI scientists have developed computational models that try to emulate the functional mechanisms of the human brain (McCarthy et al. 1955, 1969; Minsky, 1961; 1985; Moravec, 1985, 1988; Neumann, 1958, 1966; Shannon, 1950; Turing, 1948, 1950).

For instance, Robert J. Full is a biologist who helps roboticists build robots that follow the structure, function and evolutionary principles of biologic organisms (e.g., biomechanical, physiologic, developmental and evolutionary principles). J. Full analyzes the dynamics of animal locomotion (e.g., from ghost crabs, centipedes, geckos) to use as a model for building locomotion into robots. These models allow robots to demonstrate autonomous motor control in the physical world (adaptive motor behavior in various physical settings). J. Full inspired the making of robots such as "Ariel the crab-robot"[46] that autonomously explores mines, either underwater or land (this robot model follows the structure of a biologic crab)[47].

Another example is Evolutionary Robotics, a subfield of robotics inspired in biology. Floreano et al. (2008:1423) state that Evolutionary Robotics "is a method for the automatic creation of autonomous robots. It is inspired by the Darwinian principle of selective reproduction of the fittest, captured by evolutionary algorithms. In evolutionary robotics, robots are considered as autonomous artificial organisms that develop their own control system and body configuration in close interaction with the environment without human intervention".

Semi-autonomous and manual robots include, for example, *telerobotics* (e.g., Murphy, 2000; Neimeyer et al., 2008). Telerobotics consists of robotics at a distance, or, as stated by Neimeyer et al. (2008: 741), "robotics with an human operator in control or human-in-the loop". According to the authors, "telerobotics implies a user that remotely controls a robot (e.g., motion and/or forces) to interact with a distant environment (…) the user cannot (or will not) physically reach the environment (…) any high-level, planning, or cognitive decisions are made by the human user, while the robot is responsible for their mechanical implementation. In essence, the *brain* is removed or distant from the body". Telerobotics involves the use of controlling interfaces such as keyboards, joysticks, monitors to support the communication between the user and the robot.

Telerobotics comprises a variety of computational models - control architectures. As stated by Neimeyer et al. (2008:746), "telerobotic systems provide information to and require commands from the user. Their control architectures can be described by the style and level of this connection". For instance, *direct control* or *manual control architectures* (the user controls the robot directly without any automated support) imply no autonomy in the system (manual robots); *shared control architectures* imply some degree of autonomy in the robot to help the user (semi-autonomous robots); and *supervisory control architectures* in which "The supervisor gives high-level directives to and receives summary information from, in this case, the robot" (see also Murphy, 2000).

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[46] Developed by the Defense Advanced Research Projects Agency (DARPA) and iRobot.

[47] http://robosapiens.mit.edu/ariel.htm

Telerobotics has been applied in many fields, e.g., space exploration, hazardous settings (e.g., manipulate radioactive materials), rescue and medical systems (surgery) (Ortmaier et al., 2007). For example, "Robonaut 1", is a humanoid teleoperated robot (manual robot) for space exploration missions (extravehicular activity or space walks). NASA developed this machine in collaboration with the Defense Advanced Research Projects Agency (DARPA). "Robonaut 1" was built to perform manipulative tasks via teleoperated control in environments that become too risky for humans[48]. "Robonaut 1" evolved to "Robonaut 2": a semi-autonomous robot that doesn't need constant supervision[49].

In case the reader desires to expand knowledge about computational models associated to autonomous robots, semi-autonomous robots or manual robots, he may access the following external Web address provided via URL - http://biosymticrobotics.com/resources/ASMR_FERRAZ.pdf

We have performed a general description about the nature of autonomous, semi-autonomous and manual robots. Recently, researchers have been developing autonomous, semi-autonomous and manual robotic systems to interact with children.

In the next subchapter we will describe the current Child-Robot Interaction paradigm.

2.2.2 Child-Robot Interaction

Researchers have been developing autonomous, semi-autonomous and manual robots to interact with children. We allude to the field of Human-Robot Interaction. This scientific field is concerned with the design of human-robot interfaces "that makes it easier for the people to interact with robots" (Sarkar, 2007:V). In the sub-field of Child-Robot Interaction (CRI), robots have been developed and used for educational purposes (encourage learning; including programmable and tour-guide robots), entertainment purposes (entertainment robotics) and rehabilitation and health purposes (assistive robotics) (e.g., Barakova, 2011; Beran et al., 2011; Brisben et al., 2004; Colton et al., 2009; Druin & Hendler, 2000; Espinoza et al., 2011; Fujita et al., 2000; Giannopulu, 2013; Gories et al., 2008; Kornhauser et al., 2007; Kozyavkin et al., 2014; Lahey et al., 2008; Lathan et al., 2005; Marti, 2012; Martin et al., 2000; Miller et al., 2008; Papert, 1980; Resnick, 1990; Tanaka et al., 2007; Van der Drift et al., 2014; Willeke et al., 2001).

Robots have been used to encourage child learning - educational purposes. For instance, in 1967, Papert and his colleagues, at MIT, developed a computer program called "Logo". This program allowed children to write their own computer programs

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[48] http://robonaut.jsc.nasa.gov/R1/index.asp
[49] http://robonaut.jsc.nasa.gov

in order to control the motor behavior of a physical robot - turtle mobile robot. Children used a SBCD to program mathematical patterns to be drawn by the robot on physical surfaces. Papert's work was the foundation of a new generation of robotic systems for educational settings.

Researchers have developed extensions of the "Logo" program. For instance, Michael Resnick developed a program called "MultiLogo" allowing children to program robotic Lego bricks. This program aims to improve elementary-school children's learning (Resnick, 1990; see also Kornhauser et al., 2007). MIT researchers, in collaboration with the LEGO Group, introduced new robotic programmable systems to the market in 1998: the LEGO® Mindstorms™. LEGO® Mindstorms™ consists of a series of kits - hardware (e.g., brick computer; modular sensors and servo motors; connection cables; lego bricks to create a customizable mechanical system) and software (e.g., the NXT-G graphical programming environment) - to create and build programmable robots. LEGO® Mindstorms™ were developed to encourage children and teens to learn about science, technology, engineering and mathematics (STEM Education)[50][51](e.g., Martin et al., 2000).

Other researchers have been developing programmable robotic systems to help children learn through play game activities (i.e., programmable mobile robots) (e.g., Lahey et al., 2008)[52] [53].

Miller et al. (2008:1283-1284), define educational robots as devices that involve "both hardware (preassembled or as kits or components) and software (both as source code and programming environments)" components. The authors refer that educational robots are integrated in the field of Human-Robot Interaction (HRI) as they "interact with individuals and groups with the goal of inspiring learning, providing engaging recreation, and even providing therapeutic value".

Up to this point, programmable educational robots have been encouraging children to interact with SBCDs, involving visual and auditory information-gathering scenarios and user interfaces based on hand-eye coordination skills - e.g., "keyboard", "mouse", "touch-screen" interfaces. These interfaces are used to program physical actions/behaviors to be performed by robots autonomously - robots programmed through source code (e.g., Kornhauser et al., 2007; Lahey et al., 2008; LEGO® Mindstorms™; Martin et al., 2000; Papert, 1980; Resnick, 1990; Willeke et al., 2001).

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50. http://education.lego.com/nb-no/preschool-and-school/upper-primary/8plus-mindstorms-education
51. http://www.media.mit.edu/sponsorship/getting-value/collaborations/mindstorms
52. http://www.aldebaran.com/en/humanoid-robot/nao-robot
53. http://me.lab.asu.edu/alert

Researchers have also been developing non-programmable robots with educational purposes. For instance, tour-guide robots have been developed to guide children and adults in museums (e.g., Willeke et al., 2001). Tour-guide robots have autonomous mobility. These systems may perform verbal communication and usually allow for tangible formats of interaction (e.g., touch-screen interfaces to interact with digital information).

Entertainment robots have also been developed for children. For instance, the AIBO ERS-110 dog from Sony (a pet-robot) was developed to provide entertaining experiences for children. Children may give explicit verbal instructions to AIBO in order to observe it playing with a ball or dance (autonomous behavior). AIBO has preprogramed answers to verbal commands[54] (Fujita et al., 2000). Melson et al. (2005) performed a study comprising 72 children (aged 7 to 15 years) to evaluate their interaction with the AIBO pet-robot. Children's opinions were gathered through interviews while playing with the pet-robot. Children ascribed mental states, social behaviors and moral standing to the pet-robot.

Rehabilitation robots have been used to assist children with special needs (assistive or rehabilitation robotics). According to Van der Loos & Reinkensmeyer (2008:1245), rehabilitation robotics relates to the development of technology that helps "people who are limited in major life activities". Rehabilitation robots (manual and autonomous) have been used to help children with the following conditions: autism, cerebral palsy, diabetes, language impairments and motor impairments[55] (e.g., Barakova, 2011; Brisben et al., 2004; Colton et al., 2009; Giannopulu, 2013; Kozyavkin et al., 2014; Lathan et al., 2005; Marti, 2012; Tanaka et al., 2007; Van der Drift et al., 2014).

For example, "CosmoBot" is a telerehabilitation humanoid robot (remotely operated; manual robot) for children aged 5 to 12 years with special needs (e.g., autism; cerebral palsy; down syndrome; muscular dystrophy). This robot was developed by AnthroTronix Inc. "CosmoBot" is an assistive tool for therapists - they use "CosmoBot" to motivate children to develop cognitive skills faster (e.g., language skills). The therapist or the child may operate the "CosmoBot" via computer-based software (e.g., control the movement of the robot through a "keyboard interface", a "microphone", or a wearable glove sensor)[56] (Brisben et al., 2004; Lathan et al., 2005). Apparently, autistic children communicate better with robotic systems than with humans, since robots present more simplistic communication interfaces (Dautenhahn &Werry, 2004; Robins et al., 2005).

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[54] https://www.youtube.com/watch?v=4pkUU9nPpNk

[55] https://www.youtube.com/watch?v=M84NAZ4aJFs

[56] http://www.anthrotronix.com/index.php?option=com_content&view=article&id=81&Itemid=144
https://www.youtube.com/watch?v=zU2H4Ji1lj4
https://www.youtube.com/watch?v=wbb6yVC4Lg8

Marti (2012:2) developed a robot play companion for children with special needs - "Iromec"[57]. "Iromec" is a mobile robot (resembles a vacuum cleaner; semi-autonomous robot) with two graphical interfaces (displaying the mouth, eyes and other robot functions). It integrates pluggable components (e.g., textiles) that can be attached to the robot's structure in order "to explore embodied interaction as a means to promote the acquisition of social skills, in particular in children with relational disturbances". For instance, children may tickle the upper part of the robot (including a pressure sensitive textile) to obtain different emotional expressions from the robot (graphical interfaces). Furthermore, by clapping hands children can control the robot's movement. According to Lehmann et al. (2011), "Iromec" has a general positive influence on the development of children's social skills.

Health robots have been used to promote children's physical and mental health in hospital environments (Espinoza et al., 2011; Gories et al., 2008).

Espinoza et al. (2011) developed a project (ALIZ-E) that makes use of a robotic humanoid system (NAO[58]; semi-autonomous robot) to help children with diabetes in hospital environments. According to the authors, "The project aims to develop companion robots able to engage child users and support them in learning about and managing their metabolic condition" (Espinoza et al., 2011:337). An operator communicates verbally with the child as if it were the robot - incites the child to be physically active by encouraging her to imitate its dance moves (autonomous dance moves).

Goris et al. (2008) developed a teleoperated robot (manual robot resembling an elephant-like animal) to improve the living conditions of children in hospitals - "entertainment, communication, and medical assistance" (Goris et al., 2008:29). Human operators control this robot in order to establish communication with children (e.g., medical staff, researchers). The robot is able to express emotions through facial expressions[59].

Health robots have also been used to promote physical health in adults.

Kidd (2008) developed the first social robot (autonomous robot) that helps adults engage in a long-term dieting program. The robot is called "Autom". It includes four-degrees of freedom (moves its head and eyes) and a touch-screen interface. "Autom" was designed to produce speech in order to interact with the user: establishing communication with the user one to two times a day, for an average of 5-minutes, so as to track weight loss information (e.g., exercise levels and calorie's consumption).

Graether & Muller (2012) developed the "Joggobot", a social exertive flying autonomous robot for joggers. This drone (Parrot AR.Drone) tracks the jogger through a

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57. https://www.youtube.com/watch?v=n7bjPYG0bY8
58. http://www.aldebaran.com/en/humanoid-robot/nao-robot
59. https://www.youtube.com/watch?v=Bs4cPrN-oBk

built-in camera that detects a visual marker on a t-shirt (worn by the jogger). "Joggobot" maintains itself in front of the jogger while he walks or runs. Interestingly, the authors refer that "This simple behavior allows for walking and jogging with Joggobot in straight lines (…) Although joggers might not always run in straight lines, such routes are not uncommon: jogging paths in parks are often straight and treadmill running follows an 'imaginary' straight line". A few users interacted with "Joggobot" outdoors (20 minutes) and indoors (10 minutes). Accordingly, "An indoor environment allowed for more refined control due to the absence of weather influences, such as wind, which can negatively affect the Joggobot" (Graether & Muller, 2012:3). The authors indicated that the "Joggobot" promoted an "engaging exertion experience" in users (Graether & Muller, 2012:4)[60].

Educational, entertainment, rehabilitation and health robots that communicate with children, through verbal and/or non-verbal cues, are considered social robots.

Breazeal is a pioneer researcher in the development of social robots. Breazeal's research is focused on understanding the social relations between humans and robots (Breazeal, 2000; 2002; 2008). For instance, "Social (or sociable) robots are designed to interact with people in a natural, interpersonal manner – often to achieve social-emotional goals in diverse applications such as education, health, quality of life, entertainment, communication, and collaboration" (Breazeal et al., 2008:1349). Breazeal states that aspects such as appearance, eye contact, look-at-behavior and speech (production and recognition), in robots, tend to be critical in human-robot interaction.

In a recent study, Tung & Chang (2013:237) observed that children perceive robots "more socially and physically attractive when they exhibit sufficient social cues. Specifically, the display of social cues by robots that are less anthropomorphic can significantly enhance children's social perceptions of them (…) robots designed for children do not require excessively human-like designs. Middle to low-level anthropomorphic designs combined with appropriate social cues can enhance children preferences and acceptance of robots". In a study comprising 198 children aged 5 to 16 years, Beran et al. (2011:539) verified that "a significant proportion of children ascribe cognitive, behavioral, and especially affective, characteristics to robots".

Summarizing, educational robots (including programmable robots and tour-guide robots) have been encouraging children to interact with SBCDs, involving visual and auditory information-gathering scenarios and user interfaces based on hand-eye coordination skills (e.g., "keyboard", "mouse", "touch-screen" interfaces) (e.g., Fujita et al, 2000; Kornhauser et al., 2007; Lahey et al., 2008; LEGO® Mindstorms™; Martin et al., 2000; Papert, 1980; Resnick, 1990; Willeke et al., 2001). We found one study concerning

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60. https://www.youtube.com/watch?v=zivyJ05VuAA

health robotics, in children, through whole-body interaction: a robotic system (tele-operated) encouraging children to perform whole-body motion by imitating dance movements (Espinoza et al., 2011).

How do children imagine their lives in the presence of robots?

In a study conducted by Latitude$_0$ in collaboration with Lego® and Learning Institute & Project Synthesis in 2012 (Robots@ School$_0$), a group of 348 children (aged 8 to 12 years), from various countries (United States France, Australia, Germany, South Africa, and United Kingdom), was asked to imagine their lives in the presence of robots in learning contexts - classrooms settings and outside of school settings. Children were encouraged to imagine, select, draw and write a story. The researchers developed a coding scheme to classify the nature of child-robot relationships and the dimension of child-robot activities (play, learning, creation and exploration).

Children expressed that robots could make excellent friends as they would be able to communicate with them (ascribing social skills to robots). Robots would also be fun - making learning more fun even when dealing with boring subjects - and smart (pre-loaded with useful knowledge to be shared with children). Furthermore, robots were considered better companions, compared to parents and teachers, because they would have more time and patience for them (encouraging and tolerant).

As reported by a child (boy, 12 years) "RJ is a cool dude robot. He looks like a transformer robot, and with a click of a button he shows me his screen. It then looks like a laptop. I may type my work into the laptop, instead of writing. Then RJ fixes my spelling, and tells me when my sentence is wrong. That way the teacher does not see all the mistakes, but can see how good my idea is" (Latitude$_0$ et al., 2012:9).

While helping children with their responsibilities (e.g., doing homework, cooking), robots could free their time to be more creative and to learn new things (25% of the sample). 38% considered playing with robots as important as learning. In fact, children expressed that play, fun and learning are interconnected factors. Interestingly, children pointed to a connection between physical and academic skills because it was fun – stating that robots could expand space for creativity and learning through physical play.

A child (boy, 10 years) reported that, "When I got to school this morning, my teacher surprised me by giving me a robot to help me with my schoolwork. We played football at recess with my friends. In class, he wrote for me and helped me to think. Leaving school he carried my bag and transformed into a bike" (Latitude$_0$ et al., 2012:7).

Moreover, children emphasized that robots could provide them with emotional support by being their friends (behaving human-like). According to the researchers, "While many adults think about technology as separate from humanness, kids tend to think of it as fundamentally human (…) It comforts us; it keeps us company; it helps us learn and grow; and, in some cases, it can fulfill certain emotional needs more reliably than other people". Bo Stjerne Thomsen - Senior Research Manager at LEGO® Learning Institute - refers that “This study clearly emphasizes, that if you ask children about their relationship to robots, it will not only provide a glimpse into the future of technology but, more importantly, the children will describe to us how we should imagine our future relationship to each other” (Latitude[0] et al., 2012:10).

From the previous set out arguments, and taking into account children’s opinions and preferences regarding interactions with robots, we may say that:

Children ascribe cognitive, behavioral, and especially, affective characteristics to robots (behaving human-like);

Children describe robots as knowledgeable partners (pre-loaded with useful knowledge to be shared with children);

Children describe robots as patient and tolerant partners that help to perform day-by-day tasks and encourage creative learning;

Children associate robots to playful and fun learning, pursuing a connection between physical and academic skills (robots encourage creativity and learning through physical play).

Although children feel driven to interact with robotic systems that connect physical and academic skills, most of the developed educational robotic systems have been encouraging children to interact with SBCDs (indoors), involving visual and auditory information-gathering scenarios and user interfaces based on hand-eye coordination skills - restricted sensorimotor devices linked to sedentary behavior.

As previously mentioned, enhanced sensorimotor experiences tend to benefit children’s cognitive development and cognitive performance; to benefit physical and mental health, children should be encouraged to engage in MVPA; MVPA seems to be the gold standard for optimizing cognitive function (including academic achievement) and boost cognitive structure in children. Furthermore, while interacting with SBCDs in indoor settings, children lose most of the benefits from natural environments.

In order to potentiate physical and mental health in children (including cognitive development and cognitive performance), we have developed a new format of robotic devices - *Biosymtic (Biosymbiotic robotic) devices*[61]. These devices follow the principles described in subchapter 2.1.

In the next subchapter we will describe the nature of Biosymtic devices, including its computational models.

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[61] The Biosymtic (Biosymbiotic Robotic) devices here presented were developed by the doctoral student in charge of the present work.

2.2.3 The nature of Biosymtic (Biosymbiotic Robotic) Devices and associated computational models

The central goal of a Biosymtic (Biosymbiotic Robotic) device is to potentiate children's physical and mental health (including cognitive development and cognitive performance), while helping them connect to challenging natural environments offering multiple possibilities for sensory stimulation and increasing physical and mental stress to the organism [stress to the multiple systems in the human body - e.g., skeletomuscular, cardiovascular/respiratory, immune, endocrine and nervous system (including mental and emotional arousal)].

A Biosymtic (Biosymbiotic Robotic) device (BSD) is characterized as an artificial system (ranging from physical robots to virtual software agents) displaying automatic control functions while (two modes):

1) Directly connected to a human organism (human-integrated automatic control; working as a human-robot interface)

2) Disconnected from a human organism (autonomous control; working as an autonomous robot)

A BSD is able to *sense* and *act* in the environment, demonstrating adaptive functions in both conditions 1 and 2.

1) Automatic control functions in a Biosymtic device while directly connected to a human organism (human-integrated automatic control; working as a human-robot interface)

> *"Gloria pouted, "I bet he went inside the house, and I´ve told him a million times that that's not fair." With tiny lips pressed together tightly and a severe frown crinkling her forehead, she moved determinedly toward the two-story building up past the driveway. Too late she heard the rustling sound behind her, followed by the distinctive and rhythmic clump-clump of Robbie's metal feet. She whirled about to see her triumphing companion emerge from hiding and make for home-tree at full speed. Gloria shrieked in dismay. - Wait, Robbie! That wasn't fair, Robbie! You promised you wouldn't run until I found you (…) You peeked! She exclaimed, with gross unfairness. - Besides I'm tired of playing hide-and-seek. I want a ride (…) Carefully he raised the little girl and placed her on his broad, flat shoulders (…) Then "Faster, man," Gloria said pompously, "we're running out of ammunition." She aimed over her shoulder with undaunted courage and Robbie was a blunt-nosed spaceship zooming through the void at maximum acceleration."*
>
> *Asimov (1950:10-11)*

Isaac Asimov, one of the most prolific science fiction writers of all time, wrote the above excerpt in the 20th century. It is included in a science fiction novel named "Robbie". This novel is a futuristic story, in which a child - "Gloria" - shares her life with a robot - "Robbie". For most of the time, Gloria engages her robot in physical play in natural environments. In fact, Asimov's fiction was not far from reality. As stated above, children associate robots to playful and fun learning - striving for a connection between physical and academic skills.

One of the main characteristics of BSDs is that they engage children in physical play, in natural environments, through automatic feedback control mechanisms (closed-loop control).

Franklin et al. (2006:1-16) refer to automatic feedback control of dynamic systems as follows, "The central idea is that a system's output can be measured and fed back to a controller of some kind and used to effect the control (…) In feedback systems the variable being controlled - such as temperature or speed - is measured by a sensor and the measured information is fed back to the controller to influence the controlled variable" (see also Sundaram, 2013).

An example of automatic feedback control (dynamic systems) can be observed in Physiological Computing (PC). We allude to Biocybernetically adaptive systems.

In PC, physiological data from the user works as input to interact with a computer system. In turn, the computer system monitors, analyzes and responds to the user's physiological activity in real-time (replying adaptively to the user's needs). According to Fairclough (2009:133), PC systems "operate by transforming psychophysiological data into a control signal (or an input to a control signal) without a requirement for any overt response from the user (…) information exchange between human and computer is rendered symmetrical as the physiological computing system constructs, consults and responds to a dynamic representation of the user".

Allanson & Fairclough (2004) developed the concept of biocybernetically adaptive systems inspired by the cybernetic theory of Norbert Weiner (1948). The biocybernetic loop is initiated with input from the user's psychophysiological data (e.g., heart rate, electrical activity of the brain, galvanic skin response, breathing patterns) into the computing system. Psychophysiological data is usually captured through remote, ambulatory and/or wireless sensors (or biosensors) (Fairclough, 2009). The computing system quantifies, or labels, the state of the user according to the received psychophysiological data - representations of cognitive, emotional and/or motivational states.

According to Fairclough (2009:135), "The magnitude of change or specific label applied to the user representation determines an appropriate response from the adaptive system. For example, the detection of frustration may prompt the system to provide help information (…) The final stage of the loop is represented by any second-order change in user state that may occur in response to system adaptation and elicit a second-order response from the system and so on (…) The loop may be designed to detect and respond to undesirable user states (e.g., frustration, anxiety, cognitive disengagement)".

Fairclough & Gilleade (2012:571) maintain that "The biocybernetic loop is the elemental concept at the heart of all physiological computing systems. At a basic level, the loop describes the data processing protocol whereby live physiology is converted into control input for a technological system. However, the design of the loop also incorporates an explicit rationale with specific goals, e.g. to sustain a state of engagement, to prevent frustration, to select a desired command; this agenda defines the *modus operandi* of the system".

Therefore, biocybernetically adaptive systems are concerned with the control of a certain psychophysiological state in the user - cognitive and emotional states.

Analogous to Biocybernetically adaptive systems, BSDs persuade the child to achieve a specific physiological state (not a psychophysiological state) in order to improve physical and mental health. However, and in contrast to physiological computing systems (that do not require any overt response from the user), physiological data, in BSDs, is always used to persuade a covert response in the child: physical action.

We have developed a wheeled mobile BSD, named "Cratus", to test our theories.

The BSD "Cratus" mimics a Roman gladiator/inventor. The physical structure of this device consists of a head connected to a torso, integrated with a wheel mechanism on its base. It also includes a computer processor on the center back of the torso that outputs visual and audio information to the child. Inputs to the system (in order to control virtual information, e.g., put a video game avatar into action) are made through whole-body motion, e.g., the child may push, pull, rotate and throw the apparatus while walking, running, jumping or trotting on the physical terrain. The child may also skate while using this system – feet placed on top of the wheelbase (Motoric-Metamorphosis).

The system includes wireless motion sensors to capture the child's motion data (e.g., accelerometer, gyroscope and a tilt sensor integrated in the torso of the apparatus and a rotational speed sensor integrated in one of its wheels) - moving the system on the physical terrain is translated as virtual locomotion, e.g., of a video game avatar. The system also captures physiological data - communicates wirelessly with a HR biosensor placed on the child's chest. This device also includes environmental sensors (light, humidity and temperature) and servomotors connected to encoders (actuators integrated in its wheels) (see fig. 12).

"Cratus" may integrate a variety of software programs on its computing processing system. We developed a software program – video game – whose goal is to optimize children's cardiorespiratory performance. In this program, "Cratus", encourages a child to perform MVPA (MVPA benefits children's physical and mental health)[62][63].

In order to benefit the development of the cardiorespiratory system, children aged 6 to 14 years should perform aerobic exercise tasks comprising levels of oxygen consumption between 60% to 80% of its maximum capacity. HR values should not exceed 70% to 85% of its maximum (Bar-Or, 1983; Rowland, 1996; Rowland & Bar-Or,

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62. A detailed description of this software program is presented on Appendix A.
63. The child drives an avatar through a variety of game scenarios (race tracks) in order to score.

Fig. 12.

Biosymtic device Cratus

2004). The American Heart Association recommends HR intensity levels of about 50% to 85% (moderate-intense PA levels) during aerobic exercise tasks[64].

The child starts the "cardiorespiratory performance" program by introducing her age into the system. The system then calculates moderate-intense PA intensities (HR values between 50% and 85% of its maximum) based on the following equations (Karvonen method[65]):

Calculating Maximum Heart Rate (HR_{max})[66]

$$HR_{max} = 207 - (0.7 \times age)$$

Calculating Target Heart Rate (THR) for 50% intensity

$$THR_{50\%} = ((HR_{max} - HR_{rest}) \times 0.50) + HR_{rest}$$

Calculating Target Heart Rate (THR) for 85% intensity

$$THR_{85\%} = ((HR_{max} - HR_{rest}) \times 0.85) + HR_{rest}$$

In that $THR_{50\%}$ and $THR_{85\%}$ represent the interval of HR values (in beats per minute) to be maintained during the activity in order to benefit children's health.

$$HR \geq THR_{50\%} \text{ and } HR \leq THR_{85\%}$$

The BSD "Cratus" persuades the child to maintain her HR values between 50% and 85% of its maximum through an automatic feedback control mechanism. Franklin et al. (2006:16) state that an automatic feedback control mechanism "consists of the process whose output is to be controlled, the actuator whose output causes the process output to change, reference and output sensors that measure these signals, and the controller that implements the logic by which the control signal that commands the actuator is calculated".

In this case, the response from the cardiorespiratory system is the process whose output is to be controlled – average HR frequency in beats per minute (BPM). The closed loop starts by capturing HR values (output) through the HR biosensor, placed on the child's chest – it converts HR signals into digital signals to be used by the comparator and the controller. Following this, the comparator computes the difference between the reference signal - HR values between 50% and 85% of its maximum - and output signal. For example, a child aged 7 years (HR_{max} = 202.1 BPM; HR_{rest} = 67 BPM) will have an average reference interval of 134.5 BPM to 175 BPM. If the starting average output value is (average calculated each minute), e.g., <134.5 BPM or >175 BPM, the comparator will compute the difference between the lower/higher reference values

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[64] http://www.heart.org/HEARTORG/GettingHealthy/PhysicalActivity/FitnessBasics/Target-Heart-Rates_UCM_434341_Article.jsp

[65] (Karvonen & Vuorimaa, 1988).

[66] Gellish et al. (2007) method to estimate maximum heart rate values in children.

(134.5 BPM/175 BPM) and the average output value. This gives the controller a measure of system error that, in turn, computes the desired control signal.

The controller communicates with two actuators in the system (effectors) - in this case the inertial wheel mechanism actuator and the verbal actuator, both integrated in the physical structure of the apparatus.

The inertial wheel mechanism controls the rotational speed of the apparatus[67] - an electromechanical brake system (encoders placed on servo motors) integrated in two wheels. If, e.g., the child presents an average HR value <134.5 BPM (e.g., while pushing the apparatus during running), the controller will send a control signal to the inertial wheel mechanism (actuator) increasing its inertial forces (brake system locks the wheels up to a certain degree, e.g., 45%). This increase aims to raise PA levels in the child. If the child presents an average HR value > 175 BPM, the controller will send a control signal to the inertial wheel mechanism (actuator) that makes it decrease its inertial forces (brake system unlocks the wheels up to a certain degree, e.g., 36%)[68]. This decrease aims to lower PA levels in the child.

The controller also communicates with a verbal actuator producing audio output to the child. The verbal actuator consists of a single sound speaker integrated in the head of the apparatus (resembling an eye). This actuator follows the principles established in the closed loop. If, e.g., the child presents an average HR value <134.5 BPM, the controller will send a control signal to the verbal actuator that emits specific verbal feedback to the child, e.g., "Run faster!" or "Give me more power!" (preprogramed verbal commands encouraging the child to achieve the intended PA levels). If the child presents an average HR value > 175 BPM, the controller will send a control signal to the verbal actuator, which emits specific verbal feedback to the child, e.g., "Slow down!" or "My mechanisms are about to explode!" (see fig. 13).

"Cratus" demonstrates adaptive behavior. For example, for a similar task, child "A" may need to be exposed to increased inertial forces to achieve the target HR values of between 50% and 85% of its maximum, compared to child "B".

In addition, real-time HR/motion sensor data can be visualized on the software – a virtual heart that changes color according to the child's HR values (e.g., low, adequate and high intensities represented on a scale from green to red); a level meter displaying motion intensity (including angles/velocity of rotations). We termed this process *biotransfer*. In fact, one of the central goals of the "cardiorespiratory performance" program is to keep "Cratus" with a functional heart (e.g., "Give energy to

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[67] Revolutions per minute (rpm).

[68] The inertial wheel mechanism used in the experiment described in this document (chapter 4) refers to a software actuator - controls changes in the displacement speed of an avatar.

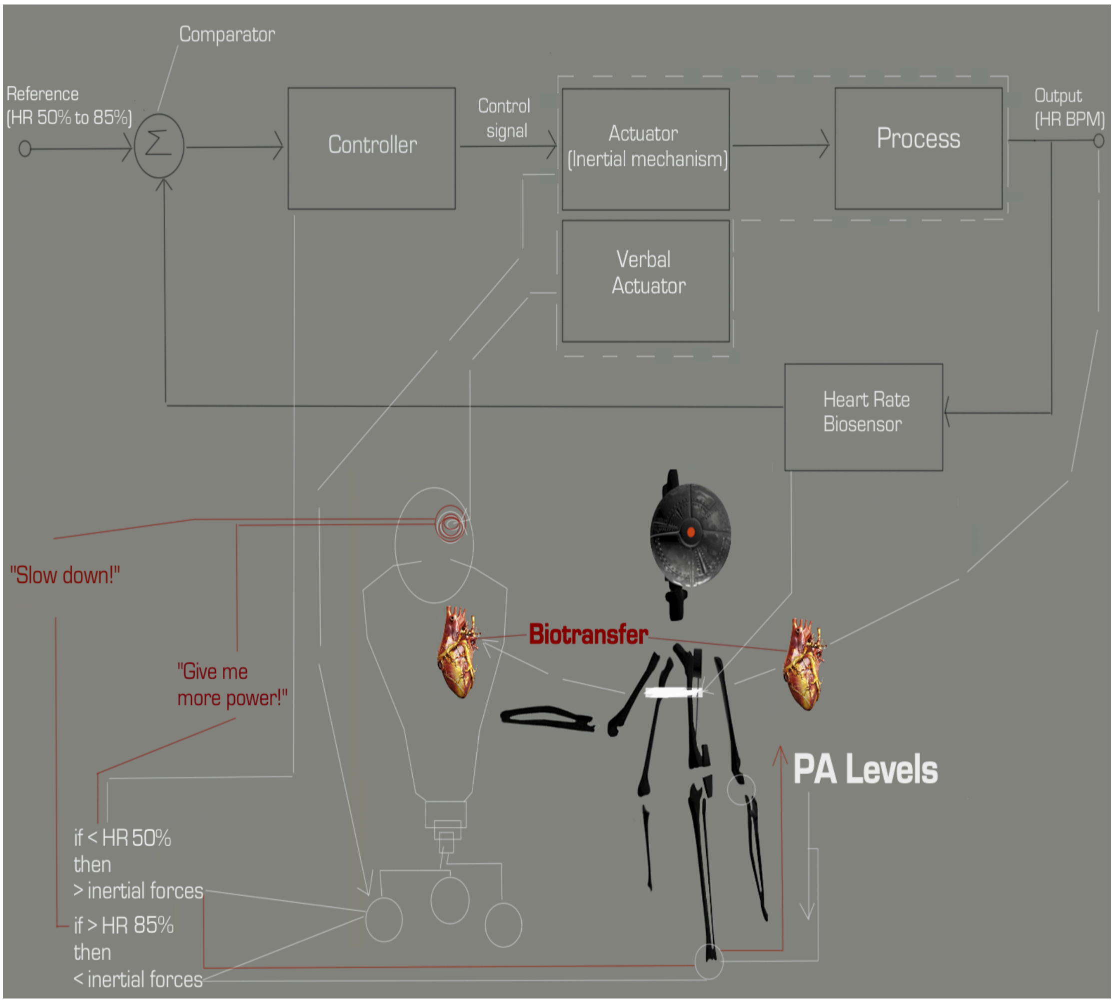

Fig. 13.

Biosymtic device automatic feedback control mechanism (cardiorespiratory performance) and Biotransfer process

Response from the cardiorespiratory system is the process whose output is to be controlled – average HR frequency in BPM. The output signal (average HR) is captured through a HR biosensor placed on the child's chest. The comparator computes the difference between the reference signal (HR values between 50% and 85% of its maximum) and the output signal (average HR), giving to the controller a measure of the system error. The controller computes the desired control signal. It communicates with two actuators – the inertial wheel mechanism (controls the rotational speed of the apparatus) and the verbal actuator (emits verbal feedback to the child, e.g., "Slow down!").

In the biotransfer process the child's average HR output values are transferred from the HR biosensor to the touch-based display on the apparatus. A virtual heart is displayed on the software - changing color according to the child's HR values (e.g., low, adequate and high intensities represented on a scale from green to red).

'Cratus' by keeping its heart on the yellow zone!"). While keeping "Cratus" with a functional heart, the child is recharging its energy sources – through a dynamo system that converts the mechanical energy of the wheels into electrical energy. BSDs encourage for ecological sustainability practices associated with the reduction of the human ecological footprint[69] (e.g., reducing fossil fuel consumption). Biosymtic devices are powered by solar and mechanical energy sources and encourage the child to understand and control those energy sources.

Another example of a BSD, integrating an automatic feedback control mechanism is "Albert".

Interaction with "Albert" is carried out through whole-body motion in the physical environment and through direct physical contact with sensor-based interfaces. The physical structure of the system consists of a wearable suit with wireless sensors communicating with a computer processor (in the center back of the suit); a monocular see-through head-mounted display connected to the computer processor, displaying virtual visual information (augmented reality); a sound speaker, embedded in the suit (auditory output); and motion sensors to capture the child's motion data (e.g., accelerometer, gyroscope and a tilt sensor integrated on the suit). The system also captures physiological data - communicating wirelessly with a HR biosensor placed on the child's chest and an electroencephalogram (EEG) placed on the scalp surface.

System inputs to control virtual information (e.g., put an avatar into motion) are made through whole-body physical action, e.g., the child may walk, run, jump, rotate, trot on the physical terrain. Virtual information may also be controlled by interacting directly with sensor-based interfaces - manipulate a "turn button sensor"; blow air into an "airflow sensor"; manipulate inflatable toys connected to sensor interfaces, e.g., connected to the "airflow sensor".

In addition, the child may control virtual information through extending physical interfaces. For example, four articulated mechanical octopus arms connected to the upper part of the body (two octopus arms on each side of the body integrated with sensing mechanisms) allowing manipulation of physical objects (Motoric-Metamorphosis)[70]. This device also integrates environmental sensors (light, humidity and temperature) and a "touch-glove sensor" (to control virtual information) (see fig. 14).

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69. Ecological footprint compares human consumption of natural resources to the nature's capacity to regenerate those resources (Rees, 1992).
70. Work in progress.

Fig. 14.

Biosymtic device Albert

"Albert" can integrate a variety of software programs on its processing system (e.g., "cardiorespiratory performance"; "cognitive performance"). The software program "cardiorespiratory performance" aims to optimize children's cardiorespiratory performance[71]. In this program, "Albert" encourages the child to perform MVPA[72]. The Biosymtic device "Albert" persuades the child to maintain her HR values between 50% and 85% of its maximum through an automatic feedback control mechanism - analogous to the mechanism included in the BSD "Cratus". A single difference is that "Albert" uses a software actuator that controls changes in the speed of displacement of the avatar ("inertial virtual actuator").

"Cognitive performance" programs, integrated in Biosymtic devices, aim to potentiate cognitive abilities in children, e.g., attention, episodic memory, problem solving. In chapter 3 (experiment I), we will refer to a software program that aims to improve children's cognitive function, specifically episodic memory performance (interaction with the Biosymtic device, "Albert").

BSDs may also encourage children to perform PA in in natural environments without external control of physiological states - encouraging "exploratory play". That is, a child may interact freely with software programs allowing exploratory physical action in the natural environment. These programs allow the child access to physiological, motion and environmental data, in real-time, through visual and auditory information (e.g., HR, brain activity; motor performance; humidity, temperature).

While accessing a variety of data, the child is encouraged to explore/regulate her body processes in relation to environmental ones. For example, she may draw inferences about the relations between motion, HR and temperature/humidity in the environment (e.g., HR increasing in humid and hot climates for similar motor performance); relations between particular contexts (e.g., mountainous areas; forested areas) and brain states (e.g., alertness, distraction, working memory load).

The "exploratory play" mode differs from mode 1) - automatic feedback control mechanisms. The former allows for larger physiological state variability; the latter is related to the control of physiological states.

Automatic feedback control mechanisms, encouraging PA in natural environments, are mostly associated with preventive and interventive medicine practices, e.g., to avoid/fight metabolic, musculoskeletal, cardiovascular, cardiorespiratory, cognitive (e.g., ADHD) and digestive disorders (associated with developmental delays). In turn, the "exploratory play" mode gives physiological states flexibility and expands opportunities for physical action in the environment. In essence, the "exploratory play"

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[71] A detailed description of this software program is presented on Appendix A.

[72] The child drives an avatar through a variety of game scenarios in order to score.

mode is associated with a process of biological self-discovery (body awareness/literacy) in confrontation with the physical world.

We will now make a brief description on how BSDs generate autonomous behavior (work in progress).

2) Autonomous functions in a Biosymtic device – building autonomous functions through a direct connection to a human organism

> *"… for life is like no machine humans have ever built: It's always more than the sum of its parts"*
>
> *Becker & Selden (1985:230)*

A BSD builds autonomous functions through interaction with a human (working as a human-robot interface). We termed this process Bio-kinesthetic programming (BKP; *or Bio-kinesthetic teaching*). BKP is an approach to robot programming by demonstration (RPD) aiming to help a robot build autonomous functions through human guidance techniques, such as direct physical control and physiological states transfer, while physically and mentally benefiting the human organism (including potentiation of cognitive development/performance). Hence, a BSD and a human organism form a symbiotic connection. Symbiosis (from Greek σύν "together" and βίωσις "living") is the association, or close union, between organisms in mutual benefit (Mutualism approach) (Boucher, 1988; Bronstein, 1994; Hoeksema & Bruna, 2000).

Margulis & Sagan (1986:29) refer that "Life did not take over the globe by combat, but by networking". These authors support the idea that biological evolution is a process resultant from interaction, cooperation and mutual dependence between biological organisms - symbiosis (e.g., insects that pollinate flowering plants; clownfish and Ritteri sea anemones protecting each other from predators). Likewise, while a BSD may benefit cognitively from a human organism, the latter may benefit physically and cognitively from a BSD.

Billard et al. (2008:1371) refer to *robot programming by demonstration* or *imitation learning* as follows, "imitation learning, is a powerful mechanism for reducing the complexity of search spaces for learning. When observing either good or bad examples, one can reduce the search for a possible solution, by either starting the search from the observed good solution (local optima), or conversely, by eliminating from the search space what is known as a bad solution. Imitation learning is, thus, a powerful tool for enhancing and accelerating learning in both animals and artifacts". According to Calinon & Billard (2007:1371), RPD "covers methods by which a robot learns new skills through human guidance".

Robots may learn new motor skills by imitating human motion models through, e.g., *kinesthetic teaching* (direct physical contact with the robot) and *virtual reality teaching* techniques (without direct physical contact with the robot) (e.g., Aleotti & Caselli, 2005; Calinon & Billard, 2007; Billard & Mataric, 2000; Ikemoto et al., 2009; Ito et al., 2006; Saunders et al., 2006).

Saunders et al. (2006) developed robots that learn new motor skills through human guidance - robots teleoperated by a human via a touch-based interface (virtual reality teaching). Calinon & Billard (2007) developed a teaching method to demonstrate manipulation skills to a humanoid robot. The authors make use of motion sensors attached to the teacher's body to demonstrate skills to the robot (virtual reality teaching). The teacher can also refine the robot's skills "by moving its arms manually, providing the appropriate scaffolds to reproduce the action" (kinesthetic teaching). According to Calinon & Billard, (2007:1372-73), "Kinesthetic teaching provides a way of supporting the robot in its reproduction of the task. By using scaffolds, the user provides support to the robot by manually articulating a decreasing subset of motors. The scaffolds progressively fade away and the user finally lets the robot perform the task on its own, allowing the robot to experience the skill independently" (see also Billard et al., 2008).

Kinesthetic teaching has been used to help robots learn motor skills associated with a certain goal, e.g., guiding the motion of a robot's arms through direct manual control in order to teach it how to manipulate objects (e.g., Ito et al., 2006).

As previously mentioned, most robotic systems in the Child-Robot Interaction field have been encouraging children to interact with SBCDS, involving visual and auditory information-gathering scenarios and user interfaces based on HECS (e.g., "keyboard", "mouse", "tactile displays") – instilling sedentary behavior. These interfaces are used to program physical actions/behaviors to be performed by robots autonomously – robots programmed through source code (symbols).

In contrast, a BSD encourages the child to use kinesthetic techniques to program physical actions/behaviors to be performed by the robot. That is, the child controls the BSD, in the environment, through whole-body physical action in order to program autonomous functions (e.g., the child's locomotion works as an example to be replicated by the device during autonomous navigation). The child's physiological states, while controlling the robot, are also used to program autonomous functions (e.g., the robot learns to manage its power sources according to the child's energetic metabolism). This is why we termed this process Bio-kinesthetic teaching (or Bio-kinesthetic programming).

Researchers have been teaching robots to learn new skills from several learning experiences. To that end, they have been using statistical techniques to extract regularities from several learning experiences - "Generalization of a skill by extracting the statistical regularities across multiple observations" (e.g., Billard et al., 2008:1975; Calinon & Billard, 2007; Gurau et al., 2014; Rockel et al., 2013; Saunders et al., 2006). For instance, Calinon & Billard (2007) make use of *Gaussian mixture model* (GMM) to teach new skills to robots - "a probabilistic of several demonstrations provided to the robot to generalize the learned skills to different contexts" (Calinon & Billard, 2007:1372-73). Billard et al (2008:1376) refer that the "generalization process consists of exploiting the variability inherent to the various demonstrations and to extract the essential components of the task. These essential components should be those that remain unchanged across the various demonstrations".

The computational model integrated in BSDs also involves statistical techniques to extract regularities from several learning experiences. Let's take our wheeled mobile BSD "Cratus" as a way of example.

After activating the "learning program" (to build autonomous functions in the BSD) the child is encouraged to control "Cratus" in the physical environment through physical action. For example, the child may push, pull, rotate and throw the apparatus while she walks or runs on the physical terrain. In the "learning program" the child interacts freely with the BSD, e.g., may select a variety of avatars/scenarios included in the software (or even previously build her own avatars/scenarios) to freely explore the physical world (visualizing the virtual scenarios on the touch-based display).

The child may also define the inertial forces applied to her avatar by controlling the actuators in the software (e.g., inertial wheel system to change effort intensity[73]). At the same time the child establishes physical interaction with the BSD, she may also teach the device physical actions/behaviors to be autonomously executed.

The device includes motion sensors in order to capture motion data (e.g., accelerometer, gyroscope and a tilt sensor integrated on the apparatus' torso; a rotational speed sensor integrated in one of its wheels). The system also captures the child's physiological data – communicating wirelessly with a HR biosensor placed on the child's chest. "Cratus" also includes environmental sensors (light, humidity and temperature); four infrared sensors (IR) at is base to detect objects in close proximity (measure infrared light radiating from objects in the field); a microphone in its head (right ear area) to record sounds; and servo motors in its wheels, which allow for autonomous motion (motion in a straight line and rotations).

The child has access to motion, physiological and environmental data captured through the sensing interfaces (visualized on the touch-based display): motion intensity scale; angles/velocity of rotations; a virtual heart that changes color according to the child's HR values; light, humidity and temperature scales. The child is encouraged to explore her own biological processes on the software, together with environmental information during the teaching experience.

The "learning program" integrated in BSDs encompasses a memory-based learning approach grounded on perception and action mechanisms, physiological states and verbal information - multimodal simulation. This learning approach is inspired on the multimodal simulation system developed by Barsalou (Embodied Cognition). Accord-

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[73] Servo motors connected to encoders (actuators integrated in the wheels of the apparatus).

ingly, mental representations are generated through simulation processes in the brain (brain computations) – reactivation of neural circuits that were activated during previous perceptual, motor and introspective experiences (Barsalou, 2008:618). Multimodal representations regarding perceptual, motor and introspective states are stored in the brain's memory system and later recalled during conceptual processing - supporting higher-order cognitive abilities such as higher-order perception, implicit memory, working memory, long-term memory and conceptual knowledge (Barsalou, 1999, 2003, 2008; Barsalou & Wiemer-Hastings, 2005).

A BSD may learn a variety of tasks through multimodal simulation processes: collecting (recording) motor, physiological and environmental data while the child interacts with the system to be later recalled/used during autonomous functions – capturing information about events in the environment through human guidance. Motor and physiological data (captured through the rotational speed sensors, gyroscopes, tilt, IR and HR sensors) represent the sensory state of the BSD. Environmental data (light, humidity and temperature) represents information external to the system. These metrics are stored in the BSD during the learning process and can be later recalled through multimodal simulation processes to support autonomous functions in the device.

The child may ascribe verbal labels to the learning experiences, e.g., "stop", "move fast", "move slow", "avoid obstacles", "touch-object", "search-light", "rotate", "dance", to activate multimodal simulation processes on the device.

For example, after activating the "learning program", on the software, the BSD immediately starts recording sensory data. The child interacts with the device freely in the physical environment – deciding which physical action/behavior to teach the device. When the child determines that the learning activity is concluded, she activates a "verbal learning" function on the software – ascribing a verbal label to the previous experience via verbal input to the system (recorded by the microphone). At this moment, the software associates the verbal label given by the child to the metrics obtained during the interaction (motion, physiological, environmental data) – creating a memory representation of the experience. Later, after a few learning experiences, the child may reactivate this memory through a speech recognition system included in the software (activating the function "autonomous behavior" in the software and pronouncing the verbal label to the system). At this moment the system should be able to reactivate the memory associated with the verbal label (accessing motion, physiological, environmental data associated with the learning experience – multimodal simulation) and autonomously replicate the behavior – also demonstrating adaptive behavior in different environmental settings.

Let's imagine that the child decides to teach the concept of "move fast" to "Cratus".

The child activates the "learning program" and eventually starts pushing the device as fast as possible in the physical world. In order to end the learning process the child activates the "verbal learning" function in the software. At this moment the software stops recording data and the child may give verbal inputs to the system (create a verbal label) – “move fast”. The child may later reactivate this behavior in the “autonomous behavior” mode by providing the system with the same verbal command – “move fast”.

During the learning experience the sensory states of the BSD and information external to the system are continuously recorded. The BSD sensory states include motion data and physiological data. Information external to the system includes light, humidity and temperature data. The child may enable or disable the inputs made to the system by activating or deactivating communication between the sensors and the software.

Data acquired during the learning experience (demonstration phase) represents perceptual symbols (Barsalou, 1999, 2003, 2008) to be stored by the BSD (stored in the software). These perceptual symbols are reactivated during the “autonomous behavior” function, according to specific verbal labels determined by the child. This learning approach allows the BSD not only to create a multimodal memory of a verbal concept (associated with motor and physiological states and environmental information) but also to act, in the environment, according to the previous learning experiences. For instance, in the previous example, the verbal label “move fast” is associated with an increase in the rotational speed in the wheels of the apparatus (the child pushes the device as fast as possible). The “learning program” records the rotational speed of the wheels from the start of the activity until the “verbal learning” function is activated. In this case, the device records motion data to posteriorly manage its locomotion functions in the environment autonomously.

The BSD also makes use of the child’s physiological data - HR data - to perform autonomous behavior in the environment. In the previous example, the verbal label “move fast” is associated to an increase in the child’s HR values (since the child pushes the device as fast as possible). Again, the “learning program” records the child’s HR values from the start of the activity until the “verbal learning” function is activated. In addition, the device captures inclination, on the physical terrain, through the tilt sensor.

The device records the child’s physiological data to posteriorly manage its power sources autonomously while in the environment. We are developing a computational model that makes an analogy between the human energetic metabolism and energetic functions in BSDs. For instance, the verbal label “move fast” is associated with an increase in HR levels. As the child moves across different terrain gradients (e.g., no inclination versus slopes), she will show variations in HR values (e.g., a slope will increase the child’s HR while she tries to push the device as fast as possible). The BSD records and associates data from the child’s HR and terrain gradient, obtained during the learning experiences, to manage its energy functions – e.g., providing more power to the servo motors when facing slopes to maintain a quick rotational speed.

The BSD learns new skills (or builds models of the skills) by computing the average and variance of continuous motion, physiological and environmental data from multiple learning experiences - in order to apply them in a new context. To that end the software makes use of a *Gaussian mixture model* (GMM), extracting the statistical regularities and the variability across multiple interactions (probabilistic model inspired in the GMM developed by Calinon & Billard, 2007). For instance, if after a few demonstrations, in different environmental conditions, the average rotational speed of the wheels of the apparatus is "X revolutions/time" then - when the child activates the "move fast" behavior in the "autonomous behavior" function - the apparatus tries to replicate this same rotational speed ("X revolutions/time") in different environmental conditions.

Variations regarding environmental conditions (e.g., terrain gradient) and on the child's HR (for different terrain gradients) are taken into account when trying to replicate the behavior "X revolutions/time". Therefore, the BSD extracts statistical regularities and the variability associated with the learning experience to apply them to new contexts. If the Biosymtic device is not able to perform the learned behavior in different environmental conditions then the child needs to provide the system more learning experiences (see fig. 15).

While the child guides the device through the learning activity, environmental data may also be recorded - light, humidity and temperature data. Since the learning process on a BSD results from multiple learning experiences, we may expect the BSD to create associations between not only motor and physiological data, but also environmental data and verbal concepts. In some cases, environmental data may be more important for the BSD to learn how to act in an environment than other types of data.

For instance, the "move fast" behavior may be more dependent on motor and physiological data, compared to environmental data, because the learning process results from finding statistical regularities and the variability across multiple interactions. On the other and, if the child tries to teach behaviors such as "search light" or "search shadow", light data becomes essential for the device. For example, starting the "learning program" with the light sensor and the motion sensors activated and driving the device multiple times to an area in the shade and vice-versa.

Because the child engages the "learning program" in an exploratory mode – e.g., the child may attribute different labels to different learning experiences/enable or disable inputs to the system by activating or deactivating sensors - she is free to define and discover what the BSD can learn. The child may even combine different previously learned behaviors to make the device act in a more complex way in the physical environment. For instance, by combining "move fast" and "search light" behaviors – giving the verbal input "move fast → search light" to the system. In this case, the software combines two previously learned behaviors in order to act in the environment (the system needs to accomplish the two behaviors according to the order assigned to the verbal labels during the verbal input). For example, the device will move fast until it finds

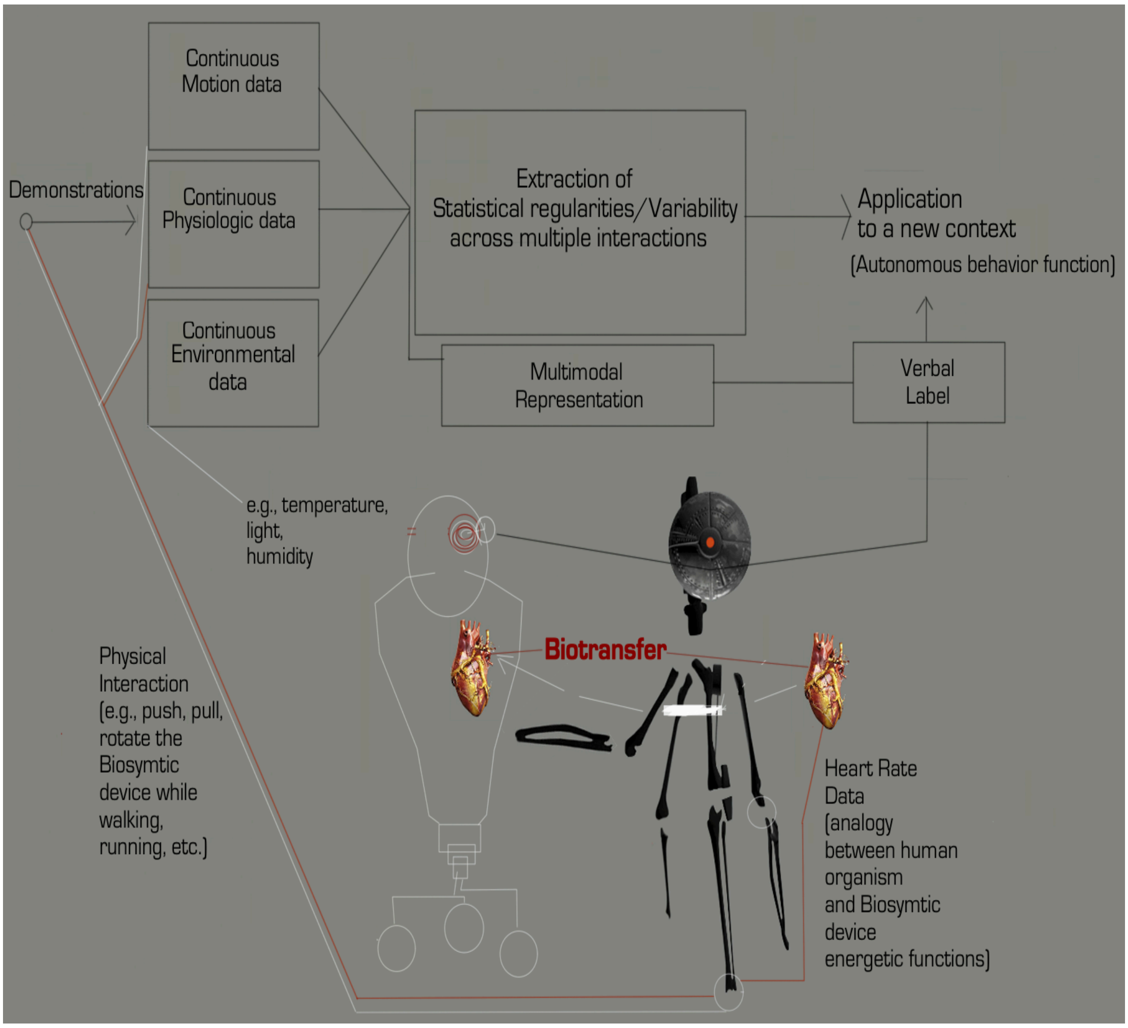

Fig. 15.

Bio-kinesthetic teaching (or Bio-kinesthetic programming) approach to robot learning (Biosymtic devices)

This approach aims to help a robot to build autonomous functions through human guidance techniques, such as direct physical control and physiological states transfer.

The BSD continuously captures motion and environmental data from its sensing mechanisms and physiological data from the child during the learning process (demonstrations). The child physically interacts with the BSD – guiding it during the learning process (e.g., push, pull, rotate the device while walking, running). Physiological data from the child - e.g., HR data – may be captured during the learning process to teach the device how to manage is energetic functions (analogy between the human organism and Biosymtic device's energetic functions). Environmental data (e.g., temperature, light, humidity) may also be combined with motion and physiological data during the learning process.

After demonstrating a skill to the BSD the child assigns a verbal label to that same skill (e.g., "move fast"; "search light"). The verbal label is recorded by the system together with a memory representation (multimodal representation) from the learning experience - motion, physiological and environmental data. In order to be able to apply learned skills (behaviors) to new contexts, the BSD extracts the statistical regularities/variability from motion, physiological and environmental data resultant from several learning experiences. The child may activate the learned skills (autonomous behavior function) through the use of verbal commands - verbal label previously defined by the child that reactivates a memory of the skills.

a lit area, where it will eventually stop. If, on the other hand, the child gives the following verbal order to the system - "search light → move fast", the device will engage in the behavior "search light" first and only after move fast[74]. Behavior activation depends on the specific verbal input order given to the system and on the environmental conditions faced by the device during autonomous functions.

The child may also control other functions in the software. For instance, the child may define "primitive autonomous behaviors" in the system that are always active during autonomous functions. For example, the child may classify the learned behavior "avoid obstacles" as a "primitive autonomous behavior" and later activate other behaviors through verbal input ("command behaviors") – e.g., "move fast" and "search light". In this case, the BSD will follow the "command behaviors" given by the child through verbal input while at the same time avoiding obstacles in environment ("primitive autonomous behavior"). The child may also delete learned behaviors[75].

One of the characteristics of the "learning program", in BSDs, is that it allows them to develop different forms of acting in the physical environment depending on the user - the software platform records data for each user. That is, the BSD behaves autonomously, in the environment, according to the biological skills of the user (e.g., motor performance, physical fitness). For instance, a younger child (e.g., age 4) trying to teach the "move fast" behavior to the BSD will likely move slower than an older child (e.g., age 9); additionally, their HR values during the learning experience will be different. Therefore, the "move fast" behavior in the device will differ according to the biological skills of the user.

While a child aged 4 (early childhood) is still learning how to coordinate their body movements (rudimentar motor control), a child aged 10 has already achieved more complex formats of motor behavior (better motor control performance) (Gabbard, 1992). Because younger children are endowed of more rudimentar formats of motor control compared to older children, we suggest that the BSD may generate different formats of perceiving/act (in) the physical world. In this way, a BSD assumes different behaviors according to the developmental state of the user. Also, the BSD's skills may progress through time (developmental process) assuming that the child keeps interacting with it throughout development. Besides, and because each child has its own creative process, it might be the case that BSDs come to demonstrate distinctive modes of behavior according to each user - demonstrating different acting "personalities".

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74. One of the first behaviors to be taught to the BSD is the "stop" behavior - to avoid collisions in the physical environment. For this reason, in the first interaction with the BSD the software program guides the child to teach the "stop" behavior.

75. Our computational model is inspired in the *behavior-based control model* developed by Mataric & Michaud (2008) presented in http://biosymticrobotics.com/resources/ASMR_24FERRAZ.pdf

We are also implementing the *Bio-kinesthetic* approach to robot learning in virtual software agents - e.g., virtual software agent in the BSD "Albert"[76].

The child controls a BSD, in natural environments, through whole-body motion in order to program autonomous functions. Therefore, while interacting with a BSD the child is encouraged to be physically active in environments that offer a variety of sensorimotor experiences – avoiding sedentary behavior and restricted sensorimotor experiences (benefiting children's physical and mental health, including cognitive development and performance).

Furthermore, while guiding a BSD through the learning process the child is encouraged to:

- Practice language skills (e.g., assigning verbal labels to learned behaviors; perform combinations of verbal commands to activate autonomous functions on the device; linking concepts to action);

- Practice memory skills (e.g., activation of autonomous functions on the device through previously assigned verbal labels – associated with performed actions in the physical environment during the learning experience);

- Practice problem solving and reasoning skills (e.g., when teaching a new skill to the device through several learning experiences - trial and error experiences until the device learns the skill properly);

- Practice decision-making skills (e.g., deciding which verbal commands to give the device during autonomous functions – actions to be accomplished by the device in the physical environment);

- Practice creative skills (e.g., defining behaviors to be accomplished by the device – including combinations of behaviors).

In addition, children are encouraged to become familiar with sustainability practices related to the reduction of human ecological footprint.

BSDs are powered by solar and mechanical energy sources (physical activity performed by the child while interacting with the device) and encourage the child to acknowledge and control those energy inputs. In fact, the time dedicated to autonomous functions in a BSD depends on how much solar and mechanical energy was previoulsy generated[77]. In this way, we are motivating the child to perform increased amounts of physical activity in order to recharge the device – for the device to perform autonomous functions.

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76. This topic will be detailed in future work.

77. We are currently building a hybrid model that allows the device to recharge 50% of its energy through photovoltaic and mechanical energy and the remaining 50% through fossil fuels.

Moreover, while giving commands to a BSD the child may engage in social skills practice, e.g., through collaborative play. For example, the child may decide to challenge another child to a race/dance/football contest between BSDs (children control the devices through verbal commands during the activities).

One of the goals of the *Bio-kinesthetic teaching* approach to robot learning is to make robots (or in this case Biosymtic devices) acquire autonomous functional features in close proximity to biological organisms; however, autonomy is always subject to previously given commands – according to the will of a human being.

For example, our learning model allows BSDs to develop adaptive functions based on memory processes (multimodal simulation). The device is able to identify human verbal commands - concepts - to perform actions in the physical environment. Concepts in a BSD become associated to motor and physiological states (transferred from the human organism to the device) in combination with sensory information from the physical environment (e.g., light, temperature). In fact, BSDs learn how to manage its energetic resources by mirroring human energetic functions in order to optimize its actions in the physical world. Hence, we may say that BSDs are endowed with cognitive skills, however, under human control activation.

As previously referenced, the central goal of the AI field has been to assign biological functions to artificial machines - the development of artificial machines that display humanlike mental abilities (Khemani, 2013; McCarthy et al. 1955, 1969; Minsky, 1961; 1985; Murphy, 2000; Neumann, 1958, 1966; Shannon, 1950; Turing, 1944, 1950). Roboticists have been working on artificial machines that aim to emulate the physical and cognitive features of a variety of biological organisms (e.g., humans, insects, reptiles, birds)[78] (e.g., Bar-Cohen & Breazeal, 2003; Delcomyn, 2007; Featherstone & Orin, 2008; Floreano et al., 2008; Franceschini et al., 1992; Meyer & Guillot, 2008; Russel & Wijaya, 2003; Webb & Consi, 2001).

Interestingly, Conrad (1972:227) cited in Tsuda et al. (2006:42), referred that "it is impossible to simulate (such a biomolecular information processing system) by a machine to which we can communicate algorithms (…) without distorting its rate of operation or the amount of hardware which it requires". Furthermore, Rodney Brooks (2001:411) stated that "the matter that makes up living systems obeys the laws of physics in ways that are expensive to simulate computationally. For instance, the membranes of cells have a shape determined by the continuous minimization of forces between molecules within the membrane and on either side of it. Another property is

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[78] Pioneering AI scientists have developed computational models that try to emulate the functional mechanisms of the human brain (McCarthy et al. 1955, 1969; Minsky, 1961; 1985; Moravec, 1988; Neumann, 1958, 1966; Shannon, 1950; Turing, 1948, 1950).

that matter does not simply appear and disappear in the physical world, but great care must be taken in a computational simulation to enforce this".

In fact, electromechanical systems differ from biological organisms in their physical properties. A biological organism is characterized as a contiguous living system that consists of a single or a complex of cells: made of organic matter. It involves chemical reactions to sustain life (e.g., energy production) (Becker & Selden, 1985)[79]. An electromechanical system integrates mechanical moving parts to carry out electrical operations: made of silicon and metals (e.g., Iron and aluminium)[80] (Neumann, 1958, 1966).

In line with Neumann (1966:70), "Our combinations of metals, insulators, and vacuums are much more unstable than the materials used by nature (…) the natural materials have some sort of mechanical stability and are well balanced with respect to mechanical properties, electrical properties, and reliability requirements. Our artificial systems are patchworks in which we achieve desirable electrical traits at the price of mechanically unsound things".

Meyer & Guillot (2008:1417) state that "Besides the fact that numerous sensors, actuators or control architectures in animals are often still more efficient than the artificial devices they have inspired – either for reasons tied to technological limitations or to lack of biological knowledge – perhaps the principal reason for the superiority of animals over robots lies in their greater degree of integration. In fact, in the 3.5 billion years since the appearance of life on Earth, natural sensors, effectors, and control architectures have been offered enough time to coevolve and produce coherent wholes, a process that contrasts strongly with the current practice of engineers, who often independently design and produce the various components that they later assemble into a given artifact. Unfortunately, the laws governing natural evolution and integration are far from being deciphered and exploited in a more efficient manner than in current evolutionary robotics applications". Meyer & Guillot (2008) emphasize that billions of years of evolution have made the functional mechanisms of biological more efficient, and that it has been difficult for artificial devices to cope with that evolutionary background.

Researchers in the field of Embodied Cognition claim that cognition in biological organisms emerges according to their structural features and associated possibilities for action (e.g., it is expected for a human to perceive a chair differently from a crocodile because these species are anatomically different – a chair suggests the action of "seating" for most humans, a crocodile will probably not notice it or destroy it)

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79. http://en.wikipedia.org/wiki/Organism
80. http://en.wikipedia.org/wiki/Electromechanics

(Barsalou, 1999, 2003, 2008; Chemero, 2009; Clark, 1997, 2000, 2008; Gibson, 1966, 1979; Gibson & Pick, 2000; Thelen et al., 2001).

It has also been emphasized that different kinds of biological organisms present particular physiological features that determine, e.g., how those organisms sense and create knowledge about the physical world.

Hall (2011:3) states that "The goal of physiology is to explain the physical and chemical factors that are responsible for the origin, development, and progression of life. Each type of life, from the simple virus to the largest tree or the complicated human being, has its own functional characteristics (…) In human physiology, we attempt to explain the specific characteristics and mechanisms of the human body that make it a living being (…) the human being is, in many ways, like an automaton, and the fact that we are sensing, feeling, and knowledgeable beings is part of this automatic sequence of life; these special attributes allows to exist under widely varying conditions". Hall emphasizes that different kinds of biological organisms have specific functional features - physiological. Those features are associated to particular attributes, e.g., how a certain organism perceives and creates knowledge about the physical world.

The previous arguments led us to the idea that structural features and associated action possibilities, as well as physiological features, determine how cognition emerges in biological organisms. Taking into account that electromechanical systems differ from biological organisms in their physical and functional properties and that, e.g., organisms present more efficient "sensing, actuating and control architectures" than current artificial devices, it may be the case that artificial machines come to benefit from a learning approach involving, not only motor (e.g., kinesthetic teaching), but also physiological learning models (bio-kinesthetic teaching). This learning approach may allow for artificial machines to demonstrate functional features in close proximity to biological organisms.

For instance, the BSD "Cratus" has a different "body structure", and energy mechanism, to that of a human. Hence, it is expected that the perception of the physical world will emerge differently. While operating the device in the physical environment through physical action – direct physical contact - the child teaches the device to generate percepts from the physical world according to the latter's "body structure" (i.e., a torso with no arms connected to a mechanism with wheels). The child also teaches the device to manage its energy functions to better perform in the environment (mirroring human energy metabolism to manage energy functions).

In addition, and as stated above, a biological organism comprises chemical reactions to sustain life (e.g., energy production). In this case, we are using heart rate data to represent the stress a certain task causes the cardiorespiratory system. The BSD may also learn from other types of physiological responses, by the human organism, to learn how to manage its own functional mechanisms, e.g., neurophysiological response, stress response. In this way, the BSD learns to interpret the functional dynamics of the human body in order to manage its functional dynamics autonomously[81]. Since the learning process results from several learning experiences it can be characterized as a developmental process.

Researchers in Developmental Robotics have been criticizing approaches to robotics that don't take into consideration the developmental process of artificial machines.

According to Metta et al. (2000:1), "'brain scientists' have studied, since a long time, the acquisition of behavior and cognitive abilities, and nobody is surprised by the fact that newborns are not simply a sort of 'reduced size human beings'. What is more surprising is that, even at that age, infants show a series of "innate" behaviors, basic control synergies, and reflexes. On this basis, more sophisticated behaviors develop, and this process undergoes through stages, where the limited abilities already formed are efficiently exploited in order to simplify the learning process itself. On the contrary, the approach followed in robotics is mainly that of designing the 'complete manufact' (i.e. the adult-like robot). One might wonder what about that is wrong. Perhaps, something was underestimated, and from a purely engineering point of view, this 'something' was the whole process of design".

Minsky (1985:17,19) refers that "machines must have the ability to learn in order to be truly intelligent (…) such machines would not be designed around a very few, always applicable principles; instead, they would be engineered to accumulate large, and eventually huge, connections of observations and experiences. These analogy machines would then make themselves better and better able to guess which situations that have been encountered in the past are most similar to a new one and thus to deal with it effectively (…) Which forms and shapes, which smells and tastes, which feelings and sensations are similar? Such judgments have a huge effect at every stage of mental growth – since what we learn depends on how we classify".

In line with Mataric (1998:83), "Learning has been called the hallmark of intelligence; thus, achieving adaptive and learning capabilities in artificial systems is one of the greatest challenges of AI". According to Kurzweil (2012:181), "Ironically, the evolu-

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[81] Researchers in *Biohybrid-Robotics* have been integrating biological components directly in robotic devices to replicate biological functions in those same devices. According to Meyer & Guillot (2008:1415), "The solutions that nature has evolved to difficult engineering problems are, in many cases, far beyond present-day engineering capability. Therefore, when engineers are unable to reproduce the functionalities of some sensor, actuator or controller embodied in a living creature, they may try to integrate the corresponding biological component into a so-called *biohybrid* robot, thus physically using biology to augment technology". For instance, Herr & Dennis (2004) built a swimming robot connected to two explanted frog semitendinous muscles - controlled by an embedded microcontroller. The muscles get their energy from a glucose solution where the robot swims in. Using open-loop stimulation protocols, the robot performed basic maneuvers such as starting, stopping, turning and straight-line swimming at a maximum speed of 1/3 body-lengths/second. Artmann et al. (2008) are using a *Physarum polycephalum* slime to control the movement of a mobile robot. The *Physarum polycephalum* slime naturally moves away from the light (by reacting to the environment) what drives the robot to dark places.

tion of computer intelligence has proceeded in the opposite direction of human maturation".

Researchers in Developmental Robotics and AI have suggested that in order for artificial machines to demonstrate cognitive abilities they must be subject to a developmental process comprising several learning experiences - contact with the environment. In the case of a *Bio-kinesthetic teaching* approach to robot learning, robotic devices are subject to several learning experiences in the physical environment to further generate autonomous control functions, however, under human control activation.

It is not by chance that Biosymtic devices encourage children to explore challenging physical environments. In fact, the educational paradigm that we are offering our children is already a glimpse of future Space exploration, or, a preparation for human development in off Earth environments.

2.3 Enhancing adaptive plasticity during human development and potentiating human evolution[82]

There has been a strong investment in research concerning the effects of Space environments on adult human biology (including biological adaptation to off Earth environments) – comprising on how technologies can sustain life in deep Space and on other planets (e.g., Clynes & Klyne, 1960; Committee on Space Biology and Medicine et al., 1998; Committee on Advanced Technology for Human Support in Space et al., 1997; Committee to Review NASA's Evidence Reports on Human Health Risks, 2013; Steering Group for the Workshop on Biology-based Technology for Enhanced Space Exploration et al., 1998).

Research in Developmental Space Biology is very recent. The first report concerning developmental processes in Space – Goldberg report - was published in 1987, followed by two reports in 1991 and 1998 (Space Studies Board & National Research Council, 1987, 1991, 1998). These reports raised primary research concerns regarding developmental processes in Space, for example, "Can organisms undergo normal development in microgravity? Are there developmental phenomena that can be studied better in microgravity than on Earth?" (Committee on Space Biology and Medicine et al., 1998:37). According to the Committee on Space Biology and Medicine et al. (1998:37), "Since 1987 research has partially answered the first question, but some important issues must still be addressed. With regard to the second point, the distinct possibility remains that the space environment may be useful for understanding certain biological phenomena occurring in specific systems".

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[82] The topic presented in this section takes a speculative scientific nature. The topic presented here is to be developed in future work.

Research in Developmental Space Biology started gaining terrain with the event of the International Space Station's (ISS) in 1998[83]. This station was built to support several studies whose goal is to investigate the effects of Space environments on human biology (e.g., microgravity and radiation effects; effects regarding simulated hypergravity environments).

Developmental Biology Research in Space has focused on evaluating effects of microgravity and hypergravity on animals from prenatal to early postnatal development - from fertilization to embryogenesis, pregnancy, birth and early postnatal maturation (including cellular, molecular, genetic, morphological, physiological and vestibular developmental processes) (e.g., Horn, 2003; Kurotani-Izumi & Kiyomoto, 2003; Moody & Sally, 2000; Ricci & Boschetti, 2003; Ronca, 2003; Wakayama et al., 2009). Studies in Developmental Space Biology (animals) have been conducted mostly in flies, sea urchins, fish, amphibians, avians, mice and rats, as these species have homologous mechanisms to humans (e.g., genetic and molecular mechanisms conserved across phylogeny).

Developmental Space Biology researchers have designed and conducted studies for/in the ISS. These studies have demonstrated, e.g., that gravitational forces affect the shape of developing bodies: e.g., embryos of Bdelloid Rotifers experiencing 20*g* (hypergravity) demonstrate some anatomical modifications in early developmental stages (Ricci & Boschetti, 2003); isolated blastomeres of Sea Urchins continuously exposed to 55*g* (hypergravity) after fertilization show almost total suppression of skeletogenesis (Kurotani-Izumi & Kiyomoto, 2003); "deprivation of the gravity sensory system (GSS) by lesioning the sense organ or by exposure to microgravity can induce malformations in the body" of Xenopus (Horn, 2003).

Researchers have also demonstrated that microgravity affects mammalian development - e.g., rats exposed to microgravity (postnatal development) present a smaller number of unmyelinated fibers in the cardiovascular system, significant reductions in muscle weight, and changes "in the number and morphology of cortical synapses" (Ronca, 2003:243); "fertilization can occur normally under microgravity conditions in mammals (mice), "but normal preimplantation embryo development might require 1G" (Wakayama et al., 2009).

The results presented above do not demonstrate an optimistic picture for the possibility of human development in Space environments (e.g., microgravity and hypergravity environments). Nevertheless, we suggest that we humans need to overcome this challenge for the most important reasons:

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[83] http://en.wikipedia.org/wiki/International_Space_Station

As referenced by Shubin (2013:13), renowned American paleontologist and evolutionary biologist, "Transformation is the order of the day for the world: bodies grow and die, species emerge and go extinct, while every feature of our planetary and celestial home undergoes gradual change or episodes of catastrophic revolution".

One fact that we humans should be aware is that the whole known Universe is in constant mutation - reason why it is possible that, in the future, planet Earth will not have the necessary conditions to support life (Hawking, 1996; Sagan, 1997).

Sagan (1997) stressed that "These are the missing practical arguments: safeguarding the Earth from otherwise inevitable catastrophic impacts and hedging our bets on the many other threats, known and unknown, to the environment that sustains us. Without these arguments, a compelling case for sending humans to Mars and elsewhere might be lacking, but with them - and the buttressing arguments involving science, education, perspective, and hope - I think a strong case can be made. If our long-term survival is at stake, we have a basic responsibility to our species to venture to other worlds."

According to Hawking, "It will be difficult enough to avoid disaster on planet Earth in the next hundred years, let alone the next thousand, or million. The human race shouldn't have all its eggs in one basket, or on one planet. Let's hope we can avoid dropping the basket until we have spread the load" [84].

In a Universe in constant mutation, it seems clear that we need to find solutions to support human development (from conception to old age) and reproduction in Space environments - to ensure the permanence of the human species in the Universe.

Push the boundaries of human development in order to generate human adaptation to off Earth environments and develop the next evolutionary stages

According to Shubin (2013:13), "bodies are kinds of time capsules that carry the signature of great events that shaped them. The molecules that compose our bodies arose in stellar events in the distant origin of the solar system. Changes to Earth's atmosphere sculpted our cells and entire metabolic machinery. Pulses of mountain building, changes in orbits of the planet, and revolutions within Earth itself have had an impact on our bodies, minds, and the way we perceive the world around us". Shubin argues that changes in the physical environment influence how human bodies develop, evolve and generate perception.

Shubin speculates, for instance, that Jupiter would cause different effects on the shape of human bodies on Earth if it formed farther or closer from the Sun: "We would

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84. http://www.space.com/8924-stephen-hawking-humanity-won-survive-leaving-earth.html

have had more elongated bodies (…) if Jupiter formed farther from the sun (…) and been short and squat if it formed closer in" (Shubin, 2013:54). This could happen due to differences in gravitational forces. Shubin was inspired by one of the innumerable scientific discoveries of the renowned Italian philosopher, scientist and inventor, Galileo Galilei. Galileo "envisioned that the gravitational pull defining the orbits of celestial bodies also has an effect on animal and plant organs. Bodies are pulled to Earth to a degree that is proportional to their mass. Heavier creatures, being pulled relatively more, need to change their shape to support themselves" (Shubin, 2013:89 citing Galileo Galilei, 1564-1642).

Not only gravitational forces affect the way human bodies develop and evolve. Other natural phenomena within the Earth's biosphere contribute to this equation (e.g., changes in atmospherical conditions). As referenced by Smith (2012:141), "What we as anthropologists have learned from the study of human evolution is that as humanity has evolved, it has continually expanded outward, finding new places to live. Evolutionary adaptation to such a wide range of environments as inhabited by our species is the force that has shape both our biological and cultural evolution".

In reality, most, if not all, major biological and behavioral changes in Hominids (e.g., anatomical transformations; the development of new verbal communication skills) emerged due to interactions with an ever-changing physical world (Ambrose, 2010; Lieberman, 2013; Llinas, 2001; Organ et al, 2011; Potts, 2012; Shubin, 2009; Smith, 2012; Stout, 2009, 2010; Striedter, 2006). Significant changes in terrestrial environments were associated with body and behavioral transformations in Hominids. These environmental changes represented physical and mental stress to the Hominids body. In turn, physical and mental stress affected how the body has developed and evolved.

It is possible that off Earth environments will alter the way human bodies develop and evolve - causing different formats of physical and mental stress to the developing body compared with terrestrial environments.

For instance, on Earth, developing human bodies are subject to the constant influence of Earth's 1*g* gravitational field. According to Ronca (2003:217), "Life on Earth, and thus the reproductive and ontogenetic processes of all extant species and their ancestors, evolved under the constant influence of the Earth's 1*g* gravitational field". (Ronca, 2003:217). On the other hand, for instance, on Mars, the developing human body will be subject to an influence of a 0.38*g* gravitational field (62% lower than Earth). Possibly, an environment like Mars, would cause variation on the structural features of a developing human body, particularly in early developmental stages, where the most prominent changes in body structure occur.

"The ability of a given genotype to produce different phenotypes in response to different environments is termed 'plasticity', and is part of the organism's 'adaptability' to environmental cues" (Hochberg, 2011:1-2). "Plasticity, or environmental responsiveness, is a universal property of living things" (West-Eberhard, 2003:34). The musculoskeletal, physiologic and cognitive mechanisms in the body are remodeled according to environmental experiences (e.g., Batenson et al., 2004; Belsky & Pluess, 2009; Hochberg, 2011; Jablonka & Lamb, 2005; Philips, 2006; Pritchard, 1995; West-Eberhard, 2003).

The human body has great *plasticity*, particularly in early developmental stages. There is evidence that cognitive structure and function in children is subject to strong influences from environmental experiences when compared adults. For example, environmental experiences are linked to a multitude of structural and functional transformations in the child's brain throughout development (e.g., synaptic pruning; cognitive performance). Here we refer to Neuroplasticity - long-term alterations in neuronal structure and function following changes in activity (Black et al., 1998; Fuster, 2002; Fuster & Bressler, 2012; Gied et al., 1999; Greenough et al., 2002; Hensch, 2004; Huttenlocher, 1979; Huttenlocher & Dabholkar, 1997; Klingberg, 2013; Nelson, 1999; Nelson et al., 2006; Waber et al., 2007). According to the Committee on Space Biology and Medicine et al. (1998:43), "Various types of changes in stimuli may lead to neuroplasticity of target neurons". Furthermore, growth and body composition show a great degree of plasticity throughout development (e.g., Hochberg, 2011).

The previous examples demonstrate that the human body is shaped by environmental experiences. The developing human organism responds to environmental change - adaptive plasticity during ontogeny – by adjusting the developmental phenotype (e.g., Hochberg, 2011; West-Eberhard, 2003). Hochberg (2011:1) states that "Plasticity in developmental programming has evolved in order to provide the best chances of survival and reproductive success to organisms under changing environments (…) Environmental conditions that are experienced in early life can profoundly influence human biology". The author maintains that "Adaptive plasticity (…) may manifest itself as polyphenism (alternative phenotypes in different environments, such as in metamorphosis) or as a continuous variation in traits (…) Trait variability, irrespective of whether it is physiological, morphological, behavioral, molecular, or cellular, is the leading edge of evolution" (Hochberg, 2011:1-2).

Because plasticity seems to be more prominent in early developmental stages it may be the case that main adaptations to Space environments also occur in this point of time. In addition, because humans present an extended childhood maturing period, compared to the other developmental periods (i.e., infancy and adolescence), it may also be the case that childhood is the ideal period to induce adaptation to other environments. Adaptation to off Earth environments during early developmental stages may generate adjustments in the human species phenotype (across generations) - representing better chances of survival and reproductive success in those environments. Therefore, children may play the most important role in the next evolutionary stage.

Hochberg (2011:1) refers that "The window of developmental plasticity extends from conception to early childhood, and even beyond to the transition from juvenility to adolescence, and could be transmitted transgenerationally" (see also Batenson et al., 2004; Belsky & Pluess, 2009; Jablonka & Lamb, 2005; West-Eberhard, 2003). The previous argument puts forward the idea that plasticity could be transmitted across generations, reason why children's progenitors could have an important role in adaptation to Space environments. That's is, the generations which will raise children in off Earth environments would have to present a high degree of plasticity - in order to pass that trait to children and facilitate their adaptation to novel environments[85]. According to Hochberg (2011:2), "organisms exist within an environment that can change rapidly, and those species with a relatively fixed phenotype may not be able to respond sufficiently quickly in order to survive an unexpected environmental change".

The previous arguments lead us to the idea that the preparation for survival in/and adaptation to other environments is associated with phenotypes that show great plasticity. We suggest that the development of this type of phenotype starts on planet Earth, which itself already presents contrasting environmental conditions.

It is not by chance that BSDs serve the purpose of encouraging children to explore challenging natural environments – also encouraging the child to engage in a process of biological self-discovery (body awareness/literacy) in relation to the physical environment. In fact, the educational paradigm that we are proposing to our children is already a glimpse of the near future of Space exploration, or, a preparation for human development in other environments.

The central goal of a BSD is to potentiate children's physical and mental health (including cognitive development/performance), while helping them connect with challenging natural environments offering multiple possibilities for sensory stimulation and increasing physical and mental stress to the organism.

While making use of BSDs in natural environments, through whole-body physical action, the child increases stress to the skeletomuscular and cardiovascular/respiratory systems; to the immune system (contact with germs); and to the nervous system (sensory stimulation; physiological and motor control). Natural environments present contrasting conditions - they combine a set of variables over time, for instance, temperature, humidity, wind speed. Natural environments also present a variety of challenges, e.g., a river to cross, trees to climb, wild animals, reason why they instill mental stress in the child (the ability to face risk; associated with mental or emotional control).

Children may interact with BSDs in different natural environments presenting contrasting conditions (e.g., climate, vegetation, soil), e.g., forests, mountains, plain landscapes. Hence, while interacting with BSDs in natural environments the child's

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[85] Garland (cited in Philips, 2006:3) points out that "directional selection, where individuals with higher values of a certain trait are favored by selection, would seem to benefit individuals with greater phenotypic plasticity and lead to increased plasticity across the generations".

organism needs to adapt to a variety of environmental conditions - what may potentiate plasticity during ontogenetic and phylogenetic processes (trait to be transmitted across generations) and thus increase human survival chances in a variety of environmental conditions[86].

It is not by mere chance that BSDs also encourage children to explore and self-regulate their biological processes as a response to environmental conditions (while having access to physiological and environmental data such as heart rate, neurophysiological states, light, humidity, temperature, oxygen concentrations). It may be the case that the child will have to self-regulate their biological processes in extreme environmental conditions, such as off Earth environments. For instance, being able to control their biological states (e.g., emotional) during risky situations (e.g., increase in atmospheric temperature; decrease in oxygen concentration).

It is also no coincidence that children may teach BSDs to perform autonomous behaviors in the physical environment. Autonomous functions represent increased chances for survival. For instance, the device may assume a leading role during risky situations (e.g., cross an unknown territory; search for oxygen/water). The child may teach and select appropriate behaviors for a diversity of situations in the physical environment[87].

Create new ways to understanding the Universe

If changes in the physical environment impact how bodies develop and evolve (multiple structural and functional modifications), then they also impact the way bodies generate perception. Maintained by Embodied Cognition researchers, the structural features of animals determine how perception emerges in relation to the environment (e.g., Barsalou, 1999, 2003, 2008; Chemero, 2009; Clark, 1997, 2000, 2008; Gibson, 1966, 1979; Gibson & Pick, 2000; Shubin, 2013; Thelen & Smith, 1994). Different kinds of biological organisms present particular physiological features that also determine how they sense and create knowledge about the physical world (e.g., Hall, 2011).

In this way, it is possible that off Earth conditions may come to change our understanding of the surrounding environment – possibly associated with significant biological modifications in the human organism (as demonstrated by Developmental Space Biology researchers). In fact, it may be the case that structural (e.g., morphological) and functional (e.g., physiological) modifications in the human organism (e.g., Ex-

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86. According to Hochberg (2011:1-2), "As a consequence of constantly changing life conditions and environment (…) children may be stunted in growth or be tall, adapt their body composition and energy metabolism, and modulate their longevity, fertility, and fecundity". The author refers that adaptive plasticity is a process that "may be carried forward for three to four generations".

87. Biosymtic devices work as a complementary sensory mechanism while giving access to extra formats of sensory information (e.g., oxygen concentrations, magnetic fields).

aptation processes[88]) may come to generate new ways of accessing different environmental properties - *thus creating new ways to understand the Universe*. We choose to employ a metaphor to describe this idea – "The Echo of the Universe".

The arguments set out in the current subchapter were developed to demonstrate that the developing human body and the physical environment are not dissociated elements - they are systems that continuously affect each other over time. We maintain that it is essential to expose the developing human body to physical and mental stress in a diversity of challenging physical environments in order to create new biological possibilities for the human species – new phenotypes associated to new evolutionary stages. This would not only extend our possibilities for survival in/but also create new ways of understanding the surrounding Universe. In essence, we suggest that the human species should consider the possibility of creating a biological connection with the properties of the surrounding Universe (multiple channels of information embedded in the Universe) - in order to create a deeper understanding of its relation to the Universe.

We propose that Biosymtic devices be associated with an educational paradigm aiming to prepare human development in Space environments (preserving the existence of human organisms on Earth and increasing the possibilities of human development in other environments) (see fig. 16).

In fact, we argue that the ultimate human-machine symbiosis is the one that will push the boundaries of our biological existence – enhancing our biological connection with the surrounding physical environment and supporting the next evolutionary stages.

We conclude our review with the following questions: Will modern children who frequently interact with screen-based computing devices, in artificially controlled environments, demonstrate adaptive capacity in a variety of challenging physical settings? Will those children contribute to trait variability (physiological, morphological, molecular or cellular), the leading edge of evolution? We leave this exercise of thought to our readers.

We developed two initial studies in order to test the premises established in a Biosymtic Approach To Human Development and Evolution - a study in the Child-Computer Interaction and Neuroscience scientific fields; a study in the Child-Computer Interaction and Physiology scientific fields. This will be the topic of the next chapters.

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88. "Exaptation refers to a structure that evolved into a new structure that serves a different purpose than it originally was evolved for in the animal. An excellent example is the jaw bones, which are theorized to have evolved to function as sound transmission structures in the ear" (Bergman, 2005:76). According to Shanks (cited in Bergman, 2005:76), Exaptation "is the primary way in which organisms acquire new genes, and eventually, entirely new organs".

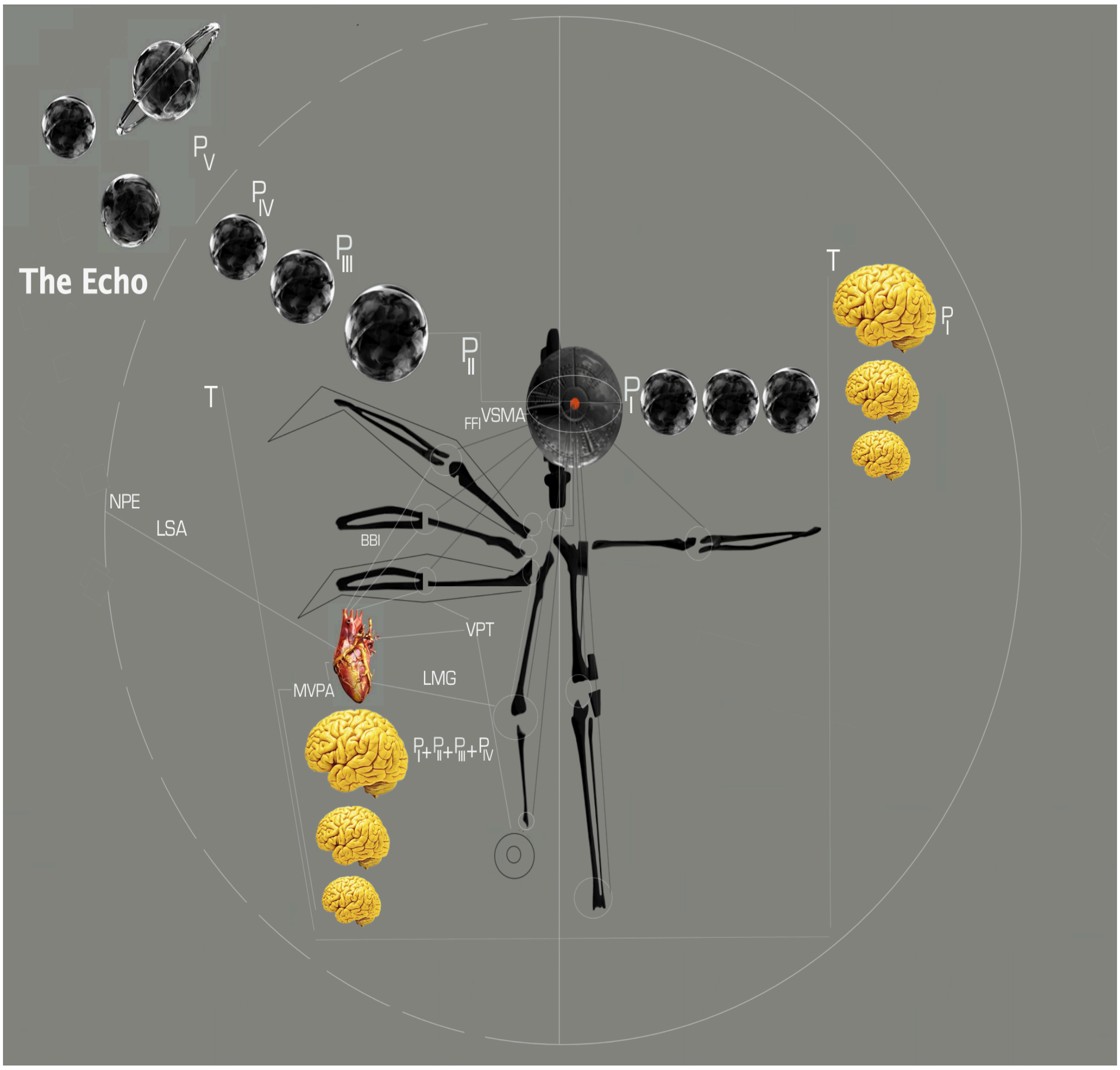


Fig. 16.

A Biosymtic (Biosymbiotic Robotic) Approach to Human Development.
The Echo of The Universe.

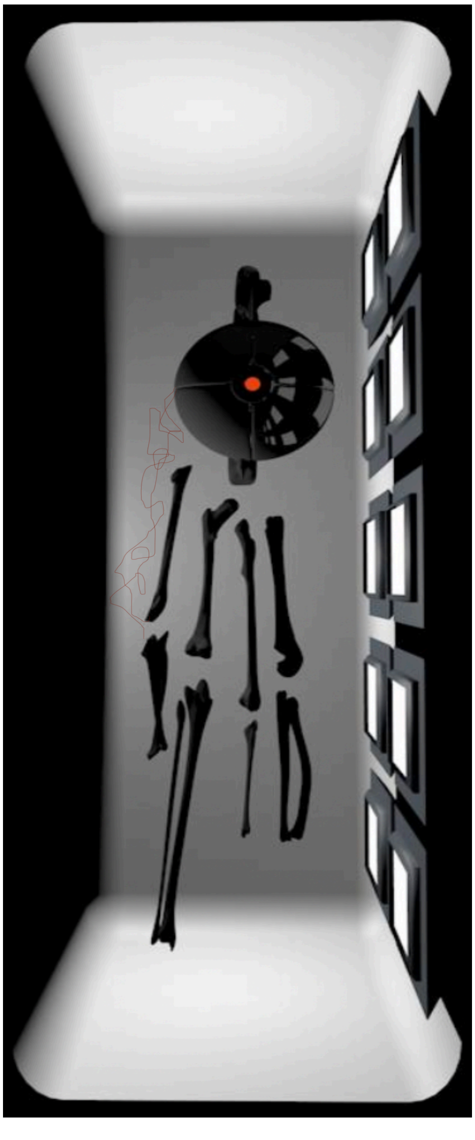
Potentiating physical and mental health in children (including cognitive development and cognitive performance) - connecting the child to challenging natural environments that offer multiple possibilities for sensory stimulation and increase physical and mental stress to the organism.

An educational paradigm for preparing human development in Space environments: enhancing adaptive plasticity during human development and potentiating human evolution.

Creating new ways to understand the Universe – new perceptual possibilities (P_v).

3

Experiment I – Enhanced Versus Restricted Sensorimotor Environments and Cognitive Function in Children Playing Video Games



3.1 Abstract

We characterized and compared the effects of enhanced versus restricted sensorimotor environments on cognitive function in a group of 10 children aged 7 to 8 years. Specifically, we measured neurophysiological response (sustained attention and working memory load levels) and episodic memory performance, while subjects interacted with a whole-body motion screen-based computer device, in a natural environment (enhanced sensorimotor environment), versus a screen-based computer device, based on hand-eye coordination skills, in an artificial environment (classroom setting - restricted sensorimotor environment) - children played a similar video game on both devices. Children's expectations, preferences and opinions regarding the interaction devices were also evaluated. Results indicate a trend for the enhanced sensorimotor environment to increase sustained attention levels in children over time, compared to the restricted sensorimotor environment. In turn, increases in sustained attention levels were associated with improvements in episodic memory performance in the video game environment. This study shows that the current Child-Computer Interaction paradigm - interaction with screen-based computer devices, based on hand-eye coordination skills, in artificial environments - may be failing to optimize cognitive performance in children.

3.2 Introduction

Children's daily activities have become, to a large extent, digital. Devices such as laptops, tablets, smartphones, among others, are now the favorite toys of young generations. Children, in developed countries, access media-saturated environments at home and educational settings (Berson & Berson, 2010; Byron Review, 2008; Common Sense Media, 2011; Calvert et al., 2005; Houses of Parliament, 2012; Kornhauser et al., 2007; McDonough, 2009; NPD Group, 2011; PEW Research Center 2009; Rideout et al., 2010; Roberts & Foehr, 2008, Vandewater & Lee, 2009).

Video game play has become a growing activity in children's daily lives, particularly sedentary video game play through user interfaces based on hand-eye coordination skills (HECS) (e.g., "mouse" and "keyboard" interfaces; multi-touch interfaces). Screen-based computer devices (SBCDs) involving visual and auditory stimuli and user interfaces based on HECS have been used to encourage child learning: a means of driving information. For example, video games have been introduced in educational settings to encourage learning (e.g., Cordes & Miller, 2010; Dickey, 2006; Gee, 2003; Prensky, 2001, 2012; Rideout et al., 2010; Shaffer, 2004; Shaffer et al., 2006; Tuzun et al., 2008).

According to Green & Bavelier (2009:204), "video games incorporate many characteristics of good pedagogy (…) including the ratio of massed versus distributed practice, personalized difficulty levels, just-right increment steps during learning, fun and engagement". Children refer that video games are engaging mainly due to the possibility of experiencing challenging fantasy worlds (Hamlen, 2011).

SBCD encourage children to experience a multitude of visual-auditory information-gathering scenarios, such as multimedia environments that combine still images, video, text and audio. The "multimedia learning theory" highlights that the use of SBCD benefits learning in users. This theory emphasizes that experiences combining visual and auditory stimuli, in SBCD, optimize the construction of mental models that facilitate the formation of schemas in long-term memory (LTM) - learning - when compared to experiences exclusively involving visual or auditory stimuli (Mayer, 2009). In fact, research in Education and Neuroscience has demonstrated that, multimodal experiences combining visual and auditory stimuli seem to reduce mental effort and facilitate children's cognitive processing during complex tasks requiring high attentional and cognitive load levels, when compared to experiences involving a single sensory modality (visual or audio) (e.g., Bagui, 1998; Stein, 2012a).

On the other hand, enhanced multisensory experiences that go beyond visual and auditory stimuli tend to optimize child learning. According to Montessori (1912, 1946), activities without direct instruction (exploratory learning) and involving a combination between visual, auditory, chemical, cutaneous, proprioceptive and vestibular senses optimize learning in children.

Recent research in Embodied Cognition has been demonstrating how sensorimotor experiences affect children's cognitive development and cognitive performance. For example, the development of motor skills - particularly gross motor skills - improves the development of cognitive function and optimizes academic achievement (Graf et al., 2003; Piek et al., 2008; Westendorp et al., 2011); gesturing reduces mental effort (cognitive load) and facilitates memory retrieval during mathematical problem solving (Broaders et al., 2007; Goldin-Meadow, 2003; Goldin-Meadow & Butcher, 2003); perceptual and motor experiences activate neural networks in the brain that later become reactivated in support of cognitive function (multimodal simulation theory), namely supporting numerical cognitive abilities (e.g., James & Maouene, 2009; Krinzinger et al., 2011); the development of language is grounded in perception and action (e.g., Engelen et al. 2011; Hahn & Gershkoff-Stowe, 2010; Pullvermuller, 2005).

Current Child-Computer Interaction (CCI) research has investigated how different types of user interface affect children's cognitive function.

Studies have explored how different types of user interfaces, based on HECS, affect children's cognitive function in children in indoor settings. Differences in physical affordances (possibilities for action) tend to affect cognitive function in distinctive ways: manipulation of physical objects optimizes numerical learning (Manches et al., 2010), problem solving (Antle et al., 2009b) and memory recall (Fails et al., 2005) in children when compared to manipulation of virtual objects SBCDs through peripheral "mouse" and "keyboard" interfaces; manipulating physical objects and manipulating virtual objects on a SBCD through a "mouse" interface optimized children's reading comprehension in similar ways (Glenberg et al., 2011).

A few studies examined how user interfaces based on HECS versus whole-body motion interfaces (computer vision), indoors, affect children's cognitive function. User interfaces based on HECS (demanding fine motor skills: small muscular groups and precise actions) require physical actions distinct from those of whole-body motion interfaces (demanding gross motor skills: large muscular groups and less precise actions). For example, a whole-body motion interface favored the construction of abstract concepts in children when compared to a standard "mouse" interface (Malinverni et al., 2010). On the other hand, a standard "mouse" interface favored the construction of abstract concepts in children when compared to a whole-body motion interface (Buching et al., 2009). Studies regarding the effects of TUIs versus whole-body motion interfaces on children's cognitive function are still scarce and results inconclusive.

In addition, researchers have also demonstrated that the use of PDAs and smartphones (HECS), in real world settings (outdoors), is associated with cognitive benefits in children, e.g., instilling engagement, motivation and concentration and favoring the construction of abstract concepts (Fitzpatrick et al., 2004) and creativity (e.g., Chipman et al., 2006; Silva et al., 2008; Williams et al., 2006).

Interestingly, we have no knowledge of studies on the effects of different types of sensory stimulation provided by users interfaces based on HECS (e.g., textures, weight) or distinct environmental settings (e.g., SBCDs indoors versus SBCDs in natural environments) on children's cognitive function.

Natural environments contain a variety of sensory information available to be processed by the agent - stimulating the visual, auditory, cutaneous, proprioceptive and vestibular senses (Calvert et al., 2004; Posner, 2012). SBCDs indoors restrict the child to processing mostly visual and auditory sources of information. Thus, one may expect that the use of SBCDs in natural environments may affect children's cognitive function in distinctive ways when compared to SBCDs in indoor settings.

This study examines the effects of enhanced versus restricted sensorimotor environments on children's cognitive function, specifically neurophysiological response (sustained attention and working cognitive load levels) and episodic memory (EM) performance during video game play - interaction with a wearable computing device in a natural environment (whole-body motion) versus interaction with a desktop computer in an artificial environment (through HECS). Physiological response (cardiovascular) was also evaluated to understand the effects of physical activity (PA) on children's cognitive function, as was behavioral response - children's expectations, preferences and opinions. To date, and to our knowledge, this study is the first to undertake such comparison, including the evaluation of children's neurophysiological response in high-mobility situations through electroencephalographic technique.

3.3 Hypotheses formulation

We hypothesize that,

1) H_0: "Interaction with a whole-body motion screen-based computing device, allowing multiple action possibilities, in a natural environment (enhanced sensorimotor environment), causes different levels of stress in the child's neurophysiological system (increases in sustained attention over time - high neuroexcitatory activity) when compared to interaction with a sedentary screen-based computing device, through the use of hand-eye coordination skills, in an artificial environment (restricted sensorimotor environment)".

2) H_0: "Interaction with a whole-body motion screen-based computing device, allowing multiple action possibilities, in a natural environment (enhanced sensorimotor environment), optimizes the processing of virtual information in children (encoding and recall of virtual information - episodic memory performance), when compared to interaction with a sedentary screen-based computing device, through the use of hand-eye coordination skills, in an artificial environment (restricted sensorimotor environment)".

The previous hypotheses have an evolutionary foundation.

Alertness relates to the maintenance of wake-states during a certain event. It prepares the brain for incoming stimuli and influences information processing - it is essential for the encoding of sensory information (e.g., Parasuraman, 1998; Posner, 2008; Sturm & Willmes, 2001). According to Caine & Caine (1990:66), "The brain absorbs the information of which is directly aware".

Tonic alertness (sustained attention) concerns the attentional ability to respond to events in the environment and is characterized as a sustained function - maintaining focus over time during a task in the presence of distracting stimuli. It is related to perceptual functions (Posner, 2008; Sadaghiani et al., 2010; Sarter et al., 2001; Valdez et al., 2008).

Alertness activates the brain-stem-thalamo-cortical networks associated with the regulation of the sleep-wake spectrum. The sleep-wake spectrum is linked to variations in neuroexcitatory activity levels: sleep states represent low neuroexcitatory activity; wake-states represent high neuroexcitatory activity (de Lecea et al., 1998; Steriade, 2000). Low levels of alertness are usually identified as "drowsiness" or "distraction" (Berka et al., 2005ab, 2007; Makeig & Jung, 1996). Wake-states rely on afferent sensory stimuli (bottom-up sensory input) (Berka et al. 2007; Moruzzi and Magoun, 1949; Oken et al., 2006).

Since wake-states rely on afferent sensory stimuli, we suggest that interaction with an enhanced sensorimotor environment may induce increases in children's wake-states (sustained attention) over time when compared to interaction with a restricted sensorimotor environment - differences in neurophysiological response.

We also suggest that differences in sustained attention, caused by exposure to dissimilar sensorimotor environments, may cause differences in children's cognitive performance, specifically in EM of virtual events on a video game.

EM concerns the capacity of encoding, storing and retrieving events - context and period associated to a certain event (e.g., a child remembering her afternoon play game in a forest) (e.g., Conway, 2001; Johnson & Hann, 2012; Purves et al., 2008; Tulving, 1972). Studies showed that improved sustained attention, in adults, is related to improvements in EM (e.g., Berka et al., 2004, 2007; Stevens et al., 2007b; Tariot et al., 1987). For example, Berka et al. (2007) demonstrated that higher levels of sustained attention and working cognitive load during encoding were positively related with memory performance in learning tasks.

Studies examining the relation between children's sustained attention and memory function are still scarce.

A recent study in developmental psychology demonstrated that executive functions such as inhibition, switching, working memory and sustained attention exhibit improvements between 5 and 8 years of age. It was also demonstrated that processes such as inhibition, switching, working memory and sustained attention present small to moderate correlation throughout development (Loher & Roebers, 2013). Magimairaj & Montgomery (2013) reviewed studies demonstrating that sustained attention is related to early learning skills, IQ, language and academic skills.

We did not find neuroscience studies relating sustained attention with EM in children. Nonetheless, we suggest that increases in sustained attention over time, caused by enhanced sensorimotor environments, may optimize children's EM in virtual settings - encoding of virtual information - when compared to restricted sensorimotor environments.

Research has been demonstrating that children have less efficient alertness and executive control mechanisms of attention compared to adults (children seem to react slower to alerting tasks; increased difficulty in disengaging from distracting sources; less efficient conflict resolution mechanisms). The outlined arguments were based on results from experiments conducted in controlled laboratory environments – a child interacting mostly with SBCDs that produce visual and auditory stimuli in artificially controlled environments (e.g., Baars, 2007; Buchman et al., 2011; Davies et al., 2004; Duncan & Owen, 2000; Enns & Brodeur, 1989; Fuster, 2002; Goldberg et al., 2001; Lavie, 2005; Lavie et al., 2004; Lin et al., 1999; Morrison, 1982; Ridderinkhof et al., 1997; Rueda et al., 2004ab; Trick & Enns, 1998; Wainwright & Bryson, 2002; Waszak et al., 2010; Wetzel et al., 2009).

We do not contradict the idea that children seem to present less efficient attentional mechanisms when compared to older children and adults in controlled laboratory environments. We suggest that children may demonstrate improvements in attentional functions in enhanced sensorimotor environments when compared to restricted sensorimotor environments.

Hominids evolved to process multiple sources of sensory information from an early age. Hunter-gatherer children spent their time actively exploring information in the surrounding physical world, using physical tools to interact with the natural environment (e.g., to forage, hunt, fish) (Lieberman, 2013). Natural environments include a variety of sensory information. Hence, hunter-gatherer children had to self-attend and self-select a multitude of sensory information to sustain task goals.

In fact, attention involves highly-competitive perceptual processes: multiple features, from various items, converge and compete to be codified in the same receptive field of neurons, whilst distracting items are filtered (Berger, 2011; Berger et al., 2012; Desimone & Duncan, 1995; Parasuraman, 2000; Posner, 2012; Posner and Petersen, 1990). Hunter-gatherer children may have needed to maintain attentional focus in challenging physical environments to survive. Since children had to, for instance, escape from predators, cross a dangerous river, while they walked and ran relatively long distances to forage (Lieberman, 2013), maintaining focus over time was probably synonym to survival: allowing children to better self-attend and self-select information in the surrounding environment to sustain task goals.

Children's attention mechanisms evolved in connection with enhanced sensorimotor environments. Hence, it may be the case that enhanced sensorimotor environments still optimize attentional functions in modern children, improving sustained attention functions and thus facilitating information processing. Children may have to sustain attention during a virtual task to better encode (memorize) episodic events within that same task - accurate representation of episodic events.

In addition, it is known that the presence of the neuromodulator norepinephrine (NE) in the brain raises alertness levels in individuals (Aston-Jones & Cohen, 2005; Marroco & Davinson, 1998; Posner, 1975). PA, particularly aerobic, raises the levels of NE in the brain (e.g., Gligoroska & Manchevska, 2012; Jensen, 2000; Ratey & Hagerman, 2013; Sachs & Buffone, 1984; Tantillo et al., 2002; Taylor et al., 1985). Moreover, moderate aerobic PA seems not to compromise cerebral regulation unless physical exhaustion is reached (Herzholz et al., 1987; Ide et al., 1999; Trudeau & Shephard, 2009). Therefore, we also suggest that interactions with enhanced sensorimotor environments, through moderate aerobic PA, may contribute to the maintenance of sustained attention, in children, due to raises in the levels of NE in the brain, thus optimizing information processing - EM (encoding of virtual events).

Furthermore, we suggest that enhanced sensorimotor environments do not overload the child's working memory (WM) system and thus optimize EM performance in virtual environments.

WM is defined as the ability to temporarily maintain and manipulate a limited amount of information while inhibiting distractive information; it allows the agent to connect time-to-time events and thus to obtain knowledge from the surrounding environment (Baars, 2007; Baddeley, 1974; Baddeley & Logie 1999; Conway et al., 2005; Fuster & Bressler, 2012 Prabhakaran et al., 2000; Smith & Jonides, 1998). According to Peterson & Peterson (1959), contents in WM that are not rehearsed can be lost in approximately 20 seconds.

WM is closely related to attention processes. For instance, the WM system cooperates with executive control of attention - associated with the ability to avoid distractive information (Fukuda & Vogel, 2011). Children exhibit increased difficulties while dealing with increased WM load (linked with information loss), requiring the intervention of executive control processes. The ability to avoid distractive elements is dependent on the maturation of the prefrontal cortex (PFC), the brain area related to executive control of attention that matures until adulthood (Fuster, 2002; Wetzel et al., 2009). As previously mentioned, multimodal experiences appear to reduce mental effort (cognitive load) in children. In children, a high WM load means a possibility for information loss (Beveridge et al., 2002; Case et al., 1982; Sanders et al., 2012; Squire & Alvarez, 1995).

Children are less efficient at using WM mechanisms when compared to adults. WM performance in children seems to be mostly dependent on low-level feature binding processes - associated with perceptual representations originating from bottom-up mechanisms (sensory driven and involuntary) (e.g., Edin et al., 2007; Fabiani & Wee, 2001; Klingberg et al., 2002; Kwon et al., 2002; Paus, 2005; Sanders et al., 2012) due to the ongoing maturation of the PFC and the frontoparietal neuronal circuitry (Anderson et al., 2001; Chugani & Phelps, 1986; Edin et al., 2007; Fuster, 2002; Johnson & Hann, 2011; Klingberg, 2006, 2013; Lambe et al., 2000; Luciana, 2003; Nagy et al., 2004; Nelson et al., 2006; Ofen et al., 2007; Paus, 2005; Raj & Bell, 2010; Shaw et al., 2008; Sluzenski et al., 2004; Yeager & Yeager, 2013; Zelazo et al., 1997; Zelazo & Muller, 2002).

According to the previous set out arguments, we speculate that enhanced sensorimotor environments may prevent the overload of the child's WM system during information processing. We reason that exposure to multiple sensory modalities, during information processing, can decrease cognitive load and thus increase WM capacity - benefiting the retention/maintenance of episodic information in the WM system. In addition, if we accept that enhanced sensorimotor environments increase children's sustained attention over time during a certain task - diminishing distractive interference - we may speculate that they also reduce cognitive load in the WM system, facilitating short-term maintenance of information (i.e., episodic information of virtual events). Interestingly, Cabeza et al. (2002) found that (fMRI study with 20 adult participants) PFC and parietal activations during episodic memory retrieval are mostly related to attentional (sustained attention) in opposition to mnemonic processes.

Furthermore, assuming that memory representations regarding EM are mostly under the influence of posterior sensory and perceptual areas in children, we suggest that enhanced sensorimotor environments may generate a variety of perceptual symbols in support of enhanced sensorimotor representations of episodic events (optimizing recall of episodic events in virtual settings).

Conway et al. (2009) state that attention, WM and long-term memory (LTM) cooperate to generate mental representations of the surrounding environment (including encoding and manipulation of sensory information to generate mental representations) and action-related functions. WM is dependent on the electrochemical activity of large populations of neurons and thus involving several brain systems. For instance, the medial temporal lobe (MTL) including the hippocampus and neighboring structures - all related to the ability to encode, maintain and retrieve information. The hippocampus establishes communication with associative areas in the brain to encode, maintain and retrieve information (generating a representation in the hippocampus). The communication between the hippocampus and associative processing areas, namely the prefrontal association cortex (frontal lobe) allows anticipation or prediction of future events (Moscovitch et al., 2007; Rowland & Kentros, 2012; Squire & Alvarez, 1995).

Sensory information is processed in the WM system along with the LTM system. The WM system receives, maintains and manipulates short bouts of sensory information (arriving from selective attention processes) in line with ongoing task goals and previously obtained knowledge stored in LTM. According to the "consolidation hypothesis", WM activates brain areas that store long-term information (e.g., frontal half of the cortex stores motor memories that were previously enacted in the WM system) (Baars, 2007; Fuster, 2003; Purves et al., 2008).

LTM is widespread through different regions in the brain, including the cortex (lobes, including association areas; insular cortex and cingulate cortex) and subcortical structures (e.g., hippocampus, basal ganglia, amygdala, thalamus, cerebellum) (Baars, 2007). WM and LTM cooperate in the process of learning in children. Learning is referred in neuroscience as the process of acquiring, modifying or reinforcing memory representations. Learning involves association between information in the WM system and past-acquired information in the LTM system. It implies storing information in LTM for later use in a variety of situations. Learning involves synaptic alterations in the brain[89] (Colom et al., 2004; Conway et al., 2003; Hebb, 1949; Moscovitch et al., 2007; Ratey & Hagerman, 2013; Sutherland & McNaughton, 2000).

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[89] Hebb (1949) developed a neuropsychological theory to explain the learning process in the brain. This theory is referred to as "Hebbian learning". According to this theory, neurons that fire together, wire together - learning occurs when synaptic connections are strengthened (thickening between the nodes of neurons). Alterations in neuronal connections imply excitatory and inhibitory synaptic changes (Hebb, 1949; Sutherland & McNaughton, 2000). Other authors have further explored this theory. For instance, Ratey and Hagerman (2013:39) describe learning through a dynamic molecular mechanism, involving long-term potentiation. Accordingly, when the brain processes information "the demand naturally

LTM includes different types of memory, namely, declarative (or explicit) memory (remembering events and facts) and nondeclarative (or implicit) memory (procedural memory; e.g., perceptuo-motor skills like learning to ride a bicycle). In turn, declarative memory subdivides into semantic memory and EM.

EM is linked to activity in the MTL [parahippocampal cortex (PHC) involving representations of isolated items during short bouts of time - seconds to minutes; perirhinal cortex (PRC); retrosplenial cortex (RSC); hippocampus involving representations of the properties of the stimuli)], PFC, posterior parietal cortex (PPC) and subcortical regions in the brain (e.g., basal forebrain, thalamus, mammillary bodies).

The MTL is related to the ability to encode, maintain and retrieve information. "The perirhinal cortex and posterior parahippocampal gyrus (PHG), which surround the hippocampus along the anterior/posterior axis, are thought to send signals to the hippocampus to represent information about events (i.e., the perirhinal cortex) and context (i.e., the PHG) to be bound in the hippocampus" (Ghetti & Bunge, 2012:383). The hippocampus allows storage and retrieval of episodic information. Information in LTM is retrieved partially and not as a perfect representation of the information that was encoded (Miller & Cohen, 2001).

Regions in the PPC are associated to encoding and retrieval of information (e.g., "maintains the episodic signal on-line for further assessment (…) a center for the direction of attention to either bottom-up stimulus-driven memory signals, or top-down, internally driven memory states"). The PPC communicates with the hippocampus and the PFC (e.g., Fletcher et al., 1997; Ghetti & Bunge, 2012:390; Miller & Cohen, 2001; Mišić, et al., 2014; Ranganath & Ritchey, 2011). According to Ghetti & Bunge (2012:390), "A graded pattern of responses is observed in this region, as a function of the source and the amount of contextual information retrieved" (as cited in Henson et al., 1999 and McDermott et al., 2000).

The hippocampus communicates with regions in the PFC (namely the right anterior and dorsolateral PFC) to encode, maintain and retrieve information in the WM system (strategic mechanism) – communicates with executive control regions to generate

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causes activity between the neurons. The more activity, the stronger the attraction becomes, and the easier is for the signal to fire and to make the connection. The initial activity marshals existing stores of glutamate in the axon to be sent across the synapse and reconfigures receptors on the receiving side to accept the signal. The voltage on the receiving side of the synapse becomes stronger in its resting state, thereby attracting the glutamate signal like a magnet. If the firing continues, genes inside the neuron's cell nucleus are turned on to produce more building material for the synapses and it is this bolstering of the infrastructure that allows the new information to stick as a memory".

mental representations of events and context. The dorsolateral PFC[90] controls encoding and retrieval of information. According to Fletcher et al. (1997:217), "the prefrontal cortex plays an important role both in the adoption and maintenance of retrieval strategies, and in verifying or monitoring the products of retrieval". In addition, the hippocampus establishes communication with associative areas (receiving polysensory input from association areas of the neocortex; e.g., visual association cortex; auditory association cortex; somatosensory association cortex) and subcortical structures in the brain (e.g., basal forebrain, thalamus, mammillary bodies) to encode, maintain and retrieve information.

EM continues to mature and presents fast improvements during middle childhood - "predominantly involves increasingly skilled encoding and retention of complex event representations that make up our ability to encode and remember episodes – as opposed to, for example, quicker recognition of past events based on familiarity". This happens because the PFC and connections between the PFC and the MTL are still maturing (changes within a brain region and in long-range connectivity between the PFC and the MTL; the MTL develops at faster rates when compared to the PFC) (Brainerd et al., 2004; Ghetti & Bunge, 2012:383; Nelson et al., 2006; Ofen et al., 2007; Raj & Bell, 2010; Shing & Lindenberger, 2011; Sluzenski et al., 2004). The development of episodic memory also depends on structural and functional associations between the posterior parietal cortex (PPC) and the hippocampus/prefrontal cortex (PFC); however, to date, these associations are still unknown.

According to Sanders et al. (2012), during WM processing, prefrontal areas control posterior sensory and perceptual areas in order to generate mental representations. Since the PFC and connections between the PFC and the MTL are still maturing in children, it may be the case that memory representations regarding EM could be mostly under the influence of posterior sensory and perceptual areas (posterior neural systems that serve sensory and perceptual functions); that is encoding and retrieval of episodic information (EM performance) mostly under the influence of posterior sensory and perceptual areas.

Shing and Lindenberger (2011:148,147) reviewed studies demonstrating that "the associative component of EM is relatively mature by middle childhood and declines in old age (…) the associative component refers to binding mechanisms that integrate features of the memory content[91] (…)" and "mostly relies on the medial temporal lobes (MTL)". The authors also mention that "the strategic component of EM matures later

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[90] In a similar fashion to adults, upholding of information in children activates the DLPFC; however, there is an additional activation of areas such as the ventral lateral regions of the PFC (Nelson et al., 2000, 2006).

[91] "integrating core content and contextual features of an event into a cohesive memory representation".

than the associative component and also declines in old age (…) the strategic component depends primarily on the prefrontal cortex".

As previously referenced, apart from prefrontal areas, the hippocampus in the MTL establishes communication with associative areas in the brain for encoding and retrieval of information. Since the PFC and connections between the PFC and the MTL are still maturing in children it may be the case that encoding and retrieval of episodic information is mostly under the influence of posterior sensory and perceptual areas. Here, we suggest that children may encode and represent episodic events closer to the sensory surface when compared to adults.

Barsalou (1999, 2008) developed the multimodal simulation systems [or the Perceptual Symbol Systems (PSS)] to explain the origins of mental representations (Embodied Cognition theory). Accordingly, mental representations are generated through simulation processes in the brain – reactivation of neural circuits that were active during previous perceptual, motor and introspective experiences. Multimodal representations regarding perceptual, motor and introspective states (perceptual symbols) are stored in the brain's memory system and later recalled during conceptual processing (supporting memory recall and other higher-order cognitive abilities).

Barsalou (1999:577, 582, 585) refers that "During perception, systems of neurons in sensory-motor regions of the brain capture information about perceived events in the environment and in the body. At this level of perceptual analysis, the information represented is relatively qualitative and functional (e.g., the presence or absence of edges, vertices, colors, spatial relations, movements, pain, heat) (…) There is little doubt that the brain uses active configurations of neurons to represent the properties of perceived entities and events".

Barsalou (1999) maintains that, from audition, humans capture perceptual symbols for the sounds in the environment, from touch, perceptual symbols for texture and temperature, from proprioception perceptual symbols for body movement, and so forth. Each symbol is integrated in its corresponding brain area (e.g., auditory areas, motor areas) that represents the properties of perceived events from the environment. Symbols are later recalled during conceptual processing, simulating the experience offline.

Conway (2001) and Rubin (2006) state that multimodal simulation occurs during the retrieval of EM. According to Conway (2001:1375), episodic memory "retains highly detailed sensory perceptual knowledge of recent experience over retention intervals measured in minutes and hours". Conway (2001:1376) refers that EM retrieval activates brain regions "most closely involved in the processing that took place during actual experience (…) sensory-perceptual details are represented in the posterior regions of the brain and especially in networks cited in the occipital lobes, posterior parts of the temporal lobes, and (conceivably) in posterior parietal lobes" (see also Rubin 2006). In a similar fashion, Fuster (2010) emphasizes that memory recall processes involve reactivation of perceptual and motor regions in the brain (see also Damasio, 1989).

Based on the assumption that memory representations regarding EM may mostly be under the influence of posterior multimodal sensory and perceptual areas in children, we suggest that EM performance (encoding and recall of episodic information) may benefit from interactions with enhanced sensorimotor environments. Enhanced sensorimotor environments may generate a variety of perceptual symbols in support of enhanced sensorimotor representations of episodic events, and thus optimize recall of episodic events (accurate representations of episodic events).

The child can rely on additional sources of sensory information to represent episodic events in the virtual environment (beyond visual and auditory information). According to Butler & James (2012:388), "recognition associated with a 'remember' (as opposed to a 'know') response is associated with greater reactivation of sensory regions that are specific to associated contextual information encountered during encoding. This greater activation of context related regions is associated with an increase in memory accuracy, and recalling more information has been shown to increase the degree of neural reactivation". Furthermore, studies have demonstrated that enhanced sensory experiences tend to optimize episodic memory recall of virtual events on virtual environments in adults (e.g., Dinh et al., 1999; Tortell et al., 2005).

Followingly, we describe how, in this experiment, the enhanced sensorimotor environment could increase sustained attention over time and improve EM performance, in children, compared with the restricted sensorimotor environment.

Children used a wearable SBCD, based on whole-body motion, to simultaneously interact with a natural forested landscape and a virtual world (in this case a video game) – constituting an enhanced sensorimotor environment. This device (comprising sensing instruments such as accelerometers and a head-mounted display to visualize virtual contents) encourages the child to move in the physical world to complete specific video game tasks – e.g., moving the game avatar by actually moving on the physical terrain. The same virtual world was also experienced on a sedentary SBCD combined with an interface based on HECS ("keyboard") in an artificial environment (classroom) – constituting a restricted sensorimotor environment.

In the natural landscape the child is surrounded by multiple sensory stimuli, e.g., sound of wind (auditory), different surfaces (proprioceptive, vestibular and cutaneous) and diverse smells (olfactory). This type of environment may induce wake-states in the child over time and thus optimize EM performance of virtual events - namely, optimizing encoding of virtual information in the game - compared to the artificial environment (offering visual and auditory stimuli only). The enhanced sensorimotor environment may facilitate encoding of virtual information by allowing continuous states of active attention in the child - increased awareness about the elements/experiences (e.g., objects, play sequences) in virtual scenarios (generating accurate mental representations of the virtual experience to be later recalled during retrieval).

The enhanced sensorimotor environment may generate a variety of perceptual symbols supporting enhanced sensorimotor representations of virtual events (optimizing recall of virtual events in the game). For instance, when a child focuses attention on game events (e.g., capturing four CO_2 molecules) (see fig. 17) in the enhanced sensorimotor environment, she receives visual and auditory inputs from both virtual and physical worlds. Proprioceptive, vestibular, cutaneous and chemical inputs from the physical world are also received. Proprioceptive and vestibular information from the position of the body relative to virtual objects in the game event (e.g., moving on the terrain from right to left to capture virtual CO_2 molecules), together with the stimulation of cutaneous (mechanical vibrations on the bottom of the feet) and chemical senses (olfactory chemoreceptors in the nose), may contribute to an enhanced sensorimotor representation of virtual events.

Barsalou (1999:586) refers that as the agent focus on different aspects in the environment "the resulting memories are integrated spatially, perhaps using an object-centered reference frame". That is, as the perceiver moves around the object (in this case the four CO_2 molecules) in a three-dimensional axis (variety of movements in the three-dimensional space; frontal, sagital, and transverse planes) "stored perceptual records (…) become integrated into this spatially organized system (…) As a result of organizing perceptual records spatially, perceivers can later simulate the object in its absence (…) simulate (…) experiences of the object".

Smith (2009:79) states that "By the dynamic field account, objects and locations are bound together - and internally represented - via motor plans, which are themselves tightly tied to the current position of the body". Therefore, mental representations of objects/locations in the virtual world are constructed in accordance with the child's physical actions. This sensory experience goes beyond the visual and auditory information available in the restricted sensorimotor environment (based on HECS).

In fact, we suggest that the experience of using HECS to control an avatar in a video game, played in an artificial environment, is a more abstract experience when compared to whole-body motion in the physical world. The former lacks whole-body coordination in three-dimensional space, including a sense of balance/effort being applied in the movement (sense of balance is projected onto the avatar in the game)[92]. Furthermore, the child loses the possibility to interact with a variety of sensory information that enhanced sensorimotor environments have to offer.

As stated by Smith (2013:169), "Although stimuli that represent environments, such as pictures of environments, video-recordings of places, or virtual reality environments, can evoke varying degrees of feelings of environmental immersion, they do

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92. Taube et al. (2013) state that spatial orientation and navigation "rely to a large extent on locomotion and its accompanying activation of motor, vestibular, and proprioceptive systems". These authors stress that virtual navigation tasks in fMRI scanners and real world navigation tasks may impact neural mechanisms in humans in diferent ways.

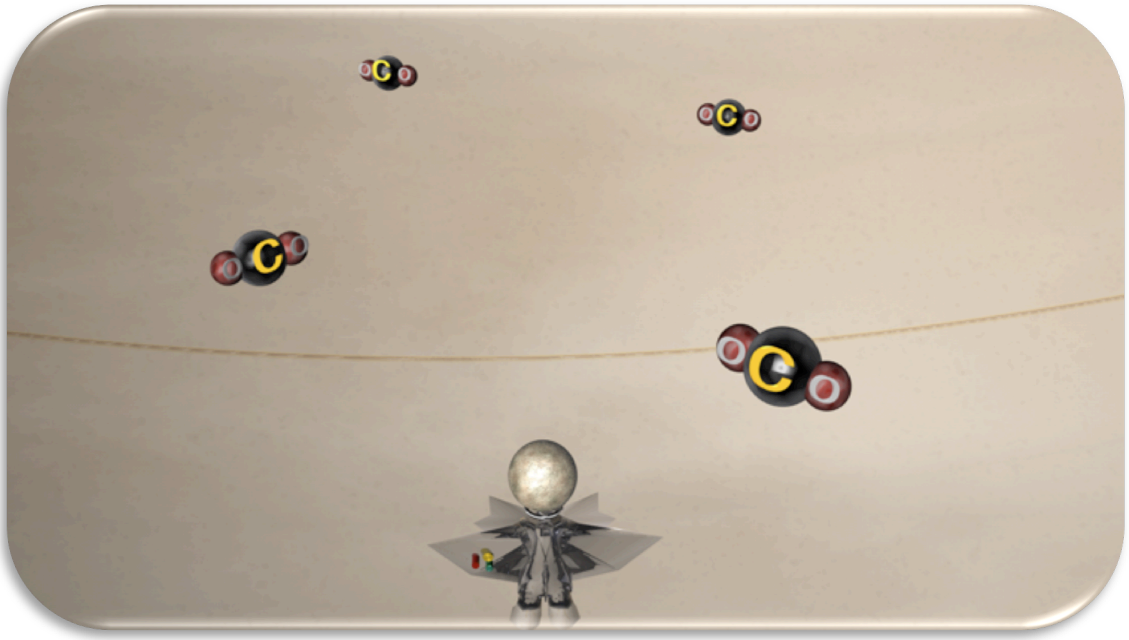

Fig. 17.

Video game task

The child is asked to move from right to left to catch Co_2 molecules in the atmosphere of Venus.

so only in an indirect way that necessarily involves the participants' projection of themselves into those virtual environments". More specifically, the enhanced sensorimotor environment may optimize recall of episodic information, from the virtual environment, due to the fact that the child can rely on additional sources of sensory information to represent virtual events (besides visual and auditory information).

According to Barsalou (1999:86), "a simulator produces simulations that are *always* partial and sketchy, *never* complete. As selective attention extracts perceptual symbols from perception, it never extracts all of the information that is potentially available. As a result, a frame is impoverished relative to the perceptions that produced it, as are the simulations constructed from it". It may be the case that additional sources of sensory information may contribute to an enriched representation of virtual events, optimizing recall of information of those same events, particularly in children - based on the hypothetical assumption that memory representations concerning episodic memory may be mostly under the influence of posterior multimodal sensory and perceptual areas.

In the following subchapters we will describe the methodological design of the present study, including, research method, evaluated devices and video game software, sample selection, study design, core elements of treatment conditions, measuring instruments, institutions and partners involved in the research project and statistical techniques.

3.4. Research method

This is a quasi-experimental, cross-sectional, descriptive and comparative study. It describes and compares children's cognitive (neurophysiological response and EM performance), physiological (cardiovascular) and behavioral response (expectations, preferences and opinions) to two types of environment: an enhanced sensorimotor environment - interacting with a wearable whole-body motion SBCD (Biosymtic device "Albert") in a natural environment (natural forested landscape); and a restricted sensorimotor environment – interacting with a traditional screen-based computer device (CD) in an artificial environment (classroom setting; based on HECS).

A group of 10 children aged 7 to 8 years was evaluated under four conditions (each child evaluated individually once under each condition): interacting with a whole-body motion device (Biosymtic device "Albert") in a natural environment – playing a closed video game narrative (condition 1) and an open video game narrative (condition 2); and interacting with a traditional CD (HECS) in an artificial environment - playing a closed video game narrative (condition 3) and an open video game narrative (condition 4).

The present study is a pilot study – the main goal is to observe if there are significant effects concerning the evaluated conditions. If this is the case, we may then proceed with a full-scale research study.

3.5 Evaluated devices and video game software

Each child interacted with a Biosymtic (Biosymbiotic robotic) device – "Albert"– in a natural forested landscape. A Biosymtic device is characterized as an artificial system that displays automatic control functions while (two modes), 1) Directly connected to a human organism (human-integrated automatic control; working as a human-robot interface); 2) Disconnected from a human organism (autonomous control; working as an autonomous robot – virtual software agent).

In this study, children interacted with "Albert" in mode 1) displaying automatic control functions while directly connected to the child's organism (working as a whole-body motion human-robot interface).

The system consists of a wearable suit with wireless sensors - I-cubeX® - communicating with a computer processor (in the center back of the suit) – Algiz 7®; a monocular head-mounted display - Vuzix Tac-Eye LT® - connected to the computer processor, displaying virtual information (placed in front of the right eye: mixed-reality); a sound speaker - GrvMini GRV6579® - embedded in the suit (auditory output); and motion sensors to capture the child's motion data (accelerometer, gyroscope and a tilt sensor). The system also captures physiological data - communicating wirelessly with a heart rate (HR) biosensor placed on the child's chest.

System inputs to control virtual information (e.g., put an avatar into motion) are made through whole-body physical action, e.g., the child may walk, run, jump, rotate, trot on the physical terrain. Virtual information may also be controlled by interacting directly with sensor-based interfaces - manipulate a "turn button sensor"; blow air into an "airflow sensor"; manipulate inflatable toys connected to sensor interfaces, e.g., connected to the "airflow sensor" (in this study, the child could select between inflatable space rockets, planets, a shark, a dragon or a bat – and could choose whether or not to use these toys).

"Albert" includes a "touch-glove sensor" to control virtual information and to interact with physical elements in the natural environment (e.g., touch a tree/plant/bush, rocks), and a "bar sensor" to control inertial forces. This device demands both gross and fine motor skills performance so as to potentiate children's motor development as a whole (see fig. 18).

Each child also interacted with a traditional screen-based computer device (CD), based on HECS, in a classroom setting (sitting at a desk – sedentary condition). The child had to manipulate a "keyboard" interface to interact with a video game ("arrow keys"/"space bar"/"number keys", e.g., to control the avatar) – fine motor skills performance. The CD offered the child visual (two-dimensional display) and auditory stimuli (sound speakers) (see fig. 19).

Both "Albert" and the CD included the video game "Vankalo. The Sedentary Cyborg", an adventure through our solar system. In the narrative, "Vankalo" tries to steal solar system planets by condensing them into microparticles to be kept inside its "H2O aquarium head". The goal is to put an end to "Vankalo's" plan by creating a new solar system homeostasis. The child adopts different avatars throughout the narrative, e.g., "Moon", "Albert" and "Water mutants". Children are encouraged to learn about the solar system through this game.

Two video game narratives of "Vankalo. The Sedentary Cyborg" were developed. The first is a closed narrative format: the child followed a predetermined sequence of game chapters (from Moon to Venus; Venus to Earth; to Mars; to Saturn; ending in Neptune). Visual and verbal instructions were received throughout the game (goals to achieve in each scenario, including location in the game; what interface/sensor or keys to use). In this narrative version, the child had to complete five multiple-choice questions at the end of each game chapter in order to score (3 points for a correct answer; total score: 0 - 15 points).

The multiple-choice questions evaluated the child's EM performance. In each game scenario the child received visual and verbal instructions, via the software, about goals to accomplish, including location (e.g., "Go jump over Mercury"; "Go to Venus"; "Catch the CO_2 molecules in Venus!"). These instructions cued the multiple-choice questions task. For instance, in the "Venus" game scenario the child had to move from right to left to capture four CO_2 molecules - the software gave visual/verbal instructions – "Catch the CO_2 molecules in Venus!". Subsequently the child was questioned about how many CO_2 molecules she observed (presented visually on the software – question and three multiple-choice answers, 3, 4, or 6 respectively; the software

Fig. 18.

Biosymtic device Albert
Whole-body motion interaction in a natural environment – forested landscape
(stimulating the visual, auditory, chemical, cutaneous, proprioceptive and vestibular senses)

Top figure: Biosymtic device Albert.

Middle figures: child interacts with a tree in both physical and virtual environments – physical action through the touch-glove sensor translated into virtual input on the video game avatar.

Bottom figures: child interacts with an inflatable toy (pressing a space rocket) connected to the airflow sensor to plant trees and create oxygen on the video game scenario.

Fig. 19.

Traditional screen-based computer device.
Hand-eye coordination interaction in an artificial environment
(traditional classroom setting)

The child interacts with a portable computer placed on a desk (while sitting - sedentary condition) through a "keyboard" interface – fine motor skills.

The device produces visual (two-dimensional display) and auditory stimuli (sound speakers).

verbally questions the child - "How many CO_2 molecules did you observe? 3, 4, or 6?"). The multiple-choice task corresponds to an EM cued recall task (immediate recall), with the help of visual and verbal cues (information that was presented during the game scenarios so as to facilitate EM recall)[93].

The closed narrative version (on the "Albert" device) included an automatic feedback control mechanism that encouraged the child to achieve moderate aerobic PA - 50% and 70% of maximum HR values (recommended by the CDC[94], 2015). This mechanism aimed at improving EM performance. A software actuator controlling changes in the displacement speed of the game avatar - "inertial virtual actuator" - maintained the desired interval of HR values. For instance, if the child presented an average HR value <134.5 BPM (<50%), while interacting with the device, the system increased the inertial forces applied to the avatar – the child needed to move faster to reach the desired interval. If the child exhibited an average HR value >161.5 BPM (>70%), the system decreased the inertial forces applied to the avatar.

The system also included a verbal actuator that produced audio output. This actuator followed the principles established for the "inertial virtual actuator". If, for in-

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93. A detailed description of this software program is presented on Appendix A.
94. Center for Disease Control and Prevention.

stance, the child presented an average HR value <134.5 BPM (<50%), the verbal actuator emitted specific verbal feedback, e.g., "Run faster!" or "Give me more power!". If the child presented an average HR value >161.5 BPM (>70%), the verbal actuator emitted specific verbal feedback, e.g., "Slow down!" or "My mechanisms are about to explode!". Reference interval of HR values were calculated and adjusted every minute (according to average HR values per minute).

Researchers stress that aerobic PA is related to physiologic changes in the body, such as increases in heart rate and systemic blood pressure that interfere with cerebral circulation. Cerebral blood flow (including supply of nutrients and oxygen to the brain) increases in children during physical exercise (e.g., Bode, 1991). Cerebral blood flow in the adult brain can increase up to 14% to 30% with moderate aerobic activity and without compromising cerebral auto-regulation - unless physical exhaustion is reached (Herzholz et al., 1987; Ide et al., 1999; Trudeau & Shephard, 2009). Studies demonstrated that increases in blood flow benefit children's cognitive function due to increased oxygen and glucose supply to the brain (post-activity evaluation) (Mokgothu citing Chodzko-Zacjko, 1991 and Madden et al., 1989). As previously mentioned, researchers have demonstrated that aerobic PA raises the levels of norepinephrine (NE) in the brain. In turn, the presence of NE in the brain raises alertness levels in individuals.

We suggest that possible increases in alertness levels and in cerebral flow, caused by moderate PA, may optimize children's cognitive performance - in this case, encoding and retrieval of virtual information in the video game narrative - reason why "Albert" encourages the child to perform moderate PA levels in the closed narrative.

The closed narrative version (on the CD) included a control mechanism analogous to the automatic feedback control mechanism on the device "Albert" - maintaining the displacement of the avatar at moderate levels. If the child pressed the "arrow keys" five times in five seconds, the software gave the feedback: "Run faster!" or "Give me more power!". If the "arrow keys" were pressed fifteen times in five seconds, the software gave the feedback: "Slow down!" or "My mechanisms are about to explode!".

The second version of the game software was an open narrative format: the child selected the chapter to play (from Moon to Venus; Venus to Earth; to Mars; to Saturn; ending in Neptune). Visual and verbal instructions were received throughout the game (goals to achieve in each scenario, including location in the game; what interface/sensor or keys to use). The child could select the game chapter to play from five virtual capsules (each capsule with a letter in it, e.g., "Y", "X"); couldn't return to finished game chapters (a visual marker placed at the right side of the capsule – round marker – activated a green light to indicate that the game scenario had been accomplished); and had to complete them all to finish the game. The game scenarios were visually the same as in the closed version.

The method for the multiple-choice questions was identical to that of the closed narrative format, however, the questions posed were different - we defined different questions, of approximately the same nature, for each of the four evaluating conditions to avoid conditioning effects on EM results[95]. If the child answered the questions correctly, a visual marker placed at the right side of the capsule (round marker) activated a yellow light.

Furthermore, in the open narrative version ("Albert" device), PA levels could be controlled by the child according to will - controlling the inertial forces of the avatar (effort intensity) via the "bar sensor" embedded in the device, before each game chapter (on a menu: "Easy" - low intensity, "Medium" - medium intensity, and "Hard" - high intensity). In the CD, the avatar's inertial forces could be controlled via "keyboard" interface (on a menu: "Easy" - low intensity, "Medium" - medium intensity, and "Hard" - high intensity).

Additionally, in both closed and open narratives, real-time HR/motion sensor data could be visualized on the software ("Albert" device) – a bar graph that changed color according to the child's HR values; a level meter displaying motion intensity (physical actions). Moreover, the system calculated the average HR/motion intensity, throughout the game, and displayed it at the end (including multiple-choice question scores). In the CD - closed and open narratives - the child could visualize data regarding her manipulative skills, via the software, through a level meter displaying motion intensity levels. The system calculated the average motion intensity value obtained throughout the game and displayed it at the end (including multiple-choice question scores).

We decided to create these two game narrative versions to understand if the effects of enhanced versus restricted sensorimotor environments, in neurophysiological function and EM, were maintained independently of the nature of the game task. In effect, in the open narrative version the child could establish the learning rhythm while interacting with the game (selecting game chapters; controlling PA levels/avatar displacement intensities), as opposed to the closed narrative version where the learning rhythm was externally imposed (driving the child to accomplish a predetermined game narrative sequence at the same time encouraging her to achieve predetermined PA levels/avatar displacement intensities).

The two video game narratives were also developed in order to understand if EM performance is favored in situations where the child establishes her own learning rhythm, or the opposite.

Figures 20 and 21 present the video game scenarios associated to the Biosymtic device "Albert" (closed and open narratives) and CD (closed and open narratives).

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[95] A detailed description of the multiple-choice questions is presented on Appendix A.

Fig. 20.

Video game scenarios associated with the Biosymtic device "Albert"
Closed and Open video game narratives

Top figure: video game scenario for both closed and open video game narratives. Name; Elapsed Time; Total Score; Visual Instruction (demonstrating the sensor to be used in each game scenario/written instruction regarding scenario goals); Game Scenario (e.g., Moon); Heart Rate/Motion Intensity data.

Bottom-left figure: menu associated with the open video game narrative. The child could select the game chapters by using the "turn button sensor" and "air flow" sensor - five capsules/game chapters.

Bottom-right figure: menu associated with the open video game narrative. The child could select the inertial forces applied to the avatar in the video game by using the "bar sensor" - "Easy" (low intensity), "Medium" (medium intensity), and "Hard" (high intensity).

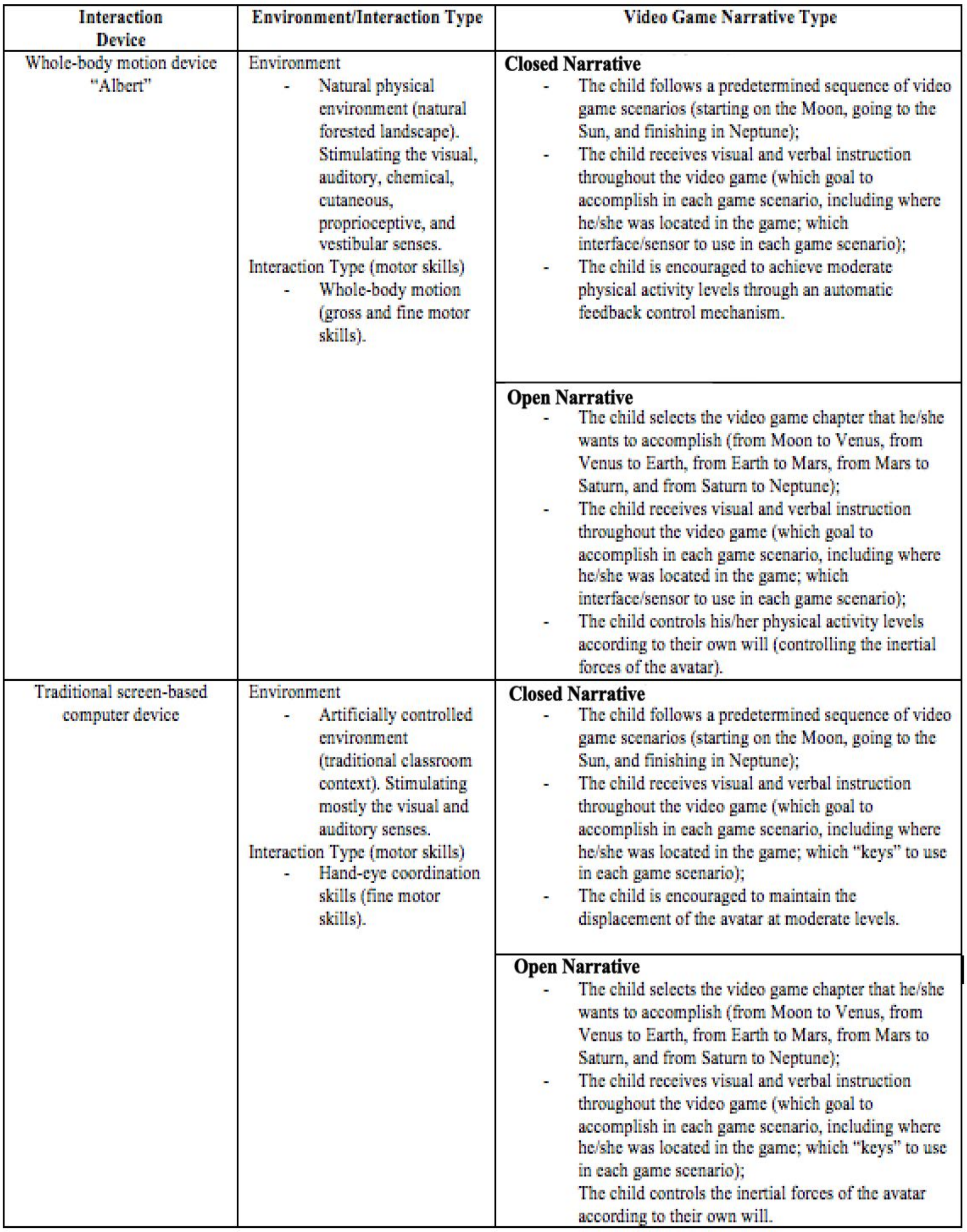
Fig. 21.

Video game scenarios associated with the Traditional screen-based computer device
Closed and Open video game narratives

Top figure: video game scenario experienced in both closed and open video game narratives. Name; Elapsed Time; Total Score; Visual Instruction (demonstrating which key to be used in each game scenario/written instruction regarding scenario goals); Game Scenario (e.g., Moon); Motion Intensity data.

Bottom-left figure: menu associated with the open video game narrative. The child could select the game chapters by using the “arrow keys” and “space bar” - five capsules/game chapters.

Bottom-right figure: menu associated with the open video game narrative. The child could select the inertial forces applied to the video game avatar by using the “arrow keys” and “space bar” - “Easy” (low intensity), “Medium” (medium intensity) and “Hard” (high intensity).



Interaction Device	Environment/Interaction Type	Video Game Narrative Type
Whole-body motion device "Albert"	Environment - Natural physical environment (natural forested landscape). Stimulating the visual, auditory, chemical, cutaneous, proprioceptive, and vestibular senses. Interaction Type (motor skills) - Whole-body motion (gross and fine motor skills).	**Closed Narrative** - The child follows a predetermined sequence of video game scenarios (starting on the Moon, going to the Sun, and finishing in Neptune); - The child receives visual and verbal instruction throughout the video game (which goal to accomplish in each game scenario, including where he/she was located in the game; which interface/sensor to use in each game scenario); - The child is encouraged to achieve moderate physical activity levels through an automatic feedback control mechanism.
		Open Narrative - The child selects the video game chapter that he/she wants to accomplish (from Moon to Venus, from Venus to Earth, from Earth to Mars, from Mars to Saturn, and from Saturn to Neptune); - The child receives visual and verbal instruction throughout the video game (which goal to accomplish in each game scenario, including where he/she was located in the game; which interface/sensor to use in each game scenario); - The child controls his/her physical activity levels according to their own will (controlling the inertial forces of the avatar).
Traditional screen-based computer device	Environment - Artificially controlled environment (traditional classroom context). Stimulating mostly the visual and auditory senses. Interaction Type (motor skills) - Hand-eye coordination skills (fine motor skills).	**Closed Narrative** - The child follows a predetermined sequence of video game scenarios (starting on the Moon, going to the Sun, and finishing in Neptune); - The child receives visual and verbal instruction throughout the video game (which goal to accomplish in each game scenario, including where he/she was located in the game; which "keys" to use in each game scenario); - The child is encouraged to maintain the displacement of the avatar at moderate levels.
		Open Narrative - The child selects the video game chapter that he/she wants to accomplish (from Moon to Venus, from Venus to Earth, from Earth to Mars, from Mars to Saturn, and from Saturn to Neptune); - The child receives visual and verbal instruction throughout the video game (which goal to accomplish in each game scenario, including where he/she was located in the game; which "keys" to use in each game scenario); The child controls the inertial forces of the avatar according to their own will.

Table 1. Evaluated interaction devices, associated environments and video game narrative type.

Table 1 displays the evaluated interaction devices, associated environments and video game narrative type (closed and open video game narratives).

3.6 Sample selection: inclusion and exclusion criteria

Participants were selected from an elementary school in Austin, Texas - ST. Andrew's Episcopal School. Ten children (n= 10) aged 7 to 8 years (x = 7.4, σ = 0.1) (5 male and 5 female) - attending an afterschool program one day per week. We opted to include typically developing children - not clinically restricted in terms of PA. Children taking medication or presenting any of the following conditions did not participate in this study: anemia; anorexia; bulimia; cardiac symptoms; chest pain; exercise induced dizziness; high blood pressure; flu and pneumonia; respiratory diseases in nature; cognitive disorders; or any surgery performed in the previous year. We also opted to include children who regularly played video games - at least once in a two-week period (due to school curricula or leisure).

This study did not include a larger number of subjects due to financial limitations; nonetheless, researchers have demonstrated that samples with 10 participants are sufficient to run a pilot study - granting validity to the pilot study (e.g., Connelly, 2008; Hill, 1998; Isaac & Michael, 1995).

We opted to include children aged 7 to 8 years due to the fact that EM shows fast improvements during middle childhood (Brainerd et al., 2004; Ghetti & Bunge, 2012:383; Nelson et al., 2006; Ofen et al., 2007; Raj & Bell, 2010; Shing & Lindenberger, 2011; Sluzenski et al., 2004). In addition, sustained attention tends to exhibit improvements between 5 until 8 years of age (Loher & Roebers, 2013).

3.7 Study design

Data collection was conducted in two stages. The first phase concerned sample characterization. For each child the following independent variables were analyzed: date of birth and cronological age; physiological variables (Resting Heart Rate); and baseline neurophysiological variables [High Engagement (HE), Low Engagement (LE), Distraction (D) and Working Cognitive Load (WL)].

The characterization procedures comprised three sessions: study explanation session and physiological and neurophysiological sessions.

Study explanation session

In this session, the main researcher informed the child and its education representatives about the research goals and necessary procedures to participate in the study. The child and her legal guardians read and signed "Consent" and "Assent" forms – the authorization to participate in the study/child's interest in participating in the study. During this session the main researcher collected the following data: child's date of birth and chronological age; information regarding video game play practice; health conditions. This session lasted 60 minutes.

Physiological session

During the physiological analysis session we measured the resting HR of each child using a HR monitor (Polar FT40®). Resting Heart Rate (HRrest) - number of HR beats in one minute at complete rest (Rowland, W.T. & Bar-Or, 2004) - was measured in a silent room during a 10-minute session with the child lying on a mat (two sessions of 60 minutes for the total sample).

Neurophysiological session

We measured each child's baseline levels for HE, LE, D and WL in a single 30 minute session - including explanation and task performance. This session allowed characterizing the baseline neuronal indexes of cognition for each child - normalize cognitive metrics to each individual (Berka et al., 2004; Johnson et al., 2011). The neurophysiological variables HE, LE, D and WL were evaluated via the B-Alert X10® electroenchephalogram (EEG) headset system - a noninvasive device placed on the scalp surface of the child along the head circumference via a neoprene strip. The B-Alert X10® system communicated wirelessly with the B-Alert Software® in a portable computer for data collection.

Children were evaluated in four different baseline EEG tasks on a portable computer in a classroom context (5 minutes for each task/ three-minute resting period between the tasks - to explain the following task, including practice period): 3-Choice Vigilance Task (3C-VT); Eyes Open task (EO); Eyes Closed task (EC); and Digit Span task (DS).

The 3C-VT, EO and EC tasks allowed characterizing the child's neurophysiological levels of engagement (or alertness/sustained attention): HE (high alertness/sustained attention levels – active alertness); LE (low alertness/sustained attention levels – passive alertness); and D (drowsiness) respectively (EEG classification metrics from 0 to 1). These tasks included reaction time/accuracy tests (continuous performance). The DS task allowed characterizing WL (mental effort) levels (classification levels from 0 to 1) (Berka et al., 2007; Stikic et al., 2011) (see fig. 22).

In the 3C-VT task the child had to identify three different visual objects on the screen as fast as possible. The child had to differentiate a primary target (upright triangle) from two secondary geometric shapes (a downside triangle and a diamond) (discriminate stimuli every 1.5 to 3-seconds). We asked the child to respond verbally to the visual stimuli - the researcher used a "keyboard" interface to enter the child response as fast as possible. The upright triangle was associated with the verbal answer "YES"; a downside triangle and a diamond were associated with the verbal answer "NO". The researcher maintained his eyes closed to eliminate any sort of interference (judgment) regarding the visual stimuli. This task allowed the identification of HE levels in the child. According to Berka et al. (2007:238), the 3C-VT task is related to sustained attention processes and induces minimal demands on "working memory or complex cognitive processing". According to Johnson et al.

(2011:243), “the 3CVT developed by ABM incorporates features of the most common measures of sustained attention, such as the Continuous Performance Test (…) Wilkinson Reaction Time (…) and the PVT-192”.

In the EO task the child had to hit the “space bar” every two seconds in order to respond to a visual intermittent stimulus: red ball object on the screen. This task allowed the identification of LE levels in the child.

The EC task was identical to EO task except that the stimulus was auditory not visual – a “gong” sound. The child had to keep her eyes closed during the task and to use headphones to listen to the auditory stimulus. This task allowed the identification of D levels in the child.

In the DS task the child had to memorize and repeat a orderly sequence of numbers displayed on the screen - five randomized numbers in a five level difficulty with 4-5 trials each (one number for the first level, two numbers for the second level, and so on). By the end of each level the child was asked how hard they thought the task was - “very difficult”, “difficult”, “neither easy or difficult”, “easy” and “very easy”. The child had firstly to verbalize the numbers aloud - memory phase (visualizing the numbers on the display - one number at a time). After memorizing the numbers sequence the child had to repeat it aloud without seeing it. The researcher introduced the sequence memorized by the child on the computer. This task allowed the identification of WL levels in the child. According to Berka et al. (2004:165), “Cognitive workload has been conceptualized as the allocation of mental resources or effort required to maintain adequate performance on one or more tasks”. Ghali & Frasson, 2014:644 refer that “Mental workload can be seen as the mental effort and energy invested in terms of human information processing during a particular task”.

Berka et al. (2007) maintain that the EEG-index of engagement is linked to sustained attention - allocation of attentional resources during encoding (information-gathering processes); the EEG-index of WL rises with increasing load to the working memory system (related to integration of information) – e.g., increased difficulty in problem solving and mental arithmetic. The authors state that both measures of engagement and WL “increase as a function of increasing task demands but the engagement measure tracks demands for sensory processing and attention resources while the mental workload index was developed as a measure of the levels of cognitive processes generally considered more the domain of executive functions” (Berka et al., 2007:232). The authors also state that “these two metrics (…) operate concordantly or independently, dependent on the task environment, the level of the task demands, and the amount of effort required by the individual to complete the task” (Berka et al., 2007:239).

The experimental procedures comprised two phases: adaptation to the "Albert" device and to the CD; experimental phase (evaluation of conditions 1, 2, 3 and 4).

Adaptation phase to the Biosymtic device "Albert" and to the CD

In the adaptation phase children got familiarized with the device "Albert" in the natural environment and the CD in the classroom setting – two children per two 60-minutes sessions (ten sessions for the total sample). The devices were introduced to the child by visually and verbally explaining the interaction techniques. Children played with both devices (30 minutes per session) - interacting with a different game narrative to those in the experimental sessions (different content and no multiple-choice questions). The child had to put game avatars into motion ("Albert" and a "spaceship") in two game scenarios ("Albert moving through a cosmic road"; "driving a spaceship to a planet")[96].

Experimental phase

In the experimental phase each child was evaluated once under conditions 1), 2), 3) and 4): completing four evaluating sessions - one session (30 minutes, including placement of the evaluating devices on the child and experimental activity) per week with a resting period of two and a half weeks. The following variables were evaluted under conditions 1) 2), 3) and 4):

- Neurophysiological variables - HE, LE, D and WL were evaluated through the B-Alert X10® EEG [brain activity was recorded from 9 electrodes located on the scalp according to the International 10-20 system - nine bipolar channels, Fz, F3, F4, Cz, C3, C4, POz, P3 and P4 (with fixed gain referenced to linked mastoids) that communicated wirelessly with mini-portable computer on the child's back];
- Physiological variables - Maximum HR frequency (HRmax) and Steady-state HR frequency (HRsteady-state) evaluated through the Polar FT40® HR monitor (transmitter connected to an elastic strap fixed bellow the child chest, wirelessly communicating with a wrist unit for data recording);
- Classification variables - Game Score Classification (GSC) regarding multiple-choice questions included in the closed and open game narratives (EM evaluation; the main researcher collected the GSC presented in the game software by the end of the activity);

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[96] A detailed description of this software program is presented on Appendix A.

Fig. 22.
EEG Baseline Tasks
Top-left figure - 3C-VT task (evaluating HE levels)
Top-right figure - EO task (evaluating LE levels)
Bottom-left figure - EC task (evaluating D levels)
Bottom-right figure - Digit Span task (evaluating WL levels)

- Behavioral variables were collected before and after the activities (individual evaluation in a classroom context). The "motivation to play" variable was gathered immediately before and after the activity (child was asked if she was enthusiastic about playing the game before the activity, if she wanted to repeat the activity after playing). The variables "device preference" (child was asked which device she preferred "Albert" or CD), "game quality" (child was aked if she enjoyed the game narrative), "video game narrative preference" (preference regarding closed and open video game narratives) and "usability" (child was asked if it was easy to interact with both devices) were evaluted after completing the four conditions.

The Smileyometer technique was used to collect expectations and opinions regarding the devices. The Smileyometer is originally composed of five visual figures arranged in a line - smiley scale (1-5 Likert scale) - with different words associated with each ("Awful; Not very good; Good; Really good; Brilliant") (Read, 2008). We opted to change the associated words to "Not really; No; More or less; Yes; Very much". This change was made according with the postulated questions - “Are you enthusiastic about playing this game? Would you like to repeat it? Did you like the video game? Was it easy to play this game?”.

The four evaluated conditions were counterbalanced (counterbalanced measures design) - in order to avoid conditioning effects on EM. Half of the participants (n=5) were firstly evaluated under condition 1), followed by condition 3), condition 2), and finally under condition 4). The other half of the participants (n=5) were firstly evaluated under the condition 4), followed by condition 2), condition 3), and finally condition 1).

3.8 Core elements of treatment conditions

All evaluating sessions were conducted between 3:30 PM and 4:30 PM (during the winter).

Evaluations in the traditional classroom context were conducted with the same spatial organization (furniture and sitting arrangements) and acoustic levels.

Participants did not ingest food during the hour prior to the evaluation sessions.

All participants wore adequate and comfortable cloth during the evaluation sessions.

The main researcher carried all the evaluation sessions with the support of a research assistant when available.

3.9 Measuring instruments

All the measuring instruments followingly described have scientific accreditation and have been validated and approved by international safety standards.

Measuring instruments for physiological variables

The physiological variables HRrest, HRmax and HRsteady-state were evaluated through the Polar FT40® HR monitor. This system integrates two parts - the WearLink transmitter and the Wrist Unit. The WearLink transmitter (connected to an elastic strap) was fixed bellow the child chest near the sternum. The WearLink transmitter detects the HR frequency and transmits it to the Wrist Unit (via infrared sensor). The Wrist Unit displays and stores the data (including activity time). HR monitoring is a validated noninvasive method to assess children’s PA levels (Livingstone et al., 2000).

Displayed HR frequency during the game (“Albert” device) was measured through the I-CubeX® Biobeat sensor[97]. This sensor measured the voltage on child’s skin surface (bipolar voltage; range of 1-200 Hz with 50/60 Hz notch filter). The sensor was

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[97] http://infusionsystems.com/catalog/product_info.php/products_id/197

attached to a micro I/O board that communicated via Bluetooth class 2 with the mini-portable computer placed on the child's back. The I-CubeX® HR sensor was fixed bellow the child chest near the heart via an elastic strap.

Measuring instruments for neurophysiological variables

The neurophysiological variables HE, LE, D and WL were analyzed through the B-Alert X10® EEG headset system. The B-Alert X10® noninvasive system was placed on the child's scalp surface via a neoprene strip - along the head circumference. The electrodes established communication with the scalp through a circular foam embedded with conductive gel (see fig. 23).

The headset acquired nine bipolar channels placed according to the International 10-20 system - Fz, F3, F4, Cz, C3, C4, POz, P3, P4 with fixed gain referenced to linked mastoids (one auxiliary differential channel) (see fig. 24). Data was acquired at 256 samples per second; band pass, 0.1Hz HPF, 100Hz 5th order LPF; fixed gain 1,000 ±μV; resolution of 16 bit, CMRR 105 dB; input impedance of 100 GΩ; noise decontamination (artifacts; eye blinking and muscle activity) performed at ~ +2 μV @ 10 Hz and 50 kO impedance @ 256 s/s; RF band, 2.4 to 2.48 GHz (ISM band). The EEG system detected the following frequencies, Delta, Theta, Alpha, Beta and Gamma - absolute and relative power spectral density (PSD) for each one-second epoch and using Fast-Fourier transform (50% Kaiser window). Data was trasmitted to the mini-portable computer placed on the child's back via bi-directional mode and using XSeries Bluetooth (Bluetooth Class 2 +4dBm). Data was continuously memorized on the B-Alert software® at ~ 45 KB/Min/channel frequency. Unit dimensions correspond to, size - 5'(L) x 2.25" (W) x 1" (H); weight - 0.11 kg with standard battery. The B-Alert X10® headset has been been validated and approved the international safety standards[98] (Berka et al., 2007).

3.10 Institutions and partners involved in this study

University of Texas at Austin (College of Education)
(http://www.utexas.edu/)

FCT/UNL – Faculdade de Ciências e Tecnologia/Nova Universidade de Lisboa
(http://www.fct.unl.pt/en)

Advanced Brain Monitoring
(http://www.advancedbrainmonitoring.com)

ST. Andrew's Episcopal School - Elementary school in Austin, Texas
(http://www.sasaustin.org/Page/Lower-School)

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[98] http://www.advancedbrainmonitoring.com/xseries/x10/

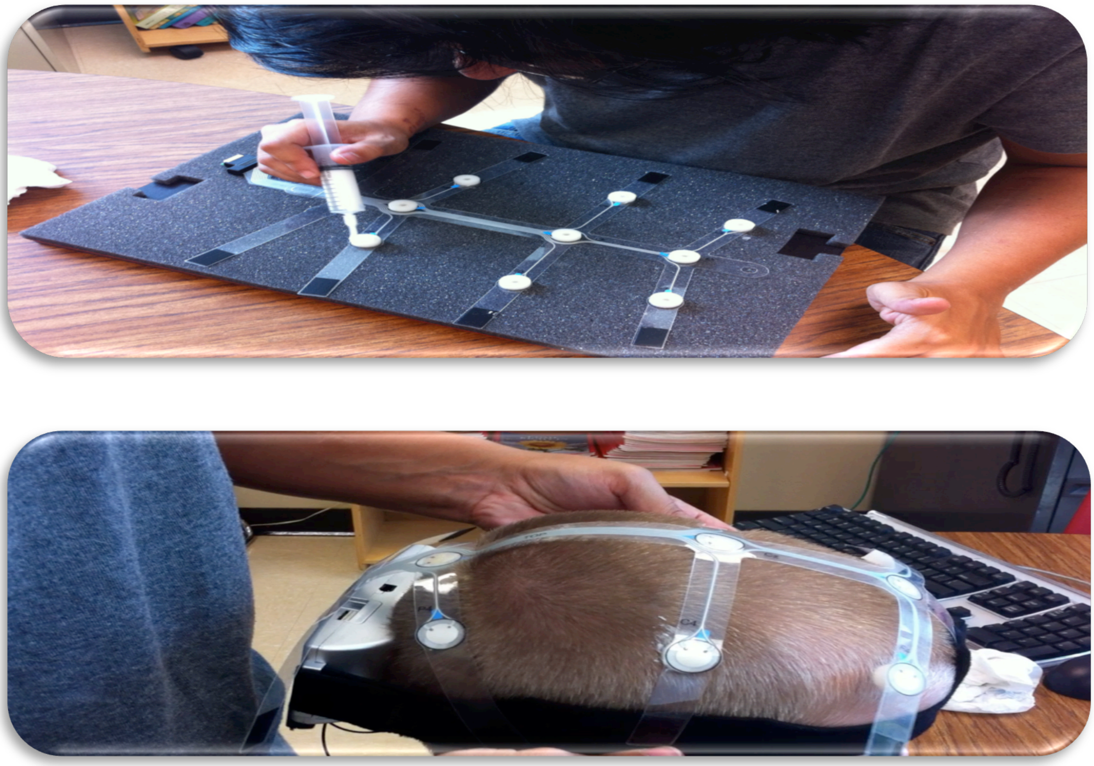


Fig. 23.

EEG headset preparation.

Main researcher preparing and placing the EEG system on the child's scalp surface.

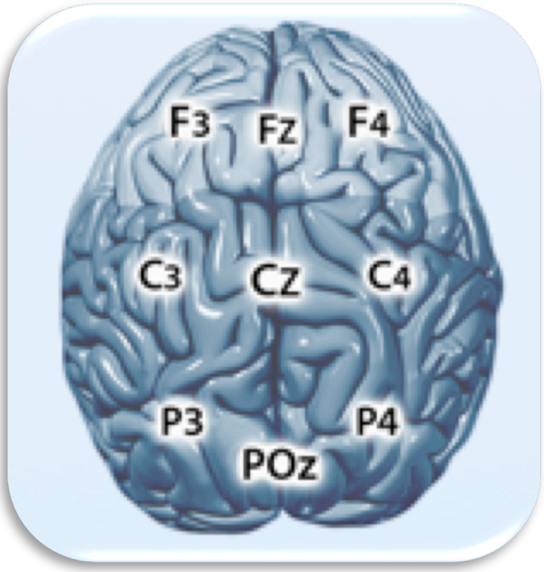


Fig. 24.

Electrode sites: Fz, F3, F4, Cz, C3, C4, POz, P3, P4.

BioSymtic Robotics
(https://www.facebook.com/BHRobot
http://biosymticrobotics.com)

3.11 Statistical techniques

Statistical analysis was performed using the IBM Statistical Package for the Social Sciences version 21.0 for Mac. We will now describe the statistical techniques applied in the analysis of dependent and independent variables - characterization and experimental procedures.

Statistical techniques - characterization procedures

Sample characterization (n=10) was conducted through measures of central tendency (means - high frequency values) and dispersion (standard deviation). These statistical techniques were applied for the following variables: chronological age, physiological variables (HRrest, HRmax and HRsteady-state) and baseline neurophysiological variables (HE, LE, D and WL).

Statistical techniques – experimental procedures

Measures of central tendency (means - high frequency values) and dispersion (standard deviation) were analyzed for the following variables: neurophysiological variables (HE, LE, D and WL); physiological variables (HRmax and HRsteady-state); Game Score Classification variables (GSC – EM).

Comparison between conditions 1), 2), 3) and 4) was conducted through the *Shapiro-Wilk adherence to normality test (Lilliefors correction technique)* followed by the *Repeated Measures ANOVA test* - the latter allowed comparing the mean values between the four conditions at a confidence interval of 95% and 99% ($p<0.05$ and $p<0.01$). In the absence of normal distribution we used the *Non-Parametric Friedman test.* We compared the following variables: neurophysiological variables (HE, LE, D and WL); physiological variables (HRmax and HRsteady-state); Game Score Classification variables (GSC - EM).

Comparison between neurophysiological variables (HE, LE, D and WL) in conditions 1), 2), 3) and 4) was conducted through the *Shapiro-Wilk adherence to normality test (Lilliefors correction technique)* followed by the *Repeatead Measures ANOVA test* - the latter allowed comparing the mean values between the four variables at a confidece interval of 95% and 99% ($p<0.05$ and $p <0.01$). In the absence of normal distribution we used the *Non-Parametric Friedman test.*

Correlation between experimental variables (neurophysiological, physiological and Game Score Classification variables), in the four conditions, was conducted through the *Shapiro-Wilk adherence to normality test (Lilliefors correction technique)* followed by the *Pearson correlation coefficient (r) test* (confidence interval of 95% and 99%

- $p<0.05$ and $p<0.01$). In the absence of normal distribution we used the *Spearman's correlation coefficient test* (confidence interval of 95% and 99% - $p<0.05$ and $p<0.01$).

The behavioral variables (motivation to play; device preference; video game narrative preference; game quality; usability) were examined through frequency analysis (percentage values).

In the following subchapter we will describe the statistical results obtained in this study.

3.12 Results

Statistical results - characterization procedures

The participants had a mean age value of 7.4 ($\sigma = 0.1$). The participants presented the following mean value for the HRrest variable: 66.8 ($\sigma = 1.6$).

The participants presented the following baseline neurophysiological values in the 3-Choice Vigilance Task (3C-VT): WL mean value of 0.39 ($\sigma = 0.07$); HE mean value of 0.7 ($\sigma = 0.12$); LE mean value of 0.24 ($\sigma = 0.1$); and D mean value of 0.04 ($\sigma = 0.04$).

The participants presented the following baseline neurophysiological values in the Digit Span task (DS): WL mean value of 0.43 ($\sigma = 0.06$); HE mean value of 0.45 ($\sigma = 0.11$); LE mean value of 0.44 ($\sigma = 0.08$); and D mean value of 0.1 ($\sigma = 0.06$).

The baseline neurophysiological levels for the 3C-VT and DS tasks are shown on table 2, figures 25 and 26.

The participants presented the following baseline neurophysiological values in the Eyes Open task (EO): WL mean value of 0.45 ($\sigma = 0.12$); HE mean value of 0.22 ($\sigma = 0.09$); LE mean value of 0.70 ($\sigma = 0.09$); and D mean value of 0.05 ($\sigma = 0.03$).

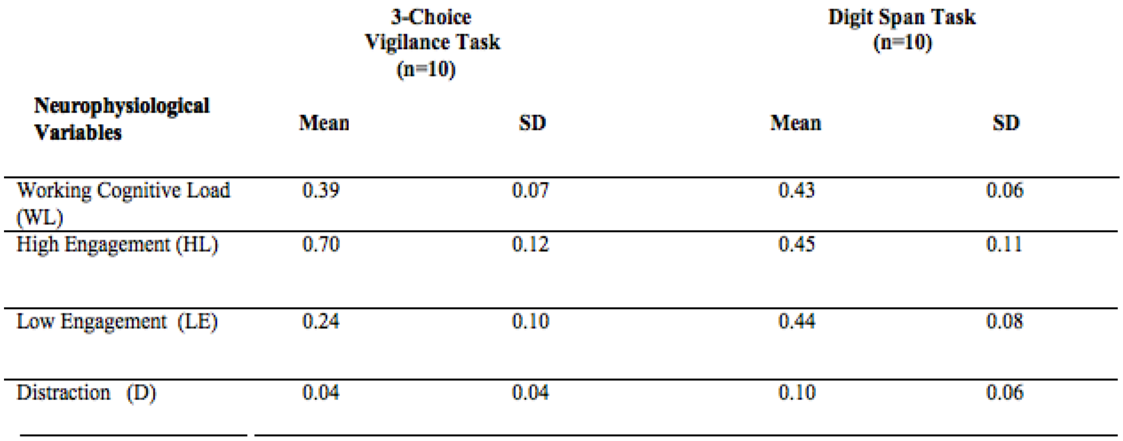
The subjects presented the following baseline neurophysiological values in the Eyes Closed task (EC): WL mean value of 0.22 ($\sigma = 0.06$); HE mean value of 0.06 ($\sigma = 0.07$); LE mean value of 0.05 ($\sigma = 0.02$); and D mean value of 0.77 ($\sigma = 0.28$).

The baseline neurophysiological levels for the EO and EC tasks are displayed on table 3, figures 27 and 28.

Statistical results - experimental procedures

Comparison between conditions 1), 2), 3) and 4)

The participants exhibited the following neurophysiological, physiological and game score classification (GSC) values under condition 1) whole-body motion device "Albert"/natural environment – closed video game narrative: WL mean value of 0.51 ($\sigma = 0.11$); HE mean value of 0.59 ($\sigma = 0.21$); LE mean value of 0.31 ($\sigma = 0.18$); D mean value of 0.07 ($\sigma = 0.07$); HRmax mean value of 186.7 ($\sigma = 8$); HRsteady-state mean value of 135.3 ($\sigma = 5.5$); and GSC mean value of 11.4 ($\sigma = 2.4$). Under this condition, 7 participants achieved moderate PA levels.



Neurophysiological Variables	**3-Choice Vigilance Task (n=10)**		**Digit Span Task (n=10)**	
	Mean	**SD**	**Mean**	**SD**
Working Cognitive Load (WL)	0.39	0.07	0.43	0.06
High Engagement (HL)	0.70	0.12	0.45	0.11
Low Engagement (LE)	0.24	0.10	0.44	0.08
Distraction (D)	0.04	0.04	0.10	0.06

Table 2. Characterization procedures (n=10). 3C-VT and Digit Span tasks: Working Cognitive Load (WL), High Engagement (HE), Low Engagement (LE) and Distraction [mean; standard deviation (SD)]. EEG metrics from 0 to 1.

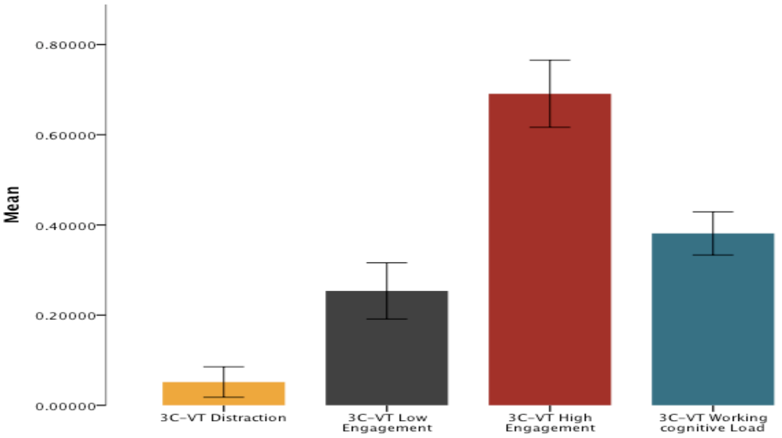


Fig. 25.

Characterization procedures (n=10). 3C-VT task: Working Cognitive Load (WL), High Engagement (HE), Low Engagement (LE) and Distraction mean values. EEG classification metrics from 0 to 1.

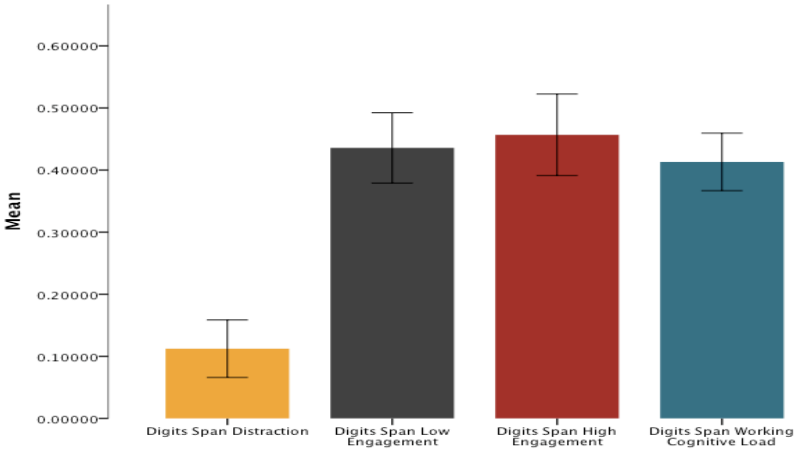


Fig. 26.

Characterization procedures (n=10). Digit Span task: Working Cognitive Load (WL), High Engagement (HE), Low Engagement (LE) and Distraction mean values. EEG classification metrics from 0 to 1.

Neurophysiological Variables	Eyes Open Task (n=10) Mean	Eyes Open Task (n=10) SD	Eyes Closed Task (n=10) Mean	Eyes Closed Task (n=10) SD
Working Cognitive Load (WL)	0.45	0.12	0.22	0.06
High Engagement (HL)	0.22	0.09	0.06	0.07
Low Engagement (LE)	0.70	0.09	0.05	0.02
Distraction (D)	0.05	0.03	0.77	0.28

Table 3. Characterization procedures (n=10). Eyes Open and Eyes Closed tasks: Working Cognitive Load (WL), High Engagement (HE), Low Engagement (LE) and Distraction [mean; standard deviation (SD)]. EEG metrics from 0 to 1.

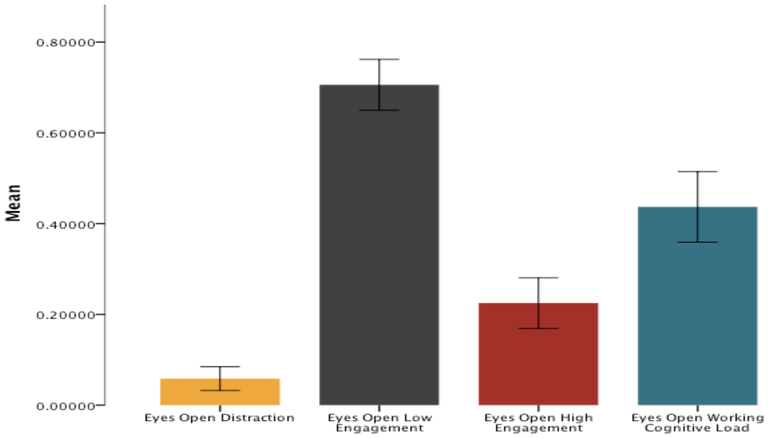


Fig. 27.

Characterization procedures (n=10). Eyes Open task: Working Cognitive Load (WL), High Engagement (HE), Low Engagement (LE) and Distraction mean values. EEG metrics from 0 to 1.

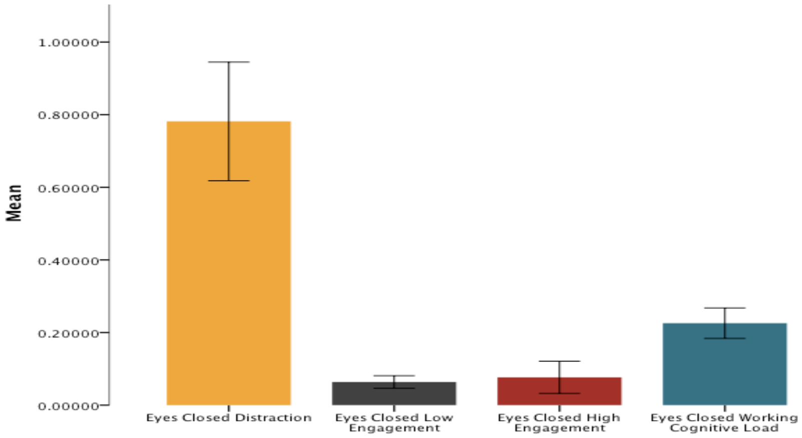


Fig. 28.

Characterization procedures (n=10). Eyes Closed task: Working Cognitive Load (WL), High Engagement (HE), Low Engagement (LE) and Distraction mean values. EEG metrics from 0 to 1.

The participants showed the following neurophysiological, physiological and GSC values under condition 2) whole-body motion device "Albert"/natural environment – open video game narrative: WL mean value of 0. (σ = 0.10); HE mean value of 0.51 (σ = 0.20); LE mean value of 0.39 (σ = 0.21); D mean value of 0.07 (σ = 0.07); HRmax mean value of 176.6 (σ = 6.2); HRsteady-state mean value of 131.4 (σ = 5.7); and GSC mean value of 10.8 (σ = 3.2). Under this condition, 3 participants achieved moderate physical activity levels.

HE assumed the highest values, followed by WL, LE and D in both conditions 1) and 2).

The subjects exhibited the following neurophysiological, physiological and GSC values under condition 3) traditional screen-based computer device/traditional classroom context – closed video game narrative: WL mean value of 0.48 (σ = 0.13); HE mean value of 0.45 (σ = 0.16); LE mean value of 0.46 (σ = 0.17); D mean value of 0.06 (σ = 0.09); HRmax mean value of 105.4 (σ = 7.9); HRsteady-state mean value of 88.6 (σ = 9.8); and GSC mean value of 7.2 (σ = 2). WL assumed the highest values, followed by LE, HE and D.

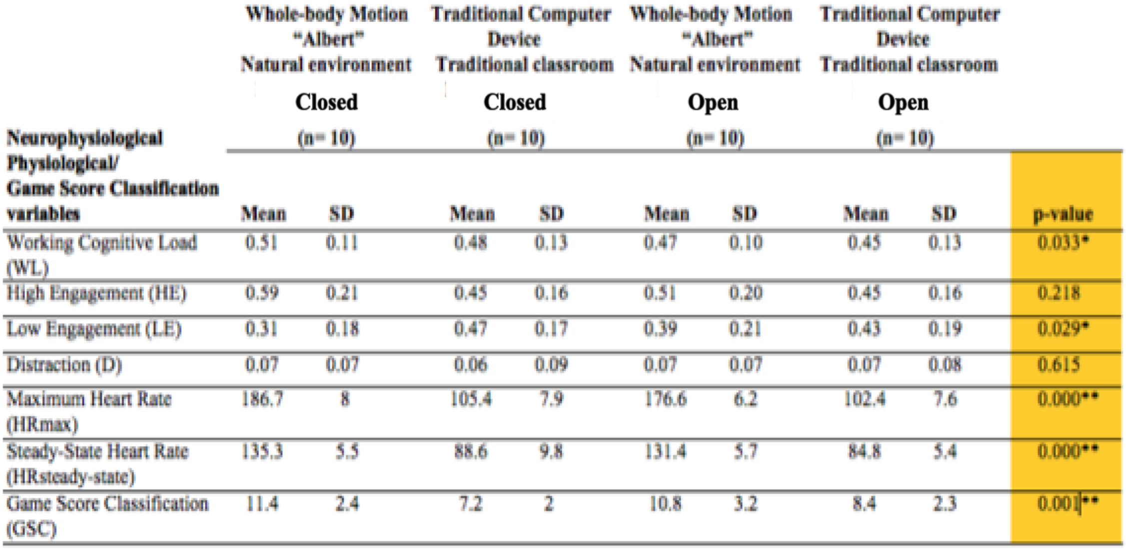
The participants showed the following neurophysiological, physiological and GSC values under condition 4) traditional screen-based computer device/traditional classroom context – open video game narrative: WL mean value of 0.45 (σ = 0.13); HE mean value of 0.45 (σ = 0.16); LE mean value of 0.43 (σ = 0.19); D mean value of 0.07 (σ = 0.08); HRmax mean value of 102.4 (σ = 7.6); HRsteady-state mean value of 84.8 (σ = 5.4); and GSC mean value of 8.4 (σ = 2.3). WL and HE assumed the highest values (similar for both variables), followed by LE and D.

We found significant differences in the following variables for the four conditions: WL (**0.033* for p<0.05**); LE (**0.029* for p<0.05**); HRmax (**0.000** for p<0.01**); HRsteady-state (**0.000** for p<0.01**); and GSC (**0.001** for p<0.01**) (see table 4, figures 29a and 29b).

We found the following significant differences regarding the variable WL: between condition 1) and condition 2) - **0.005* for p<0.01 (higher mean value for condition 1)**.

We found the following significant differences concerning the variable LE: between condition 1) and condition 3) - **0.047* for p<0.05 (higher mean value for condition 3)**. Between condition 2) and condition 3) - **0.022* for p<0.05 (higher mean value for condition 3)**.

We found the following significant differences regarding the variable HRmax: between condition 1) and condition 2) - **0.005** for p<0.01 (higher mean value for condition 1)**; between condition 1) and condition 3) - **0.005** for p<0.01 (higher mean value for condition 1)**; between condition 1) and condition 4) - **0.005** for p<0.01 (higher mean value for condition 1)**. Between condition 2) and condition 3) - **0.005****



Neurophysiological Physiological/ Game Score Classification variables	Whole-body Motion "Albert" Natural environment Closed (n= 10)		Traditional Computer Device Traditional classroom Closed (n= 10)		Whole-body Motion "Albert" Natural environment Open (n= 10)		Traditional Computer Device Traditional classroom Open (n= 10)		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	p-value
Working Cognitive Load (WL)	0.51	0.11	0.48	0.13	0.47	0.10	0.45	0.13	0.033*
High Engagement (HE)	0.59	0.21	0.45	0.16	0.51	0.20	0.45	0.16	0.218
Low Engagement (LE)	0.31	0.18	0.47	0.17	0.39	0.21	0.43	0.19	0.029*
Distraction (D)	0.07	0.07	0.06	0.09	0.07	0.07	0.07	0.08	0.615
Maximum Heart Rate (HRmax)	186.7	8	105.4	7.9	176.6	6.2	102.4	7.6	0.000**
Steady-State Heart Rate (HRsteady-state)	135.3	5.5	88.6	9.8	131.4	5.7	84.8	5.4	0.000**
Game Score Classification (GSC)	11.4	2.4	7.2	2	10.8	3.2	8.4	2.3	0.001**

Table 4. Experimental results: comparison between condition 1) whole-body motion device "Albert"/natural environment – closed video game narrative, condition 2) whole-body motion device "Albert"/natural environment – open video game narrative, condition 3) traditional screen-based computer device/traditional classroom context - closed video game narrative and condition 4) traditional screen-based computer device/traditional classroom context - open video game narrative. Neurophysiological [Working Cognitive Load (WL), High Engagement (HE)], Low Engagement (LE) and Distraction (D)], Physiological (Maximum Heart Rate, Steady-state Heart Rate) and Game Score Classification (GSC) variables [mean; standard deviation (SD)]. $p<0.05$ represented as * and $p<0.01$ represented as **.

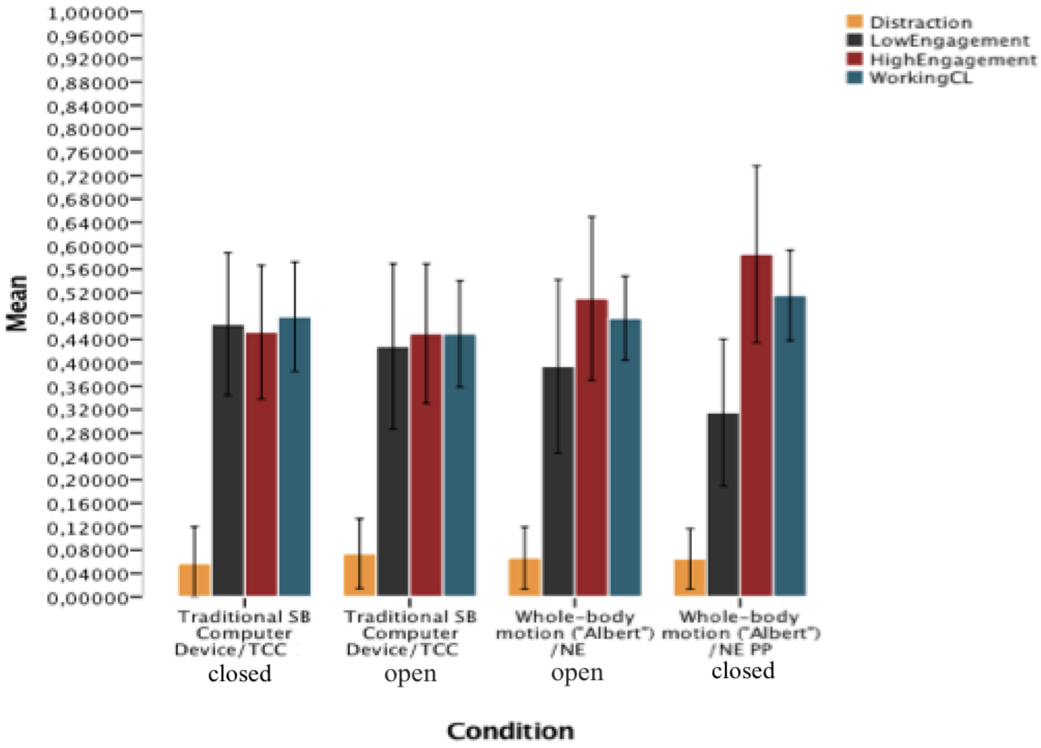


Fig. 29a.

Experimental results: comparison between conditions 1) whole-body motion device "Albert"/natural environment (NE) – closed video game narrative, condition 2) whole-body motion device "Albert"/natural environment (NE) – open video game narrative, condition 3) traditional screen-based computer device/traditional classroom context (TCC) - closed video game narrative and condition 4) traditional screen-based computer device/traditional classroom context (TCC) - open video game narrative. Distraction, Low Engagement, High Engagement and Working Cognitive Load mean values. EEG metrics from 0 to 1.

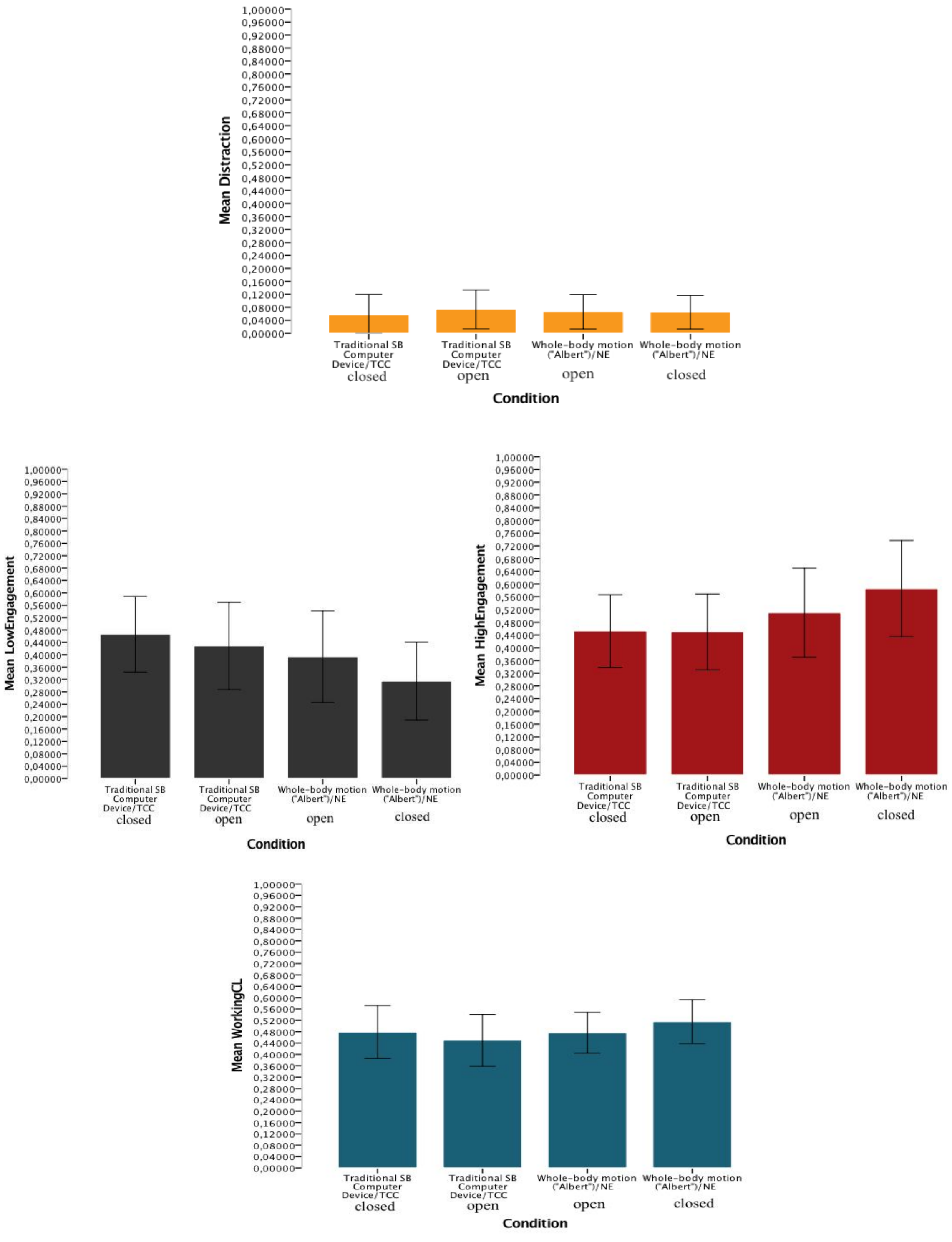


Fig. 29b.

Experimental results: comparison between conditions 1) whole-body motion device "Albert"/natural environment (NE) – closed video game narrative, condition 2) whole-body motion device "Albert"/natural environment (NE) – open video game narrative, condition 3) traditional screen-based computer device/traditional classroom context (TCC) - closed video game narrative and condition 4) traditional screen-based computer device/traditional classroom context (TCC) - open video game narrative. Distraction (top figure), Low Engagement (middle-left figure), High Engagement (middle-right figure) and Working Cognitive Load (bottom figure) mean values. EEG metrics from 0 to 1.

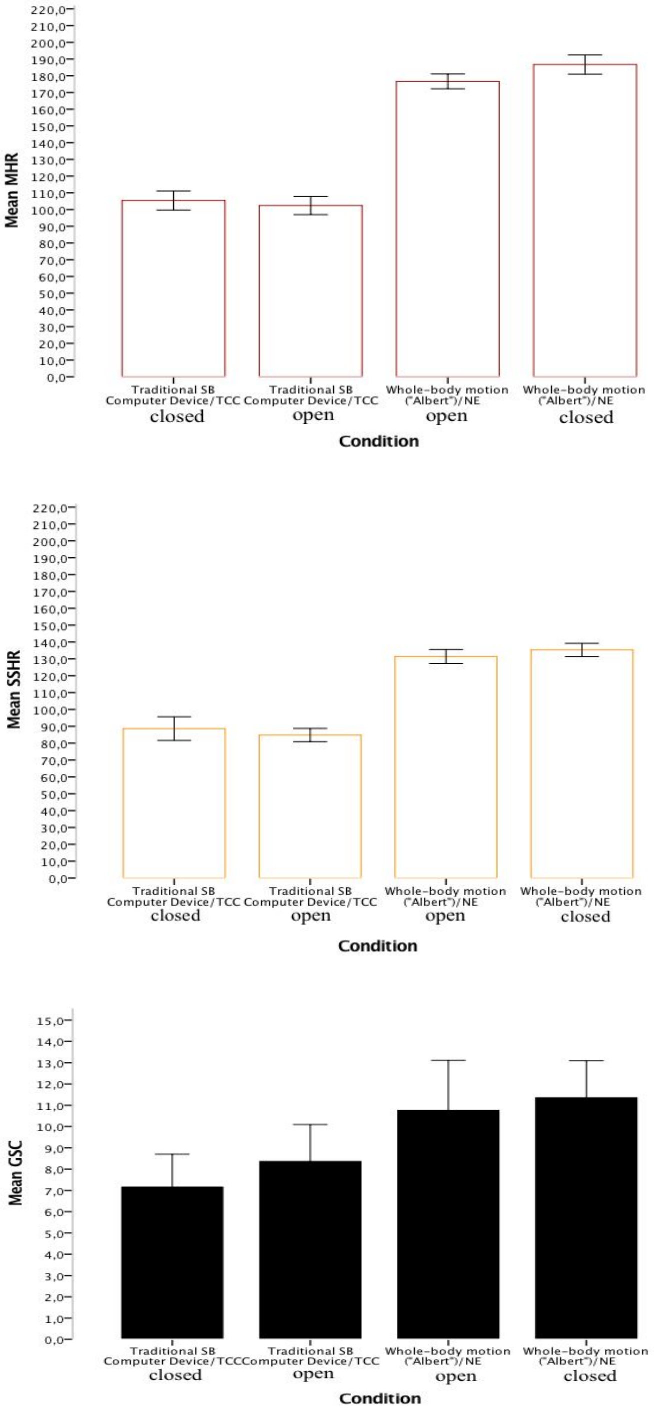


Fig. 30.

Experimental results: comparison between condition condition 1) whole-body motion device "Albert"/natural environment (NE) – closed video game narrative, condition 2) whole-body motion device "Albert"/natural environment (NE) – open video game narrative, condition 3) traditional screen-based computer device/traditional classroom context (TCC) - closed video game narrative and condition 4) traditional screen-based computer device/traditional classroom context (TCC) – open video game narrative. Maximum Heart Rate (MHR) mean values - from 0 to 220 beats per minute (top figure). Steady-state Heart Rate (SSHR) mean values - from 0 to 220 beats per minute (middle figure). Game Score Classification (GSC) mean values from 0 to 15 (bottom figure).

for $p<0.01$ (higher mean value for condition 2); between condition 2) and condition 4) - **0.005** for $p<0.01$ (higher mean value for condition 2)** (see fig. 30).

We found the following significant differences regarding the variable HRsteady-state: between condition 1) and condition 3) - **0.005** for $p<0.01$ (higher mean value for condition 1)**; between condition 1) and condition 4) - **0.005** for $p<0.01$ (higher mean value for condition 1)**. Between condition 2) and condition 3) - **0.005** for $p<0.01$ (higher mean value for condition 2)**; between condition 2) and condition 4) - **0.005** for $p<0.01$ (higher mean value for condition 2)** (see fig. 30).

We found the following significant differences regarding the variable GSC: between condition 1) and condition 3) - **0.004** for $p<0.01$ (higher mean value for condition 1)**; between condition 1) and condition 4) - **0.031* for $p<0.05$ (higher mean value for condition 1)**. Between condition 2) and condition 3) - **0.006** for $p<0.01$ (higher mean value for condition 2)** (see fig. 30).

Comparison between neurophysiological variables in conditions 1), 2), 3) and 4)

We found the following significant differences between neurophysiological variables in condition 1): between WL and D - **0.005** for $p<0.01$ (higher mean value for WL)**, and WL and LE - **0.009** for $p<0.01$ (higher mean value for WL)**. Between HE and D - **0.005** for $p<0.01$ (higher mean value for HE)**, and HE and LE - **0.037* for $p<0.05$ [higher mean value HE)**. Between LE and D - **0.009** for $p<0.01$ (higher mean value for LE)**.

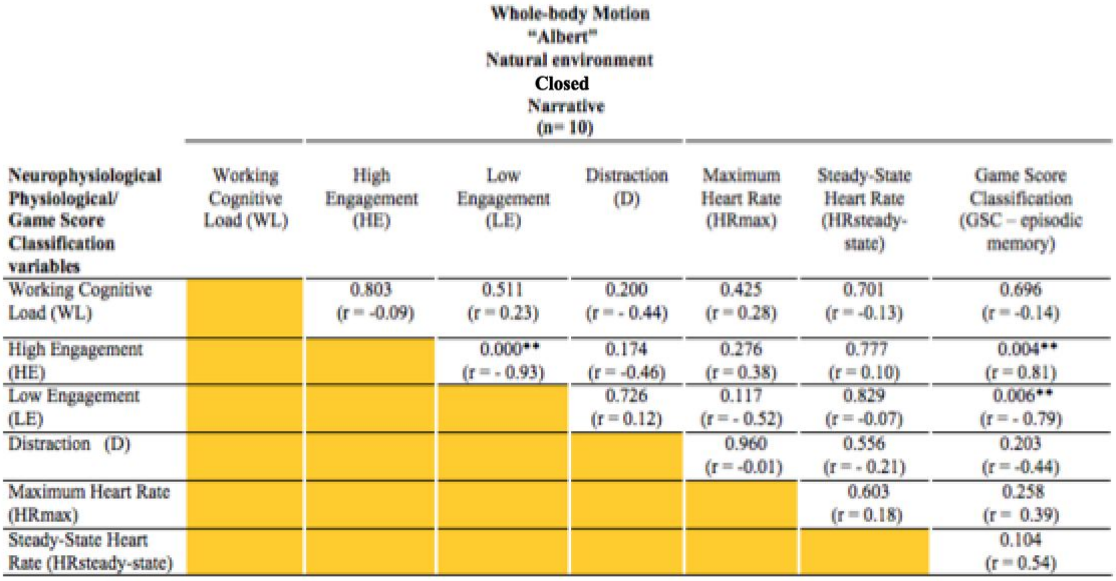
We found the following significant differences between neurophysiological variables in condition 2): between WL and D - **0.005** for $p<0.01$ (higher mean value for WL)**. Between HE and D - **0.005** for $p<0.01$ (higher mean value for HE)**. Between LE and D - **0.007** for $p<0.01$ (higher mean value for LE)**.

We found the following significant differences between neurophysiological variables in condition 3): between WL and D - **0.005** for $p<0.01$ (higher mean value for WL)**. Between HE and D - **0.005** for $p<0.01$ (higher mean value for HE)**. Between LE and D - **0.005** for $p<0.01$ (higher mean value for Low Engagement (LE)**.

We found the following significant differences between neurophysiological variables in condition 4): between WL and D - **0.005** for $p<0.01$ (higher mean value for WL)**. Between HE and D - **0.005** for $p<0.01$ (higher mean value for HE)**. Between LE and D - **0.005** for $p<0.01$ (higher mean value for LE)**.

Correlation between experimental variables in conditions 1), 2), 3) and 4)

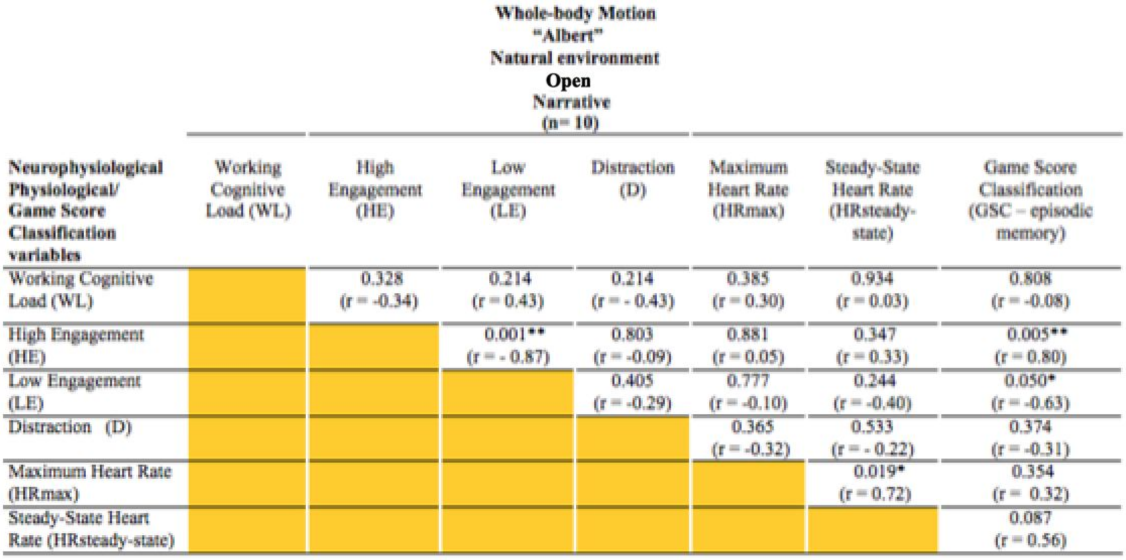
Under condition 1) we found the following significant correlations for the neurophysiological variables: a negative correlation between HE and LE (**r-value = - 0.93; 0.000** for $p<0.01$**). In addition, we found the following correlations between neurophysiological and GSC variables: a positive correlation between HE and GSC (**r-value= 0.81; 0.004** for $p<0.01$**), and a negative correlation between LE and GSC (**r-value= - 0.79; 0.006** for $p<0.01$**) (see table 5).



Whole-body Motion
"Albert"
Natural environment
Closed
Narrative
(n= 10)

Neurophysiological Physiological/ Game Score Classification variables	Working Cognitive Load (WL)	High Engagement (HE)	Low Engagement (LE)	Distraction (D)	Maximum Heart Rate (HRmax)	Steady-State Heart Rate (HRsteady-state)	Game Score Classification (GSC – episodic memory)
Working Cognitive Load (WL)		0.803 (r = -0.09)	0.511 (r = 0.23)	0.200 (r = - 0.44)	0.425 (r = 0.28)	0.701 (r = -0.13)	0.696 (r = -0.14)
High Engagement (HE)			0.000** (r = - 0.93)	0.174 (r = -0.46)	0.276 (r = 0.38)	0.777 (r = 0.10)	0.004** (r = 0.81)
Low Engagement (LE)				0.726 (r = 0.12)	0.117 (r = - 0.52)	0.829 (r = -0.07)	0.006** (r = - 0.79)
Distraction (D)					0.960 (r = -0.01)	0.556 (r = - 0.21)	0.203 (r = -0.44)
Maximum Heart Rate (HRmax)						0.603 (r = 0.18)	0.258 (r = 0.39)
Steady-State Heart Rate (HRsteady-state)							0.104 (r = 0.54)

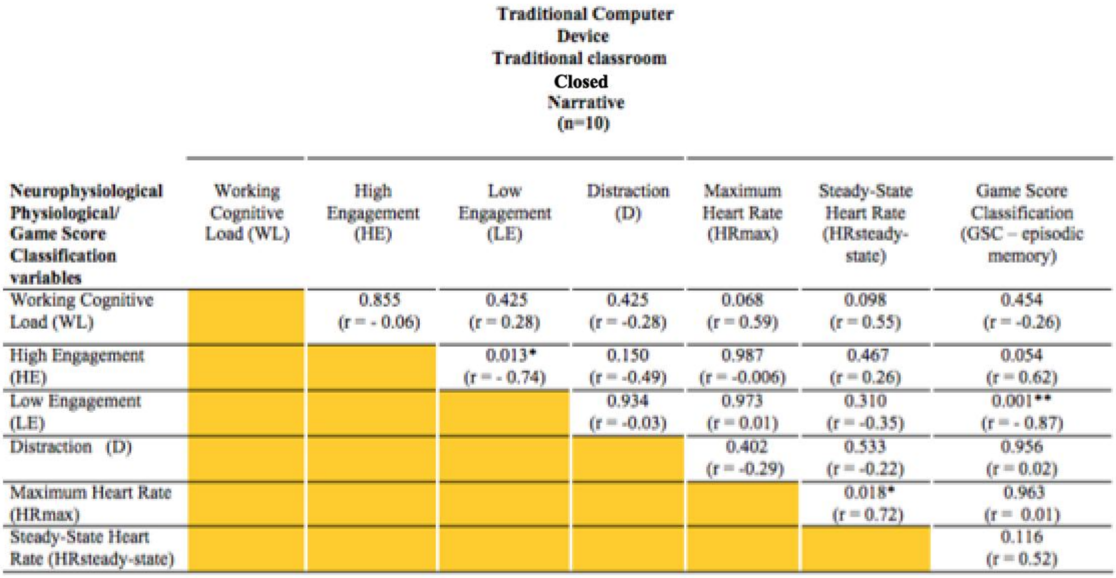
Table 5. Experimental Results. Neurophysiological, Physiological and Game Score Classification variables correlation for condition 1) whole-body motion device "Albert"/natural environment – closed video game narrative. Working Cognitive Load (WL), High Engagement (HE), Low Engagement (LE), Distraction (D), Maximum Heart Rate (HRmax), Steady-state Heart Rate (HRsteady-state) and Game Score Classification (GSR).



Whole-body Motion
"Albert"
Natural environment
Open
Narrative
(n= 10)

Neurophysiological Physiological/ Game Score Classification variables	Working Cognitive Load (WL)	High Engagement (HE)	Low Engagement (LE)	Distraction (D)	Maximum Heart Rate (HRmax)	Steady-State Heart Rate (HRsteady-state)	Game Score Classification (GSC – episodic memory)
Working Cognitive Load (WL)		0.328 (r = -0.34)	0.214 (r = 0.43)	0.214 (r = - 0.43)	0.385 (r = 0.30)	0.934 (r = 0.03)	0.808 (r = -0.08)
High Engagement (HE)			0.001** (r = - 0.87)	0.803 (r = -0.09)	0.881 (r = 0.05)	0.347 (r = 0.33)	0.005** (r = 0.80)
Low Engagement (LE)				0.405 (r = -0.29)	0.777 (r = -0.10)	0.244 (r = -0.40)	0.050* (r = -0.63)
Distraction (D)					0.365 (r = -0.32)	0.533 (r = - 0.22)	0.374 (r = -0.31)
Maximum Heart Rate (HRmax)						0.019* (r = 0.72)	0.354 (r = 0.32)
Steady-State Heart Rate (HRsteady-state)							0.087 (r = 0.56)

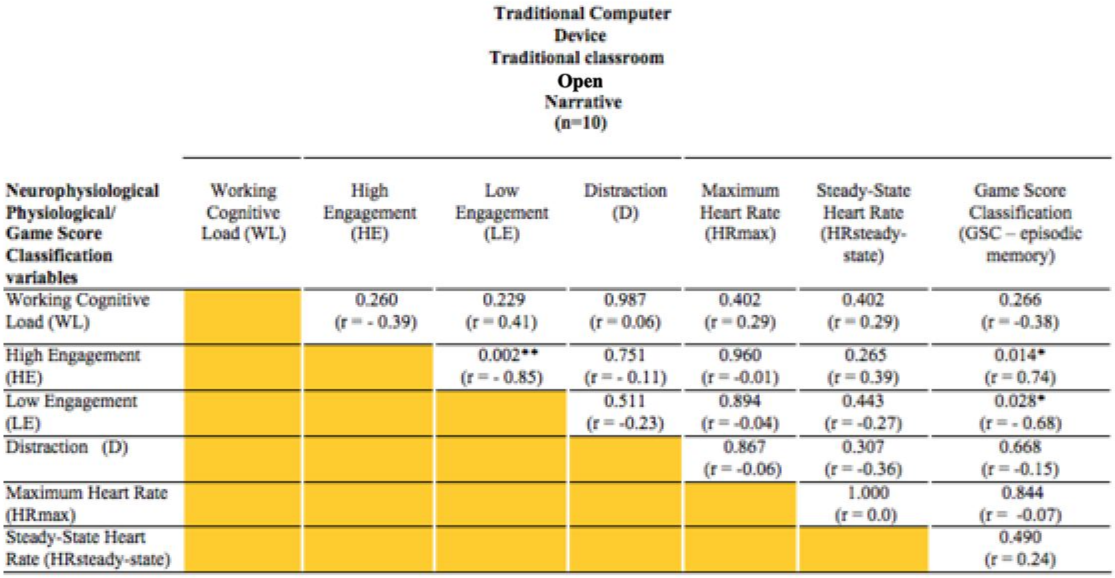
Table 6. Experimental Results. Neurophysiological, Physiological and Game Score Classification variables correlation for condition 2) whole-body motion device "Albert"/natural environment – open video game narrative. Working Cognitive Load (WL), High Engagement (HE), Low Engagement (LE), Distraction (D), Maximum Heart Rate (HRmax), Steady-state Heart Rate(HRsteady-state) and Game Score Classification (GSR).



Traditional Computer Device
Traditional classroom
Closed Narrative
(n=10)

Neurophysiological Physiological/ Game Score Classification variables	Working Cognitive Load (WL)	High Engagement (HE)	Low Engagement (LE)	Distraction (D)	Maximum Heart Rate (HRmax)	Steady-State Heart Rate (HRsteady-state)	Game Score Classification (GSC – episodic memory)
Working Cognitive Load (WL)		0.855 (r = - 0.06)	0.425 (r = 0.28)	0.425 (r = -0.28)	0.068 (r = 0.59)	0.098 (r = 0.55)	0.454 (r = -0.26)
High Engagement (HE)			0.013* (r = - 0.74)	0.150 (r = -0.49)	0.987 (r = -0.006)	0.467 (r = 0.26)	0.054 (r = 0.62)
Low Engagement (LE)				0.934 (r = -0.03)	0.973 (r = 0.01)	0.310 (r = -0.35)	0.001** (r = - 0.87)
Distraction (D)					0.402 (r = -0.29)	0.533 (r = -0.22)	0.956 (r = 0.02)
Maximum Heart Rate (HRmax)						0.018* (r = 0.72)	0.963 (r = 0.01)
Steady-State Heart Rate (HRsteady-state)							0.116 (r = 0.52)

Table 7. Experimental Results. Neurophysiological, Physiological and Game Score Classification variables correlation for condition 3) traditional screen-based computer device/traditional classroom context - closed video game narrative. Working Cognitive Load (WL), High Engagement (HE), Low Engagement (LE), Distraction (D), Maximum Heart Rate (HRmax), Steady-state Heart Rate (HRsteady-state) and Game Score Classification (GSR).



Traditional Computer Device
Traditional classroom
Open Narrative
(n=10)

Neurophysiological Physiological/ Game Score Classification variables	Working Cognitive Load (WL)	High Engagement (HE)	Low Engagement (LE)	Distraction (D)	Maximum Heart Rate (HRmax)	Steady-State Heart Rate (HRsteady-state)	Game Score Classification (GSC – episodic memory)
Working Cognitive Load (WL)		0.260 (r = - 0.39)	0.229 (r = 0.41)	0.987 (r = 0.06)	0.402 (r = 0.29)	0.402 (r = 0.29)	0.266 (r = -0.38)
High Engagement (HE)			0.002** (r = - 0.85)	0.751 (r = - 0.11)	0.960 (r = -0.01)	0.265 (r = 0.39)	0.014* (r = 0.74)
Low Engagement (LE)				0.511 (r = -0.23)	0.894 (r = -0.04)	0.443 (r = -0.27)	0.028* (r = - 0.68)
Distraction (D)					0.867 (r = -0.06)	0.307 (r = -0.36)	0.668 (r = -0.15)
Maximum Heart Rate (HRmax)						1.000 (r = 0.0)	0.844 (r = -0.07)
Steady-State Heart Rate (HRsteady-state)							0.490 (r = 0.24)

Table 8. Experimental Results. Neurophysiological, Physiological and Game Score Classification variables correlation for condition 3) traditional screen-based computer device/traditional classroom context - closed video game narrative. Working Cognitive Load (WL), High Engagement (HE), Low Engagement (LE), Distraction (D), Maximum Heart Rate (HRmax), Steady-state Heart Rate (HRsteady-state) and Game Score Classification (GSR).

Under condition 2) we found the following significant correlations for the neurophysiological variables: a negative correlation between HE and LE (**r-value = - 0.87; 0.001** for p<0.01**). In addition, we found the following correlations between neurophysiological and GSC variables: a positive correlation between HE and GSC (**r-value= 0.80; 0.005** for p<0.01**), and a negative correlation between LE and (**r-value= - 0.63; 0.050* for p<0.05**). A possitive correlation between HRmax and HRsteady-state was also observed (**r-value= 0.72; 0.019* for p<0.05**) (see table 6).

Under condition 3) we found the following significant correlations for the neurophysiological variables: a negative correlation between HE and LE (**r-value = - 0.74; 0.013* for p<0.05**). In addition, we found the following correlations between neurophysiological and GSC variables: a negative correlation between LE and GSC (**r-value= - 0.87; 0.001** for p<0.01**). A positive correlation between HRmax and HRsteady-state was also observed (**r-value= 0.72; 0.018* for p<0.05**) (see table 7).

Under condition 4) we found the following significant correlations for the neurophysiological variables: a negative correlation between HE and LE (**r-value = - 0.85; 0.002** for p<0.01**). In addition, we found the following correlations between neurophysiological and GSC variables: a positive correlation between HE and GSC (**r-value= 0.74; 0.014* for p<0.05**), and a negative correlation between LE and GSC (**r-value= - 0.68; 0.028* for p<0.05**) (see table 8).

Comparison between condition 1), 2), 3) and 4) – behavioral variables

Motivation to play

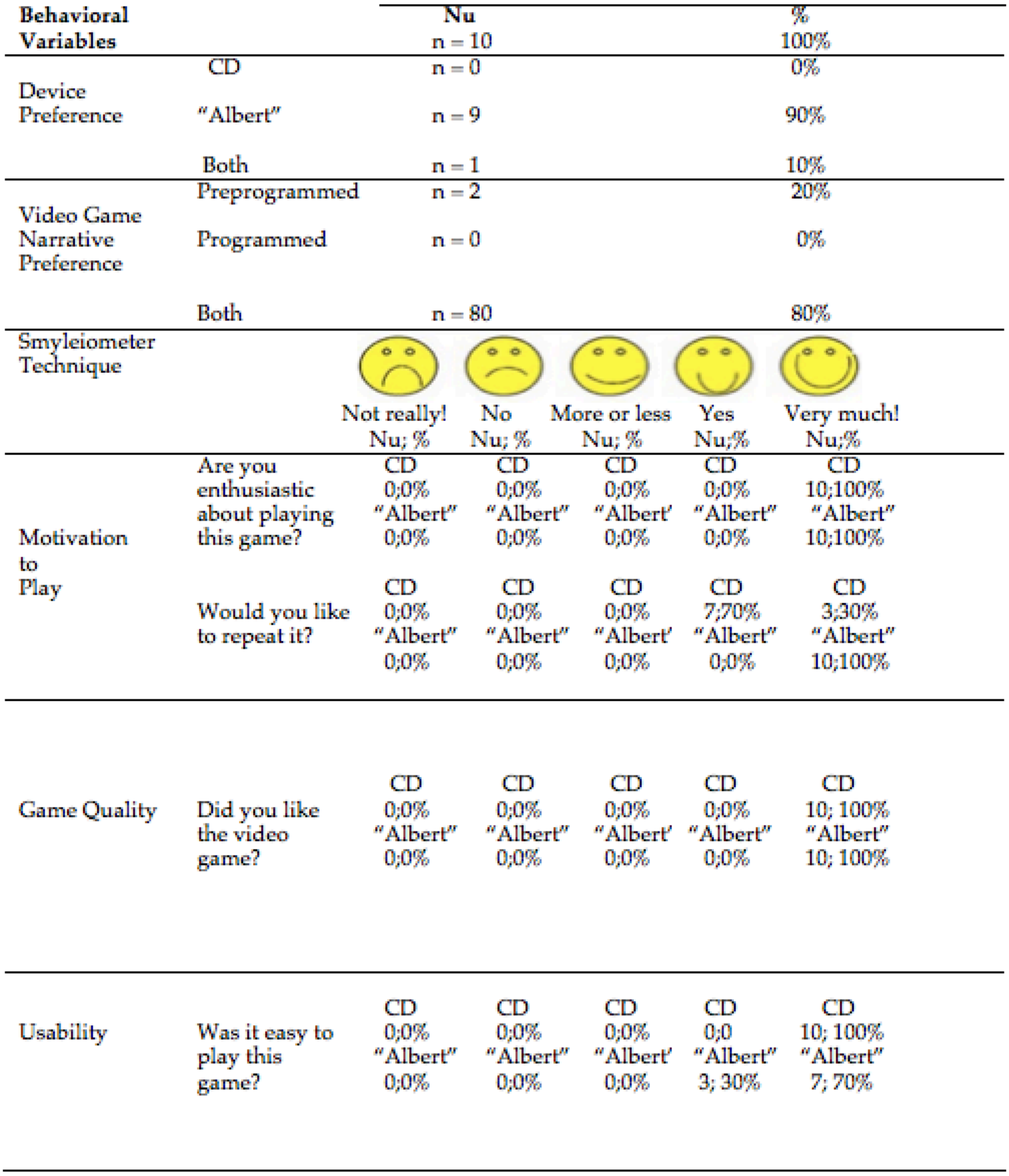
All the participants were motivated to play with both the devices ("Albert" and CD) before the activities (n=10 or 100% - "Very much" option in the Smyleiometer questionnaire). After finishing the activity with the device "Albert", all children indicated that they wanted to repeat the activity (n=10 or 100% - "Very much" in the Smyleiometer). Children also mentioned that they wanted to repeat the activity with the CD (n=3 or 30% - Very much" in the Smyleiometer - after four experimental sessions; n= 7 or 70% - "Yes" in the Smyleiometer – after four experimental sessions).

Device preference

Most children preferred to play with the whole-body motion device "Albert" in the natural environment (n= 9 or 90%). One participant indicated that he enjoyed playing with both devices – "Albert" and CD (n=1 or 10%). Children verbalized that it was funnier to interact with "Albert". They were excited about the possibility of playing with "Albert" in the natural environment (e.g., "Its fun to play a video game outside!"; "I can play with trees!"). Likewise, children mentioned that the CD was also fun, but not as fun as the device "Albert".

Video game narrative preference

Most children indicated that they enjoyed both the closed and open video game narratives (n=8 or 80%) while using both the devices - "Albert" device and the CD.



Behavioral Variables		Nu n = 10				% 100%
Device Preference	CD	n = 0				0%
	"Albert"	n = 9				90%
	Both	n = 1				10%
Video Game Narrative Preference	Preprogrammed	n = 2				20%
	Programmed	n = 0				0%
	Both	n = 80				80%
Smyleiometer Technique		Not really! Nu; %	No Nu; %	More or less Nu; %	Yes Nu;%	Very much! Nu;%
Motivation to Play	Are you enthusiastic about playing this game?	CD 0;0% "Albert" 0;0%	CD 0;0% "Albert" 0;0%	CD 0;0% "Albert' 0;0%	CD 0;0% "Albert" 0;0%	CD 10;100% "Albert" 10;100%
	Would you like to repeat it?	CD 0;0% "Albert" 0;0%	CD 0;0% "Albert" 0;0%	CD 0;0% "Albert' 0;0%	CD 7;70% "Albert" 0;0%	CD 3;30% "Albert" 10;100%
Game Quality	Did you like the video game?	CD 0;0% "Albert" 0;0%	CD 0;0% "Albert" 0;0%	CD 0;0% "Albert' 0;0%	CD 0;0% "Albert" 0;0%	CD 10; 100% "Albert" 10; 100%
Usability	Was it easy to play this game?	CD 0;0% "Albert" 0;0%	CD 0;0% "Albert" 0;0%	CD 0;0% "Albert' 0;0%	CD 0;0 "Albert" 3; 30%	CD 10; 100% "Albert" 7; 70%

Table 9. Experimental results. Behavioral variables. Device preference; Video Game Narrative Preference; Motivation to play; Game quality; Usability. Frequencies and Percentagens.

Two participants mentioned that they preferred the closed narrative (n=2 or 20%) in both devices.

Game quality

All children enjoyed the video game narrative "Vankalo. The Sedentary Cyborg" in both "Albert" and the CD (n=10 or 100% - "Very much" in the Smyleiometer). Children indicated that they enjoyed the fact that they could learn about space; found the game characters to be enigmatic; wanted to overcome Vankalo's evil plans.

Usability

Most of the participants considered that it was easy to interact with the device "Albert" (n=7 or 70% - "Very much" in the Smyleiometer; n=3 or 30% - "Yes" in the Smyleiometer. Children suggested that the device "Albert" could be lighter. All children considered that it was easy to interact with the CD (n=10 or 100% - "Very much" in the Smyleiometer).

Results regarding behavioral variables are resumed on table 9.

In the following subchapter we will discuss the statistical results obtained in this study.

3.13 Discussion

From the obtained results we observed significant differences in children's neurophysiological response: LE mean values were higher under condition 3 (CD/classroom context - closed narrative) when compared to conditions 1 ("Albert" device/natural environment - closed narrative) - 0.047* for $p<0.05$ - and 2 ("Albert" device/natural environment - open narrative) - 0.022* for $p<0.05$. WL mean values were higher under condition 1 compared to condition 2 - 0.005** for $p<0.01$.

Higher mean values of LE under condition 3 compared to both conditions 1 and 2, in addition to a negative correlation between HE and LE in all the conditions (1, 2, 3 and 4 - while HE increased, LE decreased and vice-versa), reveal that children exhibited lower levels of sustained attention over time under condition 3 compared to conditions 1 and 2. On the other hand, we observed no significant differences in neurophysiological response between condition 4 (CD/classroom context – open narrative) and condition 3.

The previous results - increased LE under condition 3 compared to conditions 1 and 2 in addition to no significant differences in neurophysiological response between conditions 3 and 4 - suggest that the nature of the interactive environment (sensorimotor stimulation) caused differences in neurophysiological response. We observed a trend for the interaction with a whole-body motion device in a natural environment to instill higher levels of sustained attention over time, compared to interaction with a CD based on HECS in a classroom context.

In fact, both video game narratives were similar under conditions 1 and 3 – closed - however, neurophysiological response was significantly different: LE levels were higher in condition 3 when compared to condition 1. In addition, HE levels were significantly higher than LE levels in condition 1 - 0.037* for $p<0.05$. Remarkably, LE levels were also higher in condition 3 when compared to condition 2 - different video game narrative (closed versus open).

Furthermore, in condition 3, LE demonstrated a trend to be higher than HE, and WL to be higher than both HE and LE. In condition 4, WL and HE assumed the highest values (similar for both variables) followed by LE and D. On the other hand, HE assumed the highest values, followed by WL, LE and D under both conditions 1 and 2.

The previous results demonstrate a trend for interaction with a CD based on HECS in a classroom context to cause high load levels in the child's WM system, compared to interaction with a whole-body motion device, in a natural environment. This occurred particularly under condition 3, where the learning rhythm was imposed externally. One study demonstrated that mental overload in K-12 students is associated with low levels of engagement (when tasks exceed the ability to cognitively model the problem due to task difficulty regarding content – acquiring unnecessary data) (Stevens et al., 2007ac) - as observed in condition 3 (WL>HE). According to Smith et al. (2005) mental effort lowers vigilance.

Our results demonstrate that differences in neurophysiological response also occurred due to the nature of the virtual task (narrative type): differences between conditions 3 (WL>HE and LE>HE) and 4 (WL=HE and HE>LE) for a similar sensorimotor environment (restricted). Moreover, we found that WL mean values were higher under condition 1 compared to condition 2 (enhanced sensorimotor environment) – in addition to no significant correlations between physiological and neurophysiological variables. These results seem to demonstrate that the virtual task where the learning rhythm was imposed externally (increases in task demands) – closed game narrative - tended to increase mental effort, compared to the virtual task where the child could establish her own learning rhythm – open game narrative.

Although there were no significant differences in neurophysiological response between conditions 3 and 4, it seems that the nature of the virtual task caused dissimilarities in neurophysiological response in children. The condition 3, where the learning rhythm was imposed externally (closed narrative), seemed to have caused high load levels in children's working memory system – overloading the working memory system when compared to condition 4 (where the child could establish her own learning rhythm). In fact, in condition 3 WL and LE assumed the highest levels – not observed in condition 4.

Furthermore, if we compare condition 3 to condition 1 – similar video game narrative type (closed) – we observe that there was a trend for condition 3 to overload the child's working memory system - not observed in condition 1 (HE>WL). We suggested that exposure to multiple sources of sensory information could not only raise sustained attention levels, but also not overload the child's working memory system during information processing. Enhanced sensorimotor environments could induce increases in sustained attention in children over time – allowing the child to maintain focus during a certain task, while diminishing distractive interference – thus reducing cognitive load in the working memory system.

In addition, we documented significant differences between the variables HE and LE in condition 1 (higher mean value for HE) – only observed under this condition. This significant difference may have occured due to two factors: PA levels achieved during the task and the nature of the virtual task. 7 participants achieved moderate PA levels in condition 1. In condition 2, only 3 participants achieved moderate levels of PA (values calculated according to the equations established for the automatic feedback control mechanism). We did not find significant correlations between physiological (HRmax and HRsteady-state) and neurophysiological variables (HE and LE) under condition 1, reason why, the significant difference found between the neurophysiological variables HE and LE in condition 1 may have occurred due to the nature of the virtual task – closed video game narrative.

According to Berka et al. (2007:232), the EEG - engagement index is directly related to sustained attention - allocation of attentional resources during encoding (information-gathering processes). The authors refer that engagement levels increase "as a function of increasing task demands" and "tracks demands for sensory processing and attention resources". Hence, it seems that the external imposition of the learning rhythm, in condition 1, was linked to an increase in task demands, and thus, to increases in HE levels. In contrast, under condition 2, task demands tended to be lower due to the fact that children could establish their own learning rhythm - reason why HE and LE levels did not present significant differences.

Increases in HRmax levels, under condition 1, can be justified due to the the nature of the video game narrative - the child was encouraged to achieve moderate PA levels through an automatic feedback control mechanism. Under condition 2, the child controlled her PA levels according to will.

We found no correlations betweeen physiological and neurophysiological variables in all the conditions, reason why the significant differences between the neurophysiological variables may be explained by the nature of the interactive environment/virtual task.

Most children preferred to interact with the device "Albert" in the natural environment (n=9; 90%), compared to the CD (n=1; 10% - both devices). Alertness depends on the agent's motivation (Oken et al., 2006). Children increase their attentional focus during tasks associated with positive emotional states (Boekaerts, 1999; Rathunde & Csikszentmihalyi, 2007; Zimmerman, 2002).

We could speculate that the trend for higher sustained attention in both conditions 1 and 2, compared to conditions 3 and 4, may have occurred due to the degree of excitement caused by the activity.

Children mentioned that the CD was fun, but not as fun as the "Albert" device. On the other hand, before the activities all participants were motivated to play with either device ("Albert" and CD; n=10 or 100% - "Very much" in the Smyleiometer). Once the activity with the "Albert" device ended, all children indicated they wanted to repeat it (n=10 or 100% - "Very much" in the Smyleiometer). Children indicated they wished to repeat the activity with the CD (n=3 or 30% - "Very much" in the Smyleiometer ; n= 7 or 70% - "Yes" option in the Smyleiometer).

The previous results demonstrate that children were also motivated to repeat the activity with the CD. We suggest that the preference for the "Albert" device may have influenced children's neurophysiological response - trend for higher sustained attention in both conditions 1 and 2. However, children were also motivated to interact with the CD. Hence, it is not clear that emotional states may have influenced neurophysiological response.

The previous discussion regarding neurophysiological results, suggests that interaction with a whole-body motion SBCD, allowing multiple possibilities for action in a natural environment, causes different levels of stress in the child's neurophysiological system (increases in sustained attention levels over time - high neuroexcitatory activity) when compared to interaction with a sedentary SBCD, through the use of HECS, in an artificial environment. In turn, higher sustained attention over time, in the enhnaced sensorimotor environment, seems to have reduced load in the WM system (not overloading WM), independently of the nature of the virtual task.

On the other hand, the restricted sensorimotor environment demonstrated a trend to be associated with low sustained attention over time, which in turn seems to have imposed increased load in the WM system, particularly in the virtual task, where the learning rhythm was imposed externally (increases in task demands overloading the WM system).

Remarkably, the trend for higher sustained attention in the enhanced sensorimotor environment seemed to be linked with improvements in EM performance.

We found the following significant differences in the GSC variable related to EM performance: between condition 1 and condition 3 (0.004** for $p<0.01$, higher mean value for condition 1), and between condition 1 and condition 4 (0.031* for $p<0.05$, higher mean value for condition 1); between condition 2 and condition 3 (0.006** for $p<0.01$, higher mean value for condition 2).

Improvements in EM performance in conditions 1 and 2, compared to condition 3, seemed to have occurred due to children being less engaged under condition 3. Apart from the previous observed significant difference, we found a strong positive correlation between HE and GSC (r-value= 0.81; 0.004** for $p<0.01$) and a strong negative correlation between LE and GSC (r-value= - 0.79; 0.006** for $p<0.01$) in condition 1. We also observed a strong positive correlation between HE and GSC (r-value= 0.80; 0.005** for $p<0.01$) and a moderate negative correlation between LE and GSC (r-value= - 0.63; 0.050* for $p<0.05$) in condition 2. In contrast, in condition 3 we only observed a strong negative correlation between LE and GSC (r-value= - 0.87; 0.001** for $p<0.01$).

In addition, and as previously mentioned, it seems that there was a trend for condition 3 to overload the child's working memory system due to the observed increases in WL and LE levels. In turn, low levels of sustained attention and high levels of cognitive load over time seem not to have optimized EM performance in children when compared to conditions 1 and 2.

Moreover, we observed improvements in EM performance under condition 1 compared to condition 4. While in condition 1 we found a strong positive correlation between HE and GSC and a strong negative correlation between LE and GSC, in condition 4 we found a weaker positive correlation between HE and GSC (r-value= 0.74; 0.014* for $p<0.05$) and a moderate negative correlation between LE and GSC (r-value= - 0.68; 0.028* for $p<0.05$). Again, the results suggest that children were more engaged under condition 1 compared to condition 4, seemingly favoring EM performance.

No significant differences in EM performance between conditions 2 and 4 were found. This lack of difference (though nearly observed - 0.057) may be ascribed to the nature of the game narrative – in this case, children performed an open game narrative where they could establish the learning rhythm (deciding on the time to explore the game scenarios).

The latter results suggest that interaction with a whole-body motion SBCD, allowing multiple possibilities for action, in a natural environment, seems to optimize the processing of virtual information, in children (encoding and recall of virtual information - EM performance), when compared to interaction with a sedentary SBCD, through the use of HECS, in an artificial environment. The trend for the enhanced sensorimotor environment to optimize EM performance, in children, occurred independently of the nature of the virtual task - explained by the increases in sustained attention over time.

Moreover, it appears that sustained attention functions had a strong influence on EM performance, as we found significant correlations between sustained attention and EM performance in the four conditions.

Increases in sustained attention, in the enhanced sensorimotor environment, may have reduced distractive interference, facilitated perceptual functions and thus diminished cognitive load in the child's working memory system.

In children, high levels of WM load represent a possibility for information loss - which seems to have happened in the restricted sensorimotor environment. Since the PFC and connections between the PFC and the MTL are still maturing in children, we suggested that encoding and retrieval of episodic information is mostly under the influence of posterior sensory and perceptual areas. We speculated that children might encode and represent episodic events more closely to the sensory surface compared to adults.

A variety of perceptual symbols in support of enhanced sensorimotor representations of episodic events – virtual events in the video game – may have reduce cognitive load in the child's working memory system: facilitating perception of the different features in the virtual environment, thus diminishing cognitive load.

In effect, if children encode and represent episodic events closer to the sensory surface, when compared to adults, perception may be facilitated when multiple sources of information are present (for an adult it might be easier to identify elements in the surrounding environment through a smaller number of sources of sensory information since an adult relies on more automatic perceptual mechanisms when compared to children).

It may be the case that children's EM performance is optimized when elements in the external world tend to be more easily labeled or identified. In this case, the combination of multiple sources of sensory information, from the physical world, and elements from the virtual environment might have facilitated labeling/interpretation of the features in the virtual environment - diminishing cognitive load in the WM system and optimizing recall of the virtual features.

For example, proprioceptive/vestibular and cutaneous input, from the enhanced sensorimotor environment, while the child crossed the "Venus" scenario in the video game – catching four CO_2 molecules – may have facilitated perception of the four objects in the virtual environment. More specifically, the enhanced sensorimotor environment seemed to optimize recall of episodic information about the different features in the virtual environment because the child could rely on additional sources of sensory information to represent those same features (apart from visual and auditory information) - thus facilitating perception of those same features.

Furthermore, we speculated that additional sources of sensory information might have contributed to greater reactivation of sensory regions that facilitated later recall of episodic events. As stated above, and maintained by Butler & James (2012:388), "recognition associated with a 'remember' (as opposed to a 'know') response is associated with greater reactivation of sensory regions that are specific to associated contextual information encountered during encoding. This greater activation of context related regions is associated with an increase in memory accuracy, and recalling more information has been shown to increase the degree of neural reactivation".

EM supports autobiographic memory, the ability to recollect and integrate ideas, and a variety of other cognitive abilities in children, e.g., problem solving (information to be manipulated in the WM system), reading comprehension and learning (long-term information storage) (e.g., Ghetti & Bunge, 2012:382; Raj & Bell, 2010; Sluzenski et al., 2004). EM is influenced by experience (Shing and Lindenberger, 2011). Therefore, encouraging children to practice activities that potentiate performance and the development of EM is essential.

Children stated that they enjoyed the game - n=10 or 100% ("Very much" in the Smyleiometer). They enjoyed the fact that they could learn about Space, found the game characters enigmatic and wanted to defeat Vankalo's plans. Children enjoyed both the closed and open game narratives - n=8 or 80% (two participants mentioned having preferred the closed narrative - n=2 or 20%). They showed motivation to interact with both the devices and associated environments, before and after the activities.

Most participants considered interacting with the device "Albert" to be easy (n=7 or 70% - "Very much" in the Smyleiometer; n=3 or 30% - "Yes" in the Smyleiometer). Children suggested that the device "Albert" could be lighter. All children considered interacting with the CD to be easy (n=10 or 100% - "Very much" in the Smyleiometer). Children were more motivated to interact with the "Albert" device in the natural environment (e.g., "Its fun to play a video game outside!"; "I can play with trees!"), compared to the CD in the classroom setting.

3.14 Conclusions

The results obtained in this study suggest that:

- Enhanced and restricted sensorimotor environments cause differences in neurophysiological response in children. Enhanced sensorimotor environments are associated with high neuroexcitatory activity and restricted sensorimotor environments are associated with low neuroexcitatory activity;

- Allowing a child to establish her learning rhythm, in the restricted sensorimotor environment (i.e., interaction with a sedentary SBCD through the use of HECS in an artificial environment, stimulating mostly the visual and auditory senses), optimized EM – encoding and recall of virtual information (not overloading WM). Hence, exploratory learning tasks in virtual environments – video game play - may be an optimal solution to promote child learning in restricted sensorimotor environments;

- The enhanced sensorimotor environment (i.e., interaction with a whole-body motion SBCD, allowing multiple possibilities for action, in the natural environment, stimulating the visual, auditory, chemical, cutaneous, proprioceptive and vestibular senses) optimized children's EM - encoding and recall of virtual information during video game play. This environment was linked to increases in sustained attention over time, not overloading WM, independently of the nature of the virtual task. Thus, this type of environment may be an optimal solution to promote learning.

Notwithstanding the limitations of the present study - small sample size - it may be the case that enhanced sensorimotor environments optimize children's EM. In any case, future research is necessary to confirm the achieved results. The current study demonstrates that the current Child-Computer Interaction paradigm - interaction with sedentary SBCDs, through the use of HECS, in artificial environments - may be failing to optimize children's cognitive performance.

This study aims to draw the attention of the education community to the fact that children's learning may benefit from interactions with enhanced sensorimotor environments. We may have to rethink the current educational paradigm associated with child learning through computing devices.

In addition, we submit that there is an urgent need to encourage children to interact with challenging physical environments so as to cause different types of stress on the cognitive system.

While frequently interacting with sedentary SBCDs, through the use of HECS, in artificial environments, modern children are repeatedly exposed to restricted sensorimotor experiences. Children who frequently interact with this type of devices/environment, may come to establish a tendency in neurophysiological response throughout development – low levels of neuroexcitatory activity. In turn, low levels of neuroexcitatory activity may hamper the ability to process multiple sources of information from the environment throughout development. We suggest that, in the future, these children may demonstrate increased difficulties in interpreting/acting in a multisensory physical world.

3.15 Limitations and future work

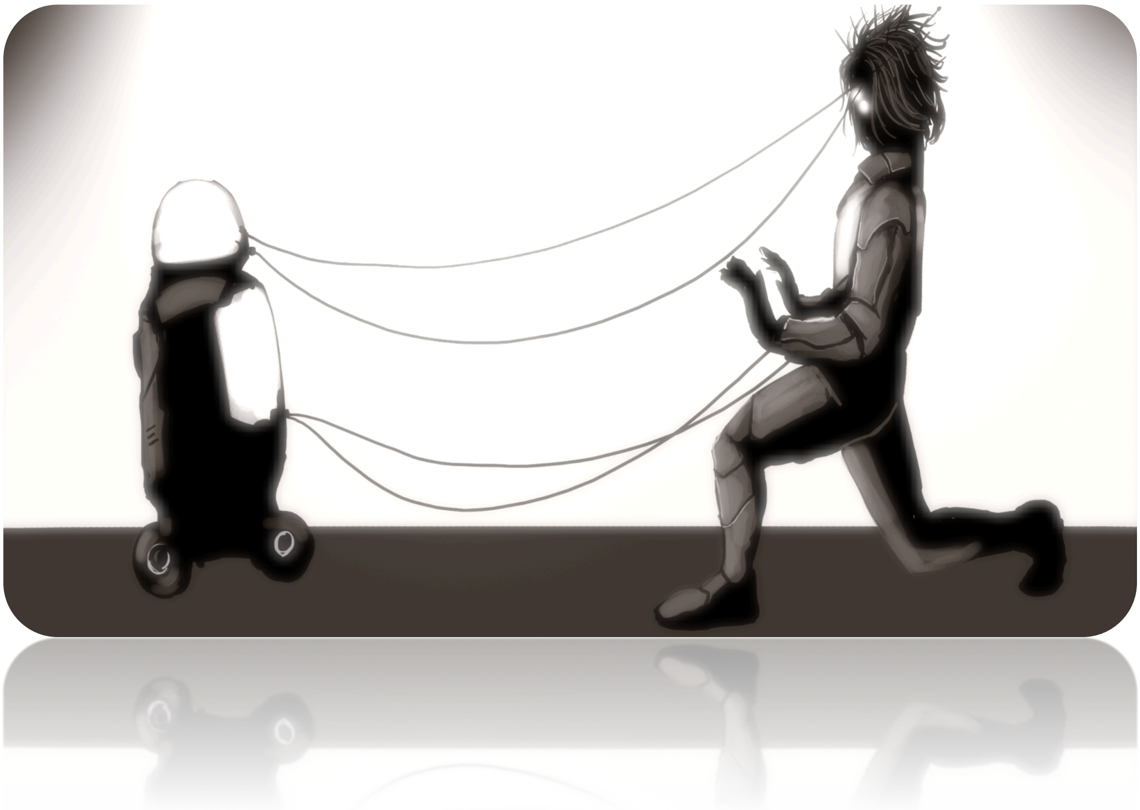
Children were evaluated in a single moment - immediate episodic recall was evaluated once in each of the four evaluated conditions. Therefore, we did not evaluate the process of learning per se. Hence, in order to determine if learning as occurred in children we will have to conduct multiple evaluations in future studies and confirm if the memorized information is maintained over time.

The present study is a pilot study. Notwithstanding the major limitation of the present study – small sample size (a major source of error) – we found potential value in the achieved results – strong trends were observed in the evaluated conditions. It hence becomes necessary to develop full-scale research studies in order to confirm (validate) the results.

In future work we will try to understand the effects of different types of environments (different types of sensory stimulation) in children's cognitive function (beyond episodic memory, e.g., problem solving, long-term memory), including its relation to overall body processes. At the same time, we will try to raise the potential value regarding children's exposure to different environmental contexts - how different environments may affect cognitive development and contribute to the enhancement of the human evolutionary condition.

4

Experiment II – Increasing Children's Physical Activity Through Biosymtic Robotic Devices



4.1 Abstract

We describe the effects of a Biosymtic robotic device - “Cratus” - on physical activity levels in a group of 20 children aged 6 to 8 years. Children interacted with “Cratus” via whole-body motion in a natural environment - playing a video game. Children’s expectations and opinions regarding the device were also evaluated. Results indicate that interacting with the “Cratus” device, in a natural environment, instilled vigorous physical activity. Moreover, children mentioned they were highly motivated to interact with the device. Hence, the “Cratus” device and the natural environment seem to be a promising solution to promote children’s physical and mental health. This study shows that in order to increase physical activity, children should be encouraged to perform activities in large spatial areas such as natural environments that offer variation of climatic conditions. As the use of equipment may increase physical activity levels, children should be encouraged to interact with user interfaces that promote the use of gross motor skills. Furthermore, since situations of excitability or fear may increase children’s heart rate values, video game play seems to be an optimal solution to raise physical activity levels.

4.2 Introduction

The amount of time children spend with digital media has increased substantially in recent years. Screen-based computer devices (SBCDs) such as laptops, tablets, smartphones, among others, are now the favorite toys of young generations (Berson & Berson, 2010; Byron Review, 2008; Common Sense Media, 2011; Calvert et al., 2005; Houses of Parliament, 2012; Kline, 2004; McDonough, 2009; NPD Group, 2011; PEW Research Center 2009; Rideout et al., 2010; Roberts & Foehr, 2008; Vandewater & Lee, 2009). Children interact with these devices through the use of interfaces based on hand-eye coordination skills (HECS; e.g., “mouse”, “keyboard”, multi-touch interfaces).

The increased use of SBCDs is linked to lower levels of physical activity (PA) in children - sedentary behavior. Sedentary behavior is characterized by diminished or complete lack of PA (Cole, 2000) and is one of the main factors negatively influencing children’s health. It correlates with overweight, obesity, type 2 diabetes, ADHD, anxiety, depression, bone loss leading to osteoporosis, mobility and postural problems, high cholesterol, hypertension, breathing difficulties, sleep disorders and gastro-esophageal reflux. This type of behavior has also been linked to increased cancer risk (e.g., colorectal, endometrial, ovarian and prostate cancer) and premature death (American Medical Association, 2013; Center for Disease and Prevention Control, 2010; 2011; 2012; Fontaine et al., 2003; Hamilton, 2006; Nieman, 1999; Rowland & Bar-Or, 2004; WHO, 2010, 2013).

In fact, overuse of sedentary SBCDs is associated with obesity, anxiety, increased risk of depression, addictive and aggressive behaviors, poor self-esteem, hyperactivity, attention problems, sleep disorders, attachment and obsessive-compulsive disorders, tendonitis, hand-arm vibration syndrome, bodily discomfort, physical fatigue, reduction of physical and emotional awareness, poor fitness, photosensitive epilepsy, visual problems and motion sickness (e.g., American Academy of Pediatrics 2001; Chang et al., 2012; Cleary et al., 2002; Cornwell, 2008; Cranz, 1998; Ferguson, 2013; Gentile, 2009; Griffiths, 2002; Lui et al., 2011; Paavonen et al, 2006; Reichhardt, 2003; Small & Vorgan, 2008; Swing et al., 2010; Tremblay et al., 2011; Wallace, 2012; Wiegman, 1998; Zacharkow, 1988). According to Ward (2013), children under the age of 4 are becoming so addicted to smartphones and "iPads" that are requiring mental therapy.

In order to avoid sedentary behavior and to potentiate physical and mental health in children, researchers have been integrating SBCDs with whole-body motion (WBM) user interfaces. WBM interfaces make use of whole-body movements to control virtual information on SBCDs. For example, visual and audio data control can be accomplished through the use of gesture-based (e.g., computer vision) and/or sensor-based (e.g., infrared sensing) interfaces (Noble, 2009). Children use these systems mainly in artificially controlled environments (ACE).

In the field of Human-Computer Interaction, computer games requiring physical effort are characterized as exergames, or active video games (AVGs) – integrated with WBM interfaces (Altamimi & Skinner, 2012; Mueller et al., 2008). Mueller et al. (2008:265) state that "An exertion game has an input mechanism in which the user is intentionally investing physical exertion. Such an exertion interface has been previously defined as being physically exhausting and requiring intense physical effort". Researchers have studied how AVGs improve children's physical and mental health.

For example, Active Healthy Kids Canada conducted a meta-analysis of scientific studies, analyzing the long-term effects of AVGs in health and behavior in children (aged 3 to 17 years). This meta-analysis comprised 1367 published papers dated from 2006 to 2012 (Cochrane Central Database and MEDLINE, EMBASE, psycINFO, and SPORTDiscus databases). The reviewed papers included 1992 participants from 8 countries. It concluded that AVGs did not promote the 60 minutes of moderate to vigorous PA (MVPA) necessary to benefit children's health. There was also a lack of evidence suggesting long-term spontaneous adherence to AVGs. In addition, researchers mentioned that AVGs are not a substitute for physical activity in natural environments (LeBlanc et al., 2013; Tremblay, 2012). Other studies have supported these findings (e.g., Baranowski et al., 2012; Whitehead et al., 2010).

In the Child-Robot Interaction field, robots have been mostly developed and used for educational, entertainment and rehabilitation purposes, typically in artificial environments (indoors) (e.g., Barakova, 2011; Beran et al., 2011; Brisben et al., 2004; Colton et al., 2009; Druin & Hendler, 2000; Espinoza et al., 2011; Fujita et al., 2000; Giannopulu, 2013; Kornhauser et al., 2007; Kozyavkin et al., 2014; Lahey et al., 2008;

Lathan et al., 2005; Marti, 2012; Martin et al., 2000; Miller et al., 2008; Papert, 1980; Resnick, 1990; Tanaka et al., 2007; Van der Drift et al., 2014; Willeke et al., 2001).

Robots have been used to encourage child learning - educational purposes. For instance, in 1967, Papert and his colleagues at the Massachusetts Institute of Technology (MIT) developed a computer program called "Logo". This program enabled children to write their own computer programs in order to control the motor behavior of a physical robot (turtle mobile robot). Children used a SBCD to program mathematical patterns to be drawn by the robot on physical surfaces. Papert's work was the foundation of a new generation of robotic systems for educational settings (Papert, 1980).

Researchers have developed extensions of the "Logo" program. For instance, Michael Resnick developed a program called "MultiLogo" that allows children to program robotic Lego bricks, aiming to improve learning in elementary-school children (Resnick, 1990; see also Kornhauser et al., 2007). MIT researchers, in collaboration with the LEGO Group, introduced new robotic programmable systems in 1998: LEGO® Mindstorms™. Mindstorms consists of a series of kits (e.g., brick computer; modular sensors and servo motors; connection cables; lego bricks) and software (e.g., the NXT-G graphical programming environment) to create and build programmable robots. Mindstorms were developed to encourage children and teens to learn about science, technology, engineering and mathematics (STEM Education)[99][100](e.g., Martin et al., 2000).

Other researchers have been developing programmable robotic systems to help children learn through game play (i.e., programmable mobile robots) (e.g., Lahey et al., 2008)[101][102].

Thus far, educational robots have been encouraging children to interact with SBCDs involving mostly visual and auditory information-gathering scenarios and interfaces based on HECS (e.g., "keyboard", "mouse", multi-touch). Children use HECS to program physical actions/behaviors to be performed by the robots (programing autonomous control through source code).

Researchers have also been developing non-programmable robots with educational purposes. For instance, tour-guide robots to guide children and adults in museums. These systems may communicate verbally and allow tangible interaction (HECS; e.g., multi-touch interfaces to interact with digital information) (e.g., Willeke et al., 2001).

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99. http://education.lego.com/nb-no/preschool-and-school/upper-primary/8plus-mindstorms-education
100. http://www.media.mit.edu/sponsorship/getting-value/collaborations/mindstorms
101. http://www.aldebaran.com/en/humanoid-robot/nao-robot
102. http://me.lab.asu.edu/alert

Entertainment robots have also been developed for children. For example, the AIBO ERS-110 dog from Sony (a pet-robot) was developed to provide entertaining experiences. Children may give explicit verbal instructions to AIBO for it to play with a ball or dance (autonomous behavior). AIBO has preprogramed answers to verbal commands (Fujita et al., 2000). Melson et al. (2005) conducted a study, comprising 72 children aged 7 to 15 years, to evaluate their interaction with the AIBO pet-robot. Children's opinions while playing with the robot were measured through interviews. Children ascribed mental states, social behaviors and moral standings to the robot.

The tour-guide and entertainment robots described previously are associated with sedentary behavior - encouraging children to make use of interfaces based on HECS and/or verbal commands to interact with robotic systems.

Health robots have been used to promote children's physical and mental health, particularly in hospital environments.

Espinoza et al. (2011) developed a project - ALIZ-E - that makes use of a robotic humanoid system (NAO; semi-autonomous robot) to help children with diabetes in hospital environments. NAO is a companion robot that helps children learn about and manage their metabolic condition. It is a teleoperated robot: the operator communicates verbally with the child as if it were the robot. NAO incites children to be physically active by suggesting they imitate its dance moves.

Goris et al. (2008) developed a teleoperated robot (manual robot) to improve the living conditions of children in hospitals. This robot, resembling an elephant-like animal, provides entertainment, communication and medical assistance to children. Human operators control this robot to communicate with children (e.g., medical staff, researchers). The robot is able to express emotions through facial expressions.

Health robots aiming to promote increases in children's PA are still scarce.

In a study conducted by Latitude® in collaboration with Lego® and Learning Institute & Project Synthesis, in 2012 (Robots@ School), a group of 348 children (aged 8 to 12 years), from various countries were asked to imagine their lives in the presence of robots in learning contexts (classroom settings and outside of school). One of the main outcomes of this study was that children associated robots with playful and fun learning, pursuing a connection between physical and academic skills - robots encourage learning through physical play. A child (age 10) reported that, "When I got to school this morning, my teacher surprised me by giving me a robot to help me with my schoolwork. We played football at recess with my friends. In class, he wrote for me and helped me to think. Leaving school he carried my bag and transformed into a bike" (Latitude® et al., 2012:7).

Although children feel driven to interact with robotic systems that connect physical and academic skills, most of the developed robotic systems seem to instill sedentary behavior. In effect, current SBCDs (including AVGs) and robotic systems seem to promote sedentary behavior in children.

Already in 2001, children were spending 600 calories less every day compared to the last five decades. Nowadays, levels of energy expenditure are still insufficient in order to benefit children's health (Boreham & Riddoch, 2001; Riddoch et al., 2007).

On the other hand, it is known that physical activity (PA) has a variety of benefits for children's physical and mental health.

PA imposes high energetic demands on the human body. It is defined as any bodily activity produced by the skeletal muscles requiring energy expenditure levels above resting state (Caspersen et al., 1985; National Institutes of Health, 2013; Welk, 2002; World Health Organization, 2013).

MVPA benefits children's physical health (Rowland & Bar-Or, 2004; WHO, 2013; Center for Disease Control and Prevention, 2011). The "Surgeon General's Report on Physical Activity and Health" recommends a daily practice of PA - providing expenditure rates of at least of 150 calories in order to yield health benefits (US Department of Health and Human Services, 1996). The World Health Organization (WHO, 2013) also recommends at least 60 minutes of daily MVPA for children aged 5 to 17 years. Accordingly, "Most of the daily physical activity should be aerobic. Vigorous-intensity activities should be incorporated, including those that strengthen muscle and bone, at least 3 times per week"[103].

MVPA optimizes the development of the cardiovascular system and musculoskeletal tissues - contributes to neuromuscular awareness and a healthy body weight. MVPA increases oxygen transfer efficiency to the muscles, which in turn metabolize fat resources, in addition to carbohydrates. Therefore, MVPA is a gold standard to prevent overweight and obesity in children (Rowland & Bar-Or, 2004; Spear et al., 2007).

PA benefits human development in multiple ways. It benefits the development of the sensorimotor system by stimulating the vestibular, proprioceptive and visual channels; promotes physical fitness (e.g., cardiorespiratory fitness and muscular and bone strength); reduces anxiety and depression by raising the levels of serotonin (5-HT), norepinephrine and dopamine (DA); boosts self-esteem (raising levels of 5-HT and DA); it is associated with the reduction of ADHD symptoms; and benefits cognitive function in children with cerebral palsy (Braswell & Rine, 2006; Gallaue & Ozmun, 2005; Jensen, 2000; May-Benson & Cermark, 2007; Neto, 2003; Payne, 1995; Pellegrini & Smith, 1998; Rowan, 2010; Tantillo et al., 2002; Taylor et al., 1985; Sachs et al., 1984; Verschuren et al., 2007).

In addition, MVPA seems to be the gold standard to optimize cognitive function (including academic achievement) and boost cognitive structure in children (post-

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103. http://www.who.int/dietphysicalactivity/factsheet_young_people/en/

activity benefits) (Brown, 1967; Chaddock et al., 2010ab; Davis et al., 2007, 2011; Ellemberg & St-Louis-Deschênes, 2010; Gabbard & Barton, 1979; Grissom, 2005; Hillman et al., 2005; 2009ab, 2011; Pesce et al., 2009; Tomporowski et al., 2008).

Moreover, it has been referenced that natural environments (NE) may optimize children's physical and mental health.

Natural bright light, in outdoor environments, helps children develop their visual system (structure and function) (e.g., Morgan & Rose, 2005; Mutti, 2007; Rose et al., 2008). It also contributes to the regulation of melatonin and cortisol hormones (optimizing cognitive function by increasing alertness and reducing stress levels) (Harmon, 1951; Jensen, 2000). Benefits from natural solar ultraviolet radiation (B UVB) include synthesis of vitamin D for normalization of blood levels, increased bone mineral density and prevention of autoimmune diseases (FreedHoff, 2012; Tremblay, 2012).

NE reduce aggressive behaviors, restore attention levels and improve learning and creativity in children (Dannenmaier, 1998; Fjortoft & Sageie, 2000; Kellert, 2002; Kuo & Faber, 1997; Louv, 2006). NE increase children's contact with germs - stressing the immune system, which requires contact with germs to properly mature (increased production of antibodies that protect children from life-threatening pathogens) (Lieberman, 2013).

For the aforementioned reasons, it is urgent to include PA, in NE, in children's daily lives so as to promote healthy lifestyles.

Taking into account that children are highly motivated to interact with digital devices and that the current SBCDs (including AVGs) and robotic systems are not promoting the recommended 60 minutes of MVPA, we propose a new format of robotic devices to increase PA levels and encourage children's contact with NE: Biosymtic (Biosymbiotic Robotic) devices.

The main goal of the present study is to investigate the effects of a Biosymtic (Biosymbiotic Robotic) device - "Cratus" - on PA levels in children. Physiological response and motor response were evaluated in a group of 20 children aged 6 to 8 years, while interacting with the Biosymtic device "Cratus" in a NE (natural forested landscape). Children played a video game (12-minutes evaluation session; two children per session). Behavioral response - children's expectations and opinions regarding the evaluated device - was evaluated before and after children's interaction with the device.

4.3. Hypotheses formulation

A high heart rate (HR) frequency correlates with high levels of PA; a low HR frequency correlates with low levels of PA (Armstrong & Welsman, 2000). HR frequency may vary due to emotional states or excitement caused by an activity (Rowland & Bar-Or, 2004). HR values in children increase in situations of excitability or fear: it may increase 20-40 beats per minute (BPM) above the actual resting value (Lumley et al., 1993). PA in hot or humid climates tends to increase HR values (15 to 20 BPM higher than in neutral climates). HR values also tend to be higher if the produced mechanical work includes gross motor skills (Rowland & Bar-Or, 2004). The use of equipment and larger spatial areas increases children's PA levels (Ridgers et al., 2010; Verstraete et al., 2006).

Hence, in order to increase PA, we suggest that children should be encouraged to perform activities in large spatial areas, such as NE, that offer variation of climatic conditions (to increase HR values). As the use of equipment may increase levels of PA, children should also be incited to interact with a variety of physical tools (user interfaces) that promote the use of gross motor skills. Furthermore, since situations of excitability or fear may increase children's HR values, video game play seems to be an optimal solution to raise PA levels. In fact, children refer that video games are engaging mainly due to the opportunity to experience challenging fantasy worlds (Hamlen, 2011).

One of the main characteristics of the Biosymtic device "Cratus" is that it engages children in physical play, in NE, through video gaming. Children interact with "Cratus" through whole-body motion - involving gross motor skills practice.

PA levels are often assessed through energy expenditure levels. A common way to access energy cost during PA is by measuring the Metabolic Equivalent of Task (MET or rate of energy consumption based on multiples of the resting metabolic rate). One MET corresponds to the metabolic energy expended by an individual per kilogram of body weight at rest [1MET= 1kCal/kg*h=4.184kJ/kg*h or 1MET=VO2=3.5 (mLO2·kg−1·min−1)] (Ainsworth et al., 2011).

We hypothesize:

H_0: "The Biosymtic robotic device "Cratus" instills MVPA (as measured in METs, 3 to 8,9 METs) in children aged 6 to 8 years and thus optimizes their physical and mental health".

In the following subchapters we describe this study's methods, including research method, evaluated system and video game software, sample selection, study design, core elements of treatment conditions, measuring instruments, institutions and partners involved in the research project and statistical techniques.

4.4 Research method

This is a quasi-experimental, cross-sectional and descriptive study. It describes children's physiological [metabolic intensity (METs); energy expenditure (kCalories); cardiovascular response (heart rate levels)], motor (steps taken) and behavioral (children's expectations and opinions) response to the interaction with a Biosymtic robotic device - "Cratus" - in a NE (natural forested landscape) – playing a video game.

Each child interacted with a Biosymtic device – "Cratus"– in a natural forested landscape.

"Cratus" is a Biosymtic (Biosymbiotic Robotic) Device: characterized as an artificial system (physical robot) that displays automatic control functions while (two modes): 1) Directly connected to a human organism (human-integrated automatic control; working as a human-robot interface); 2) Disconnected from a human organism (autonomous control; working as an autonomous robot). A Biosymtic (Biosymbiotic Robotic) device is able to sense and act in the environment demonstrating adaptive functions in both conditions 1) and 2). In this sudy, children interacted with "Cratus" in mode 1).

The central goal of a Biosymtic device is to potentiate children's physical and mental health, while connecting them with challenging NE offering multiple possibilities for sensory stimulation and increasing physical and mental stress to the organism [e.g., stress to the skeletomuscular, cardiovascular/respiratory, immune, endocrine and nervous systems (mental and emotional arousal)].

The "Cratus" device mimics a Roman gladiator/inventor. The physical structure of this device consists of a head connected to a torso, integrated with a wheel mechanism on its base (three wheels). The system includes a touch-based display (with a computer processor) - Algiz 7® - on the center back of the torso displaying virtual information to the child - visual output. Auditory output is produced by a sound speaker integrated in the apparatus' head (resembling an eye).

System inputs to control virtual information (e.g., put the video game avatar into motion) are made through whole-body physical action, e.g., the child may push, pull, rotate and throw the apparatus while walking, running, jumping or trotting on the physical terrain. The child may also skate while using this system - feet placed on top of the base where the wheels of the apparatus are. The system includes wireless motion sensors - I-CubeX® - to capture motion data (e.g., accelerometer, gyroscope and a tilt sensor integrated on the device's torso). Moving the system on the physical terrain is translated as virtual locomotion of the video game avatar. The system also captures physiological data from the child - communicating wirelessly with a HR biosensor - I-CubeX® - placed on the child's chest (see fig. 31).

"Cratus" may include a variety of software programs on its computing system. We developed a video game - "Cratus Robot. The Space Traveller" - whose goal is to optimize children's cardiorespiratory performance. In this video game narrative, "Cratus" is an old Roman inventor that reinvented his body in order to become a time traveller. The "wheeled teleportation system" is one of his great inventions. This system allows "Cratus" to travel the Universe at the speed of light. "Cratus" begins a journey throughout the Universe to discover the ancient architectural periods of planet

Fig. 31.

Biosymtic device Cratus

Whole-body motion interaction in a natural environment - forested landscape (large muscular groups/gross motor skills practice)

Top figure: Biosymtic device Cratus.

Left bottom figure: physical action translated as virtual locomotion of the video game avatar (child moving the avatar in the Parthenon game scenario).

Right bottom figure: children interacting collaboratively with Cratus.

Earth (classical antiquity, e.g., Roman coliseum - IV century, Eiffel Tower – XIX century, Parthenon - V century).

At the beginning of his adventure, “Cratus” discovers that his “wheeled teleportation system” has technical flaws – somehow “Cratus” has endowed the mechanism with some sort of intelligence that does not obey to his commands. Due to this technical defect it becomes very difficult to coordinate his body with the “wheeled teleportation system”. The main goal of the game is to help “Cratus” control his “wheeled teleportation system” while exploring a variety of 3D game scenarios.

The child is encouraged to move, as fast as possible, in each game scenario in order to score – completing each racetrack (e.g., Roman coliseum, Parthenon, Eiffel Tower) in the shortest time possible.

In this video game, “Cratus” encourages the child to perform MVPA through an automatic feedback control mechanism.

The automatic feedback control mechanism incited the child to achieve MVPA levels - 50% and 85% of maximum HR values (recommended by the American Heart Association, 2015). A software actuator controlling changes in the displacement speed of the game avatar - “inertial virtual actuator” - maintained the desired interval of HR values. For instance, if the child presented an average HR value <134.5 BPM (<50%), while interacting with the device, the system increased the inertial forces applied to the avatar – the child then needed to move faster to reach the desired interval. If the child exhibited an average HR value >175 BPM (>85%), the system decreased the inertial forces applied to the avatar.

The system also included a verbal actuator that produced audio output. This actuator followed the principles established for the “inertial virtual actuator”. If, for instance, the child presented an average HR value <134.5 BPM (<50%), the verbal actuator emitted specific verbal feedback, e.g., “Run faster!” or “Give me more power!”. If the child presented an average HR value >175 BPM (>85%), the verbal actuator emitted specific verbal feedback, e.g., “Slow down!” or “My mechanisms are about to explode!”. The reference interval of HR values was calculated and adjusted every minute (according to average HR values per minute).

“Cratus” demonstrates adaptive behavior by adapting to the performance of each child. For instance, for a similar task, child “A” may need to be exposed to increased inertial forces to achieve the desired HR values when compared to child “B”.

Additionally, real-time HR/motion data could be visualized on the software: a bar graph that changed color according to the child’s HR values; a slider (disk) displaying the angles and the velocity of rotation in three-dimensional space. The system displayed angles and velocity of rotation to facilitate the child’s performance during the game. This information was also accompanied by verbal instructions - e.g., “Straight ahead!”; “Turn right!”; “Turn backwards!”; “Rotate 45 degrees to the right!”; “Rotate 360 degrees to the left!”.

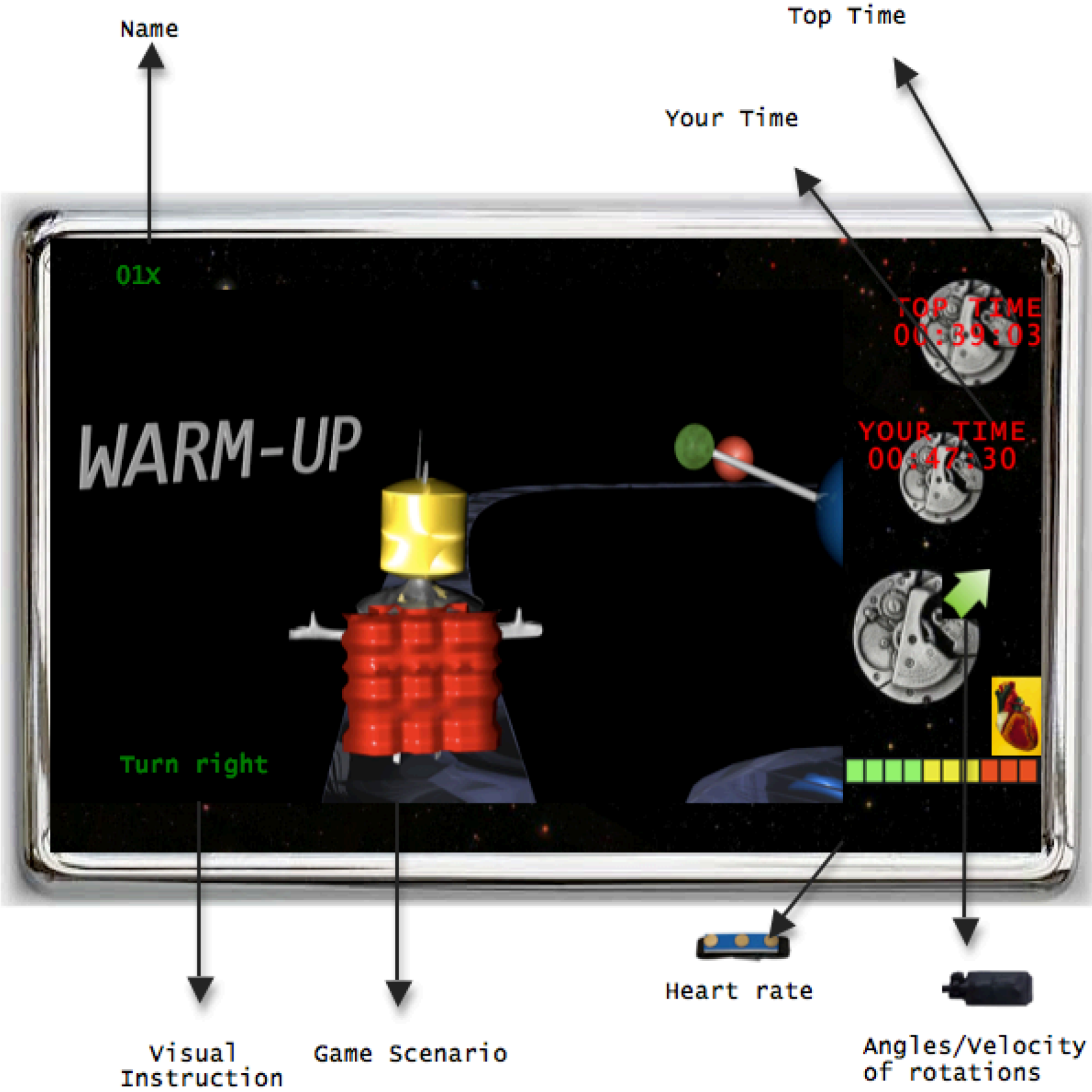

Fig. 32.

Video game scenario associated with the Biosymtic device "Cratus".

Name; Top Time (minutes, seconds, milliseconds); Your Time (minutes, seconds, milliseconds); Visual Instruction (demonstrating which direction to be taken in the racetrack); Game Scenario (e.g., "warm-up"); Heart rate / Angles and velocity of rotation.

While having access to real-time physiological and motor data, the child is encouraged to explore (regulate) her body's physiological processes in relation to the performed physical actions – relating her HR levels to motion intensity levels. A key objective of this process is to increase body literacy, including how the body's processes manifest themselves in relation to the surrounding physical environment.

Moreover, the system calculated the average HR values obtained throughout the game, including game scores, and displayed them at the end (time taken to cross each racetrack; "top time" obtained by a player on each racetrack)[104].

Figure 32 illustrates video game scenarios included in the Biosymtic device "Cratus".

4.6 Sample selection: inclusion and exclusion criteria

Participants were selected from an elementary school in Austin, Texas - ST. Andrew's Episcopal School. Twenty children (n=20) aged 6 to 8 years ($x = 7.3$, $\sigma = 0.7$) – male (n=9) and female (n=11) - attending an afterschool program one day per week. We opted to include typically developing children - not clinically restricted in terms of PA. Children taking medication or presenting any of the following conditions did not participate in this research study: anemia; anorexia; bulimia; cardiac symptoms; chest pain; exercise induced dizziness; high blood pressure; flu and pneumonia; respiratory diseases in nature; or any surgery performed last year.

4.7 Study design

Data collection was conducted in two phases.

The first phase concerned sample characterization. For each child the following independent variables were analyzed: age; gender; height (ft); weight (lb); Body Mass Index (BMI); and resting heart rate (HRrest).

The sample characterization phase comprised three sessions: study explanation session, morphological and physiological analysis sessions.

Study explanation session

In this session, the main researcher informed the child and its education representatives about the research goals and necessary procedures to participate in the study. The child and her legal guardians read and signed "Consent" and "Assent" forms – the authorization to participate in the study/child's interest in participating in the study. During this session the main researcher collected the following data: child's

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[104] A detailed description of this software program is presented on Appendix A.

date of birth, chronological age and gender; health conditions. This session lasted 60 minutes.

Morphological session

Height (ft) was measured with a standard measuring tape (fixed to a wall) - with the child with her back against the wall and without shoes. Weight (lb) was measured with a common scale - with the child wearing the least number of clothes possible and without shoes. BMI was analyzed through the "Quetelet index" - ratio between weight and square of height (W/H^2 - "W" corresponding to weight and "H" to height) (Quetelet, 1874).

Physiological session

During the physiological analysis session we measured the resting HR of each child using a HR monitor (Polar FT40®). Resting Heart Rate (HRrest) - number of HR beats in one minute at complete rest (Rowland & Bar-Or, 2004) was measured in a silent room during a 10-minute session with the child lying on a mat (two sessions of 60 minutes for the total sample).

The second phase concerned experimental procedures. There were two experimental stages: adaptation to the "Cratus" device; experimental stage.

Adaptation stage

In the adaptation stage children got familiarized with the device "Cratus" in the NE - five children per 60-minute session. The devices were introduced to the child by visually and verbally explaining the interaction techniques. Children played with the "Cratus" device (10 minutes per session) - interacting with the same video game narrative as later used in the experimental session - "Cratus Robot. The Time Traveller".

Experimental stage

In the experimental phase each child was evaluated in a single moment (once) and collaboratively (pairs) while interacting with the "Cratus" device in a natural forested landscape. Each child performed a single 12-minute session.

The following variables were evaluated during the experimental session:

- Physiological variables - maximum HR frequency (HRmax) and steady-state HR frequency (HRsteady-state) evaluated via the Polar FT40® HR monitor (transmitter fixed bellow the child chest, wirelessly communicating with a wrist unit);
- Metabolic intensity (METs) and energy expenditure (kCalories) evaluated through the SenseWear® Arm Band medical instrument (noninvasive instrument placed around the child's right upper arm that recorded data for later analysis in the SenseWear® professional software);

- Motor variables - steps taken (ST) also evaluated through the SenseWear® Arm Band medical instrument. The SenseWear®;
- Behavioral variables were collected before and after the activity (individual evaluation in a classroom context). The "motivation to play" variable was gathered immediately before and after the activity (child was asked if she was enthusiastic about playing the game before the activity, if she wanted to repeat the activity after playing). The variables "game quality" (child was asked if she enjoyed the game narrative), "usability" (child was asked if it was easy to interact with the "Cratus" device) and perceived exertion (levels of physical exertion perceived by the child after interacting with the device) were evaluted after interaction with the device.

The Smileyometer technique was used to collect expectations and opinions regarding the device. The Smileyometer is originally composed of five visual figures arranged in a line – smiley scale (1-5 Likert scale) - with different words associated to each ("Awful; Not very good; Good; Really good; Brilliant") (Read, 2008). We opted to change the associated words to "Not really; No; More or less; Yes; Very much". This change was made according with the postulated questions - "Are you enthusiastic about playing this game? Would you like to repeat it? Did you like the video game? Was it easy to play this game? Did you feel active while playing this game?"

4.8 Core elements of treatment conditions

The evaluating sessions were conducted between 3:30 PM and 4:30 PM (during spring).

Participants did not ingest food or participate in a PA program for the hour prior to the evaluation sessions.

All participants wore adequate and comfortable clothing for the evaluation sessions.

The main researcher conducted all the evaluation sessions with the support of a research assistant when available.

4.9 Measuring instruments

All the measuring instruments followingly described have scientific accreditation and have been validated and approved by international safety standards.

Measuring instruments for physiological and motor variables

The physiological variables HRrest, HRmax and HRsteady-state were evaluated through the Polar FT40® HR monitor. This system integrates two parts - the WearLink transmitter and the Wrist Unit. The WearLink transmitter (connected to an elastic strap) was fixed bellow the child chest near the sternum. The WearLink transmitter detects the HR frequency and transmits it to the Wrist Unit (via infrared sensor). The Wrist Unit displays and stores the data (including activity time).

HR monitoring is a validated noninvasive method to assess children's PA levels (e.g., Livingstone et al., 1992, 2000; Van den Berg-Emons, 1996).

Displayed HR frequency during the game was measured through the I-CubeX® Biobeat sensor[105]. This sensor measured the voltage on child's skin surface (bipolar voltage; range of 1-200 Hz with 50/60 Hz notch filter). The sensor was attached to a micro I/O board that communicated via Bluetooth class 2 with the computer placed on the "Cratus" device. The I-CubeX® HR sensor was fixed bellow the child chest near the heart via an elastic strap.

Metabolic intensity (METs), energy expenditure (kCalories) and Steps Taken (ST) were evaluated through the SenseWear® portable Arm Band medical instrument. This noninvasive device contains five sensors that evaluate metabolic and motor response in specific time intervals: skin temperature sensor; heat flux sensor; galvanic resistance sensor; a pedometer; and two accelerometers. It is constantly updated through the use of algorithms that compare income data to standard parameters in situations of rest and exercise (doubly labeled water methods with an intra class correlation of 0.8) (Fruin & Rankin, 2004; Johannsen et al., 2010).

The SenseWear® Arm Band unit communicates with the body through a wireless anti-allergic stainless steel monitor. Data is recorded for later analysis in the SenseWear® professional software. This device was validated in several scientific studies (e.g., Arvidsson et al., 2007, 2009). It allows for an accurate measure of energy expenditure levels and has been used in several studies to assess physical activity levels in children (e.g., Andreacci et al., 2006; Vorwerg et al., 2013).

4.10 Institutions and partners involved in this study

University of Texas at Austin (College of Education)
(http://www.utexas.edu/)

FCT/UNL – Faculdade de Ciências e Tecnologia/Nova Universidade de Lisboa
(http://www.fct.unl.pt/en)

BioSymtic Robotics
(https://www.facebook.com/BHRobot
http://biosymticrobotics.com)

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[105] http://infusionsystems.com/catalog/product_info.php/products_id/197

4.11 Statistical techniques

Statistical analysis was performed using the IBM Statistical Package for the Social Sciences version 21.0 for Mac. We will now describe the statistical techniques applied in the analysis of dependent and independent variables - characterization and experimental procedures.

Statistical techniques - characterization procedures

Sample characterization (n=20) was conducted through measures of central tendency (means - high frequency values), dispersion (standard deviation), extreme values (minimum and maximum values) and probability distribution (variance). The statistical techniques above were applied for the following variables: chronological age; morphological variables [height (ft), weight (lb) and BMI]; and physiological variables (HRrest).

Statistical techniques – experimental procedures

Measures of central tendency (means - high frequency values), dispersion (standard deviation), extreme values (minimum and maximum values) and probability distribution (variance) were applied for the following variables: physiological variables (METs; kCalories; HRmax; HRsteady-state) and motor variable (Steps Taken).

Correlation between morphological, physiological and motor variables was conducted through the *Shapiro-Wilk adherence to normality test* (*Lilliefors correction technique*) followed by the *Pearson correlation coefficient* (*r*) *test* (confidence interval of 95% and 99% - $p < 0.05$ and $p < 0.01$). In the absence of normal distribution we used the *Spearman's correlation coefficient test* (confidence interval of 95% and 99% - $p < 0.05$ and $p < 0.01$).

The behavioral variables (motivation to play; game quality; usability; perceived exertion) were examined through frequency analysis (percentage values).

In the following subchapters we will describe and discuss the statistical results obtained in this study.

4.12 Results

Statistical results - characterization procedures

The participants presented the following values for the morphological and physiological variables: height 4.1 (ft) ($\sigma = 0.3$); weight 55.5 (lb) ($\sigma = 9$); BMI 16.1 ($\sigma = 2.9$); HRrest 66.2 ($\sigma = 2.3$) (see table 10).

According to the American Academy of Pediatrics (2015), the previous BMI value is considered to be adequate for children aged 6 to 8 years - representing a healthy weight. This value is between the 5th and 85th percentiles (Body Mass Index-for-age percentiles).

Statistical results - experimental procedures

The participants presented the following physiological and motor values while interacting with the Biosymtic device "Cratus" in a natural forested landscape: metabolic intensity (METs) mean value of 8.1 ($\sigma = 1.4$); energy expenditure (kCalories) mean value of 56.8 ($\sigma = 7.6$); maximum HR frequency (HRmax) mean value of 190.6 ($\sigma = 10.4$); steady-state HR frequency (HRsteady-state) mean value of 150.9 ($\sigma = 9.9$); steps taken (ST) mean value of 1220 ($\sigma = 129.3$) (see table 11 and figure 33).

Statistical results - Morphological, physiological and motor variables correlation

We found the following significant correlations between morphological and physiological variables: a positive correlation between BMI and kCalories (r-value= 0.48; 0.030* for $p<0.05$).

We found the following significant correlations between physiological and motor variables: a positive correlation between METs and kCalories (r-value= 0.45; 0.042* for $p<0.05$) and METs and HRmax (r-value= 0.54; 0.014* for $p<0.05$); a positive correlation between kCalories and HRmax (r-value= 0.59; 0.006** for $p<0.01$) and kCalories and HRsteady-state (r-value= 0.77; 0.000** for $p<0.01$); a positive correlation HRmax and HRsteady-state (r-value= 0.49; 0.027* for $p<0.05$); and a positive correlation between HRsteady-state and ST (r-value= 0.48; 0.029* for $p<0.05$) (see table 12).

Statistical results - Behavioral variables

Motivation to play

All the participants were motivated to play with the Biosymtic device "Cratus" in the natural environment (natural forested landscape) (n=20 or 100% - "Very much" option in the Smyleiometer questionnaire) before the activity. After finishing the activity with the device, all children indicated that they wanted to repeat the activity (n=20 or 100% - "Very much" in the Smyleiometer). Even after the experimental phase, children were highly motivated to interact with the device - children mentioned that they wanted to play longer with "Cratus", to take the device home and that they would be very happy to have it in their school setting.

Game quality

All children enjoyed the video game narrative "Cratus Robot. The Space Traveller" (n=10 or 100% - "Very much" in the Smyleiometer). Children indicated that they enjoyed the fact that they could explore different scenarios and that "Cratus" was able to communicate with them. They wanted to beat the scores of previous players.

Morphological/Physiological variables (n=20)	**Mean**	**SD**	**Max**	**Min**	**Var**
Height (ft)	4.1	0.3	4.5	3.6	0.11
Weight (lb)	55.5	9	75.8	40.8	82
Body Mass Index (BMI)	16.1	2.9	21.4	10.2	8.5
Resting heart rate (RHR)	66.2	2.3	69	59	5.5

Table 10. Characterization procedures. Height (ft), Weight (lb), Body Mass Index (BMI) and Resting Heart Rate (RHR). Mean, standard deviation (SD), maximum (Max), minimum (Min) and probability distribution (Var - variance).

	Biosymtic (Biosymbiotic Robotic) device "Cratus" Natural environment (n=20)				
Physiological/Motor Variables	**Mean**	**SD**	**Max**	**Min**	**Var**
Metabolic Intensity (METs)	8.1	1.4	10.4	4.1	2.1
kCalories (kCal)	56.8	7.6	64	27	59.1
Maximum Heart Rate (HRmax)	190.6	10.4	200	155	109.1
Steady State Heart Rate (HRsteady-state)	150.9	9.9	162	116	98.3
Steps Taken (ST)	1220	129.3	1422	1029	16737.9

Table 11. Experimental results. Metabolic intensity – METs, kCalories (kCal), Maximum Heart Rate frequency (HRmax), Steady-state Heart Rate frequency (HRsteady-state) and Steps Taken (ST). Mean, standard deviation (SD), maximum (Max), minimum (Min) and probability distribution (Var - variance).

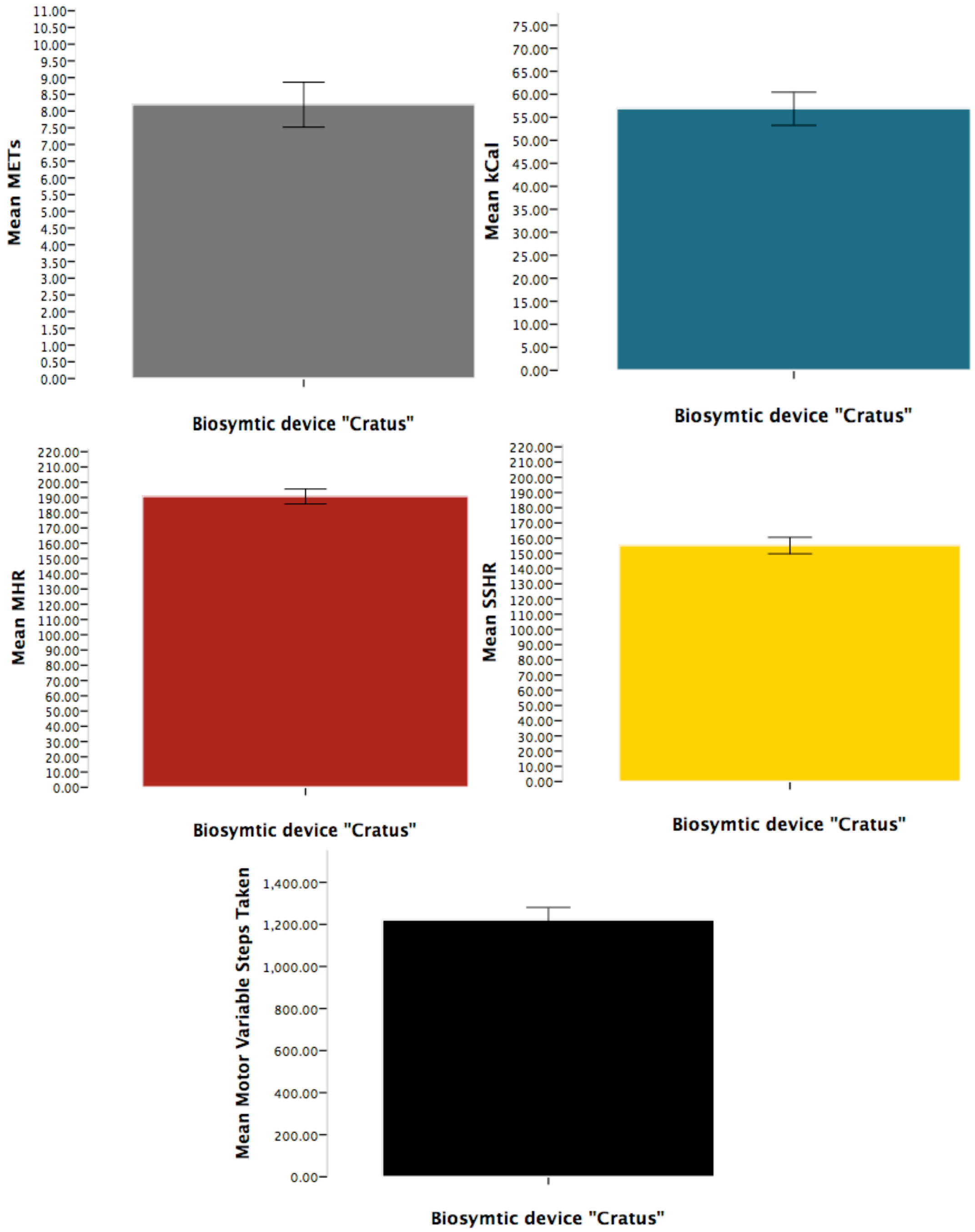

Fig. 33.

Experimental results. Interaction with the Biosymtic device “Cratus” in a natural environment (natural forested landscape). Mean average physiological and motor results.

Top-left figure: Metabolic intensity – METs [low intensity or rest (inferior to 3 METs); moderate intensity (3 to 5,9 METs); vigorous intensity (6 to 8,9 METs); and very vigorous intensity (equal or superior to 9 METs)];

Top-right figure: kCalories (kCal) (0 to 75 kCal);

Middle-left figure: Maximum Heart Rate frequency (HRmax) (0 to 220 beats per minute);

Middle-right figure: Steady-state Heart Rate frequency (HRsteady-state) (0 to 220 beats per minute);

Bottom-figure: Steps Taken (0 to 1400 steps)

Morphological Physiological/ Motor Variables	Metabolic Intensity (METs)	kCalories (kCal)	Maximum Heart Rate (HRmax)	Steady-State Heart Rate (HRsteady-state)	Steps Taken (ST)
Body Mass Index (BMI)	0.659 (r = 0.10)	0.030* (r = 0.48)	0.531 (r = 0.14)	0.123 (r = 0.35)	0.054 (r = 0.43)
Metabolic Intensity (METs)		0.042* (r = 0.45)	0.014* (r = 0.54)	0.098 (r = 0.38)	0.662 (r = 0.10)
kCalories (kCal)			0.006** (r = 0.59)	0.000** (r = 0.77)	0.085 (r = 0.39)
Maximum Heart Rate (HRmax)				0.027* (r = 0.49)	0.205 (r = 0.29)
Steady-State Heart Rate (HRsteady-state)					0.029* (r = 0.48)
Steps Taken (ST)					

Table 12. Experimental results. Morphological, physiological and motor variables correlation. Body Mass Index (BMI); Metabolic intensity (METs); kCalories (kCal); Maximum Heart Rate frequency (HRmax); Steady-state Heart Rate frequency (HRsteady-state); Steps Taken (ST).

Usability

Most participants considered that it was easy to interact with the device “Cratus” (n=18 or 90% - “Very much” in the Smyleiometer questionnaire; n=2 or 10% - “Yes” in the Smyleiometer questionnaire). Two children mentioned that sometimes the device “Cratus” fell to the floor and that this behavior should be avoided as it was making them lose points.

Perceived exertion

Fifteen participants considered that they had been “Very much” physically active while playing with the device “Cratus” (n=15 or 75%). Four participants mentioned that they were physically active while playing with the device “Cratus” (n=4 or 20% - “Yes” in the Smyleiometer). One participant indicated that he had been “More or less” active while playing with the device “Cratus” (n=1 or 5%).

Results concerning behavioral variables are summarized on table 13.

In the following subchapters we will discuss the statistical results obtained in this study followed by conclusions.

Behavioral Variables						
Smyleiometer Technique		Not really! Nu; %	No Nu; %	More or less Nu; %	Yes Nu;%	Very much! Nu;%
Motivation to Play	Are you enthusiastic about playing this game?	0;0%	0;0%	0;0%	0;0%	20;100%
	Would you like to repeat it?	0;0%	0;0%	0;0%	0;0%	20;100%
Game Quality	Did you like the video game?	0;0%	0;0%	0;0%	0;0%	20;100%
Usability	Was it easy to play this game?	0;0%	0;0%	0;0%	2;10%	18;90%
Perceived Exertion	Did you feel active while playing this game?	0;0%	0;0%	1;5%	4;20%	15;75%

Table 13. Experimental results. Behavioral variables. Motivation to play, Game quality, Usability and Perceived exertion. Frequencies and Percentagens.

4.13 Discussion

From the obtained results we observed that interacting with the Biosymtic device "Cratus", in a natural environment, instilled vigorous PA levels in the evaluated children ($x = 8.1$, $\sigma = 1.4$).

As previously mentioned, PA comprising moderate to vigorous intensity levels benefits children's physical health. In addition, aerobic-based PA at moderate-intense levels seems to be the gold standard to optimize cognitive function and boost cognitive structure in children. Since interacting with the Biosymtic device "Cratus", in a natural environment, instilled vigorous PA in the evaluated children, it seems that this device and associated environment are a suitable solution to promote physical and mental health.

While interacting with the biosymtic device "Cratus", in a natural environment, children spent an average of 56.8 ($\sigma = 7.6$) kCalories during 12 minutes – an average of 4.7 kCal/min.

As previously mentioned, already in 2001, children were spending 600 calories less every day compared to the last five decades. Nowadays, levels of energy expenditure are still insufficient in order to benefit children's health. The "Surgeon General's Report on Physical Activity and Health" recommends a daily practice of PA - providing expenditure rates of at least of 150 calories in order to yield health benefits. We speculate that it would be necessary for children to interact for approximately 36 minutes with the "Cratus" device in order to achieve the expenditure rates recommended by the "Surgeon General's Report on Physical Activity and Health".

Although we have conducted only a single evaluation moment in this study - 12-minutes - we observed that after the experimental phase children were highly motivated to interact with the "Cratus" device - n=20 or 100% ("Very much" option in the Smyleiometer questionnaire). Children mentioned that they wanted to play longer with "Cratus", to take the device home and that they would be very happy to have it in their school setting.

Despite the fact that children were highly motivated to interact with "Cratus", future studies need to be developed in order to find evidence suggesting long-term spontaneous adherence to this type of device.

In addition, children showed a HRmax mean value of 190.6 ($\sigma = 10.4$) and a HRss mean value of 150.9 ($\sigma = 9.9$). We observed that 19 children achieved the reference (desired) interval of HR values (moderate-intense PA intensities) - between 50% and 85% of maximum HR values (recommended by the American Heart Association), instilled by the automatic feedback control mechanism.

In order to benefit the development of the cardiorespiratory system, children aged 6 to 14 years should practice aerobic exercise tasks comprising levels of oxygen consumption between 60% to 80% of its maximum capacity - HR values should not exceed 70% to 85% of its maximum (Bar-Or, 1983; Rowland & Bar-Or, 2004).

Therefore, the Biosymtic device "Cratus" may benefit the development of the cardiorespiratory system as it instilled values between 50% and 85% of maximum HR in the evaluated children.

Furthermore, as previously mentioned, MVPA improves cognitive function and boosts cognitive function in children. Therefore, the Biosymtic device "Cratus" may also benefit cognition in children.

We found a moderate positive correlation between BMI and kCalories. Previous studies have demonstrated that BMI has a moderate positive correlation with energy expenditure (kCalories) in children (e.g., Bandini et al., 2003; Maffeis et al., 1996).

We also found a moderate positive correlation between METs and kCalories, and METs and HRmax. That is, increases in metabolic intensity (METs) levels were linked to increases in energy expenditure (kCalories). On the other hand, increases in HRmax were linked to increases in metabolic intensity (METs). Specifically, increases in stress to the cardiorespiratory system were linked to increases in metabolic intensity, which in turn triggered increases in energy expenditure. As previously mentioned, high HR frequency correlates with high levels of PA; low HR frequency correlates to low levels of PA.

In addition, we found a strong positive correlation between kCalories and HRmax, and kCalories and HRss. That is, increases in HRmax and HRss were linked to increases in energy expenditure (kCalories). We also observed a moderate positive correlation between HRmax and HRss, and also between HRss and Steps Taken (ST).

According to Livingstone (1997), HR frequency exhibits a positive correlation with energy expenditure rates. The fact that there was a positive correlation between HRmax and HRss reveals that this activity was a demanding one for children, as HR values increased linearly with increases in the intensity of the physical activity.

According to Montoye et al. (1996), physical activity levels can be expressed in counts (steps taken), representing units of movement. In this case, increases in the number of steps taken was linked to increases in stress caused to the cardiovascular system - HRss - which in turn was associated with increases in energy expenditure (kCalories).

The previously observed correlations demonstrate that interacting with the Biosymtic device "Cratus", in a natural environment, increased the stress caused to the cardiovascular system. In turn, increases in stress to the cardiovascular system were linked to increases in metabolic intensity (METs) and energy expenditure (kCalories) levels in the evaluated children.

As previously mentioned, HR values tend to be higher if the produced mechanical work includes gross motor skills. The use of equipment and large spatial areas seem to increase children's physical activity levels.

Inputs to the Biosymtic device "Cratus" (to control virtual information) were made through whole-body physical action, for instance, the child could push, pull, rotate and throw the apparatus while walking, running, jumping or trotting on the physical terrain. Furthermore, while generating force against a resistance - the apparatus - the child was encouraged to perform muscular strength exercise. The use of large muscular groups (gross motor skills) in a large spatial area - natural environment - was possibly associated with increases in HR values and thus energy expenditure levels in the evaluated children.

HR frequency may vary due to emotional states or degree of excitement caused by the activity. HR values in children and adults increase in situations of excitability or fear: it may increase 20-40 BPM above the actual resting value (even in situations of moderate intensity).

HR values and energy expenditure levels may also have increased due to the fact that children were highly motivated to interact with the "Cratus" device, in the natural environment – mentioning they were highly motivated to interact with the device before and after the activity (n=20 or 100%; "Very much" option in the Smyleiometer questionnaire). Children were bewildered when they first saw "Cratus", expressing excitement, for example: "Uau!", "The robot is so cool!". One child stated: "We finally have real robots to play! They are always in the movies".

Another factor that may have increased HR values/energy expenditure levels was the natural environment itself - evaluations were conducted during spring in hot temperatures. PA in hot or humid climates tends to increase HR values (15 to 20 BPM higher than in neutral climates).

The previous arguments demonstrate that use of equipment encouraging whole-body physical action in natural environments, seems to represent an advantage where increases in children's physical activity are concerned.

Thus far, and to our knowledge, there are no references to studies on robotic systems evaluating physical activity in children for us to compare the obtained results. Nevertheless, we can compare our system to the current AVGs.

As previously stated, recent research indicates that AVGs, in indoor settings, are not promoting the recommended 60 minutes of MVPA, in children, in order to benefit health. In addition, researchers have been arguing that AVGs are not a substitute for physical activity in natural environments. Furthermore, there is a lack of evidence suggesting long-term spontaneous adherence to AVGs. Paradoxically, there has been a growing use of AVGs in physical education classes (Hansen & Sanders, 2010).

On the other hand, while interacting with the Biosymtic device "Cratus", in a natural environment, children may achieve vigorous physical activity and moderate-intense HR frequency levels, while they benefit from what natural environments have to offer.

It has been mentioned that physical education classes, in schools (organized PA), should contribute to high rates of energy expenditure to yield health benefits in children. Recommendations call for MVPA for at least half of the sessions (Center for Disease Control and Prevention, 2010; Ridgers et al., 2005). However, physical education classes and recess programs (spontaneous PA), in elementary schools, are not promoting the necessary MVPA levels (Stratton, 2005; UCLA Center to Eliminate Health Disparities and Samuels & Associates, 2007). In fact, recess programs contribute 16.3% to 16.9% of the necessary daily energy expenditure. Several studies have reported that children in elementary years devote 9% to 42% of their daily activities to MVPA (Cardon et al., 2004; Datar & Sturm, 2004; Parrish et al., 2013; Pate et al., 2011; Ridgers et al., 2007, 2013; Simons-Morton et al., 1994).

A longitudinal study (data collected from 1980 to 2001), including 1563 individuals aged 3 to 19 years, concluded that frequent practice of PA, while young, positively correlates with the practice of PA in adulthood (Telama et al, 2005; Twisk et al., 1997). Thus, it becomes essential to develop strategies to encourage children to practice physical activities that produce noteworthy energy expenditure (MVPA levels) in order to promote healthy lifestyles.

The biosymtic device "Cratus" may help children increase their daily energy expenditure and contribute to a healthy lifestyle. For instance, this type of device could be included in physical education classes (outdoors) and recess programs.

Furthermore, all children enjoyed the video game narrative "Cratus Robot. The Space Traveller" - n=10 or 100% ("Very much" in the Smyleiometer). Children indicated that they enjoyed the fact that they could explore different scenarios and that "Cratus" was able to communicate with them. They wanted to beat the scores of previous players.

In fact, children considered "Cratus" as a human, assuming he was a real friend. Although "Cratus" was endowed with a reduced number of verbal commands, it was enough for children to establish communication with the system. For instance, one child after "Cratus" issued the command "Turn right!" answered back - "Ok 'Cratus'! I get it!". A few children spoke to the robot "Where should I go now?/You must know I need to go faster so I can beat him".

Robots that communicate with children through verbal and/or non-verbal cues are considered social robots.

Breazeal (2000; 2002; 2008) is a pioneer researcher on the development of social robots. Her research is focused on understanding the social relations between humans and robots. Breazeal states that aspects such as appearance, eye contact, look-at-behavior and speech (production and recognition), in robots, tend to be critical in human-robot interaction.

In a recent study, Tung & Chang (2013:237) observed that "Children perceive robots (…) more socially and physically attractive when they exhibit sufficient social cues. Specifically, the display of social cues by robots that are less anthropomorphic can significantly enhance children's social perceptions of them (…) robots designed for children do not require excessively human-like designs. Middle- to low-level anthropomorphic designs combined with appropriate social cues can enhance children preferences and acceptance of robots".

In a study comprising 198 children aged 5 to 16 years, Beran et al. (2011:539) observed that children ascribe cognitive, behavioral and affective features to robots. The results achieved by Beran et al. have also been supported by other studies (Latitude^{0}, 2012).

The physical structure of the Biosymtic device "Cratus" consists of a head, connected to a torso, integrating a wheel mechanism on its base – mimics a Roman gladiator/inventor. It does not have arms or legs (less anthropomorphic form), however, children attributed "Cratus" social and communication skills – in accordance to Tung & Chang. Interestingly, children even projected themselves into the device/character, e.g., "I was 'Cratus'. My heart was his" – referring to the visualized heart rate data; "I run faster and so does 'Cratus'. We are the soldier!". In fact, a few children could relate their actions to their physiological response.

Furthermore, the movement produced on the video game scenario allowed children to understand spatial directions. For example: "Cratus was turning, and turning so fast to the left, and sometimes to the right!"; "I made Cratus rotate 360 degrees".

Moreover, most participants considered easy to interact with "Cratus" (n=18 or 90% - "Very much" in the Smyleiometer; n=2 or 10% - "Yes" in the Smyleiometer). Two children mentioned that sometimes the device "Cratus" fell to the floor and that this behavior should be avoided as it was making them lose points. In future work we will need to correct the ergonomical features of the device.

Fifteen participants considered that they were "Very much" physically active while playing with the device "Cratus" (n=15 or 75%). Four participants mentioned they were physically active while playing with the device "Cratus" (n=4 or 20% - "Yes" in the Smyleiometer questionnaire). One participant indicated that he was "More or less" active while playing with the device "Cratus" (n=1 or 5%). These results demonstrate that most children considered being physically active while interacting with the device.

4.14 Conclusions

Results indicate that interaction with the Biosymtic device "Cratus", in a natural environment (natural forested landscape), instilled vigorous physical activity levels in children. Children were highly motivated to interact with the Biosymtic device "Cratus". The Biosymtic device "Cratus" and natural environment are a promissing solution to promote children's physical and mental health.

The current Child-Computer Interaction and Child-Robot Interaction paradigms – interaction with screen-based computer devices (including AVGs) and robotic systems in artificially environments – are associated with sedentary behavior and seem not to be potentiating children's physical and mental health.

In order to increase physical activity levels and benefit physical and mental health, we submit to the educational and scientific communities that children should be encouraged to perform activities in large spatial areas such as natural environments that offer variation of climatic conditions. As the use of equipment may increase physical activity levels, children should be encouraged to interact with user interfaces that promote the use of gross motor skills. Furthermore, since situations of excitability or fear may increase children's heart rate values, video game play seems to be an optimal solution to raise physical activity levels.

We suggest that there is an urgent need to bring children back into natural environments. We ask the educational and scientific communities to assume this challenge and, most of all, to contribute to a definition of what a healthy lifestyle means for children.

4.15 Limitations and future work

One of the main limitations of this study concerns its methodology - the evaluations were performed on a single experimental moment and were not repeated successively in order to validate the results. Hence, it is necessary to develop full-scale research studies (comprising large samples) in order to confirm the obtained results (including long-term spontaneous adherence to the device).

In future work we will endeavor to understand the role of different types of environment and the Biosymtic device “Cratus” on children’s physiological and cognitive functions. We will also demonstrate how children can build autonomous functions into the device. At the same time, we will demonstrate how different challenging physical environments contribute to the enhancement of the human evolutionary condition.

5

General Conclusions and Future Work

In the present work we have demonstrated that the current Child-Computer Interaction paradigm is not potentiating human development to its fullest – it is associated with several physical and mental health problems and appears not to be maximizing children's cognitive performance and cognitive development.

In order to potentiate children's physical and mental health (including cognitive performance and cognitive development) we have developed a new approach to human development and evolution. This approach proposes a particular synergy between the developing human body, computing machines and natural environments. It emphasizes that children should be encouraged to interact with challenging physical environments offering multiple possibilities for sensory stimulation and increasing physical and mental stress to the organism.

We created and tested a new set of computing devices in order to operationalize our approach - Biosymtic (Biosymbiotic Robotic) devices: "Albert" and "Cratus".

In two initial studies we were able to observe that the main goal of our approach is being achieved. We observed that, interaction with the Biosymtic device "Albert", in a natural environment, managed to trigger a different neurophysiological response (increases in sustained attention levels) and tended to optimize episodic memory performance in children, compared to interaction with a sedentary screen-based computing device, in an artificially controlled environment (indoors) - thus a promising solution to promote cognitive performance/development; and that interaction with the Biosymtic device "Cratus", in a natural environment, instilled vigorous physical activity levels in children - thus a promising solution to promote physical and mental health.

The results achieved in the previous studies are starting to demonstrate that the current Child-Computer Interaction paradigm may be failing the goal of optimizing physical and mental health in children, including cognitive performance and cognitive development.

We may have to rethink the current educational paradigm associated with child learning through computing devices.

We suggest that there is an urgent need to bring children back into natural environments. We ask the educational and scientific communities to assume this challenge and, most of all, to contribute to a definition of what a healthy lifestyle means for children.

It is not by chance that Biosymtic devices encourage children to explore physical environments through whole-body physical action - encouraging the child to engage in a process of biological self-discovery in relation to the physical environment. In fact, the educational paradigm that we are offering our children is already a glimpse of future of Space exploration, or, a preparation for human development in off Earth environments - potentiating adaptive plasticity.

We also suggested that it is necessary to expose the developing human body to physical and mental stress, in a diversity of challenging physical environments (besides Earth), not only to extend our possibilities for survival in, but also create new formats to understand the surrounding Universe. We decided to employ a metaphor to describe this idea - "The Echo of the Universe".

We argued that the ultimate human-machine symbiosis is the one that will push the boundaries of our biological existence – enhancing our biological connection with the surrounding physical environment and supporting the next evolutionary stages.

Our concept of health is not restricted to the perpetuation of life in terrestrial environments. It includes the survival and transformation of human beings – human biology - in Space environments. We will not be able to express "well-being" if we are not capable of surviving a universe in constant mutation.

Impelling human beings into highly sedentary biological machines may be a failure for human survival possibilities, compromise human species expansion into new cosmic pathways and an obstruction to new biological possibilities.

The present work concerns to "A Biosymtic Approach to Human Development and Evolution. The Echo of the Universe". In future work we will continue validating the obtained results. We will also improve our inventions – Biosymtic device "Albert" and "Cratus" – and start developing new devices that may serve the goal of potentiating human development and evolution.

Many new ideas have emerged from this work. One such idea is a new approach to human development in Space environments through technological enhancement. We propose to develop work in this field that may ultimately generate some useful ideas on how to achieve such a goal.

In a universe in constant mutation, maintaining biological adaptability is the core goal of the human species.

6

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Appendix A

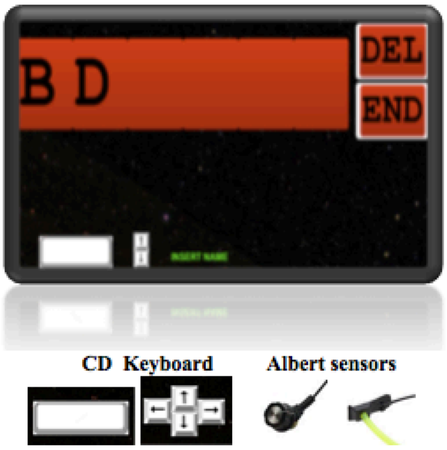
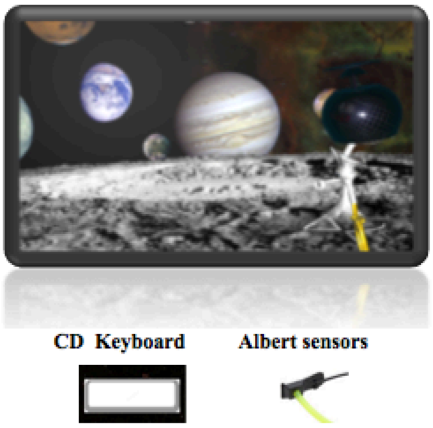
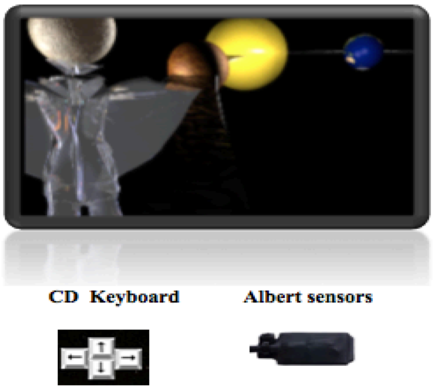
VIDEO GAME SOFTWARE "VANKALO. THE SEDENTARY CYBORG"

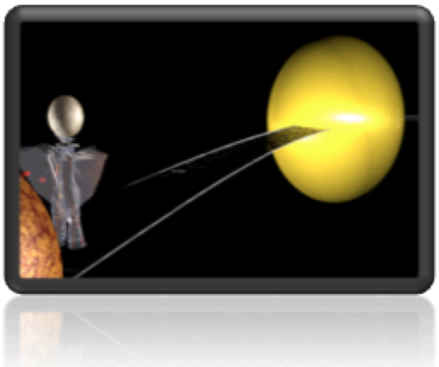
In this video game the child engages an adventure through the solar system. "Vankalo. The Sedentary Cyborg", tries to steal our solar system's planets, condensing them into micro-particles and placing them inside his "H_2O aquarium head". The child's goal is to put an end to "Vankalo's" plan by creating a new homeostasis in the solar system. The child assumes different avatars throughout the narrative, e.g., "Moon", "Albert" and "Water mutants". In this video game children are encouraged to learn about the solar system.

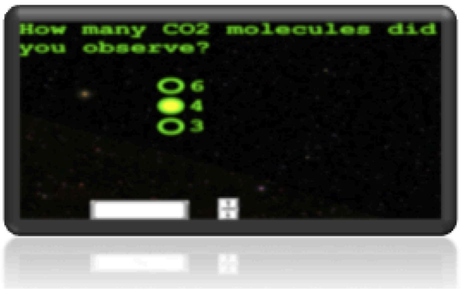
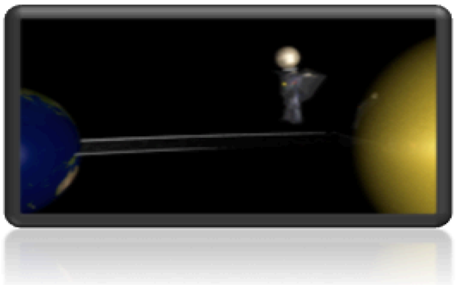
BIOSYMTIC DEVICE ALBERT/TRADITIONAL SCREEN-BASED COMPUTER DEVICE CLOSED NARRATIVE

In the closed narrative the child follows a predetermined sequence of video game scenarios (starting on the Moon, going to the Sun and finishing in Neptune). The child receives visual and verbal instructions throughout the video game (goals to accomplish, location in the game; sensors to use; "keys" to use in each game scenario). While using the Biosymtic device "Albert", the child is encouraged to achieve moderate physical activity levels, through an automatic feedback control mechanism. While using the traditional screen-based computer device, the child is encouraged to maintain the displacement of the avatar at moderate levels via an automatic feedback control mechanism. The child is presented with multiple-choice questions between the game chapters.

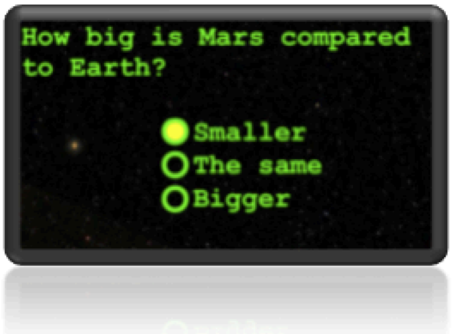
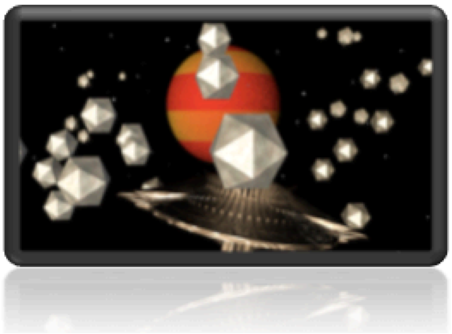
The child has to move through the video game scenarios in order to score - scores automatically after accomplishing each game scenario (e.g., Venus, Mars, Saturn, etc.; from 0 to 21 points according to the game scenario difficulty; total game score 56 points). The child also scores if she is able to answer the multiple-choice questions at the end of each game chapter (from Moon to Venus; from Venus to Earth; from Earth to Mars; from Mars to Saturn; from Saturn to Neptune) – five questions presented at the end of each game chapter, each with three answer choices (for each correct/incorrect answer the child gained 3 or 0 points respectively; total game score regarding episodic memory between 0 and 15 points). The presented multiple-choice questions in the Biosymtic device "Albert" are different from those in the traditional screen-based computer device.

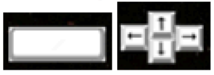
Scenario	**Visual Scenario**	**Task/Instruction** **Sensor/key** **(Game action)**
01 **Name/Age input**		**Task/Instruction** Name and age input/ "Insert name; Insert age" **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** - "Arrow pad" letters/numbers selection; - "Space key" letter input. **Biosymtic device "Albert"** - "Turn button sensor" letters/numbers selection; - "Airflow sensor" letters/numbers input.
02 **MOON**		**Task/Instruction** Child makes "Moon" avatar born/ "You're in the Moon. Bring the 'Moon' character to life!" **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Space key" game action input. **Biosymtic device "Albert"** "Airflow sensor" game action input.
03 **From SUN to MERCURY**		**Task/Instruction** Child makes "Moon" avatar move forward/ "You're in the Sun. Go, and jump over Mercury" **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Arrow pad" game action input. **Biosymtic device "Albert"** "Accelerometer, gyroscope and tilt sensor" game action input.

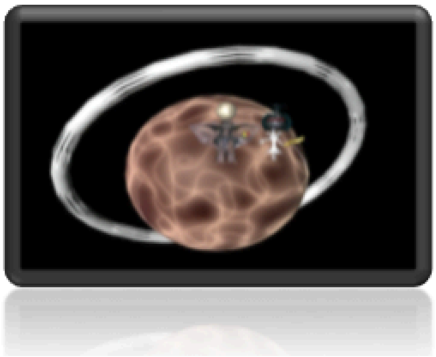
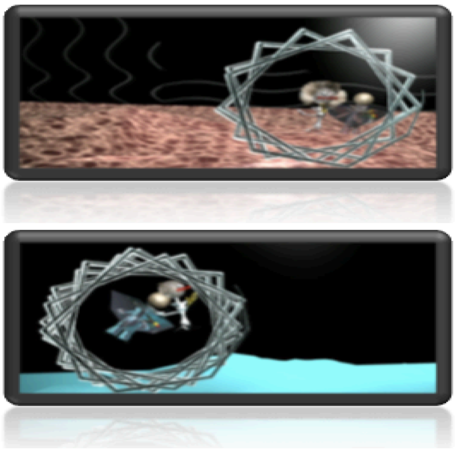
Scenario	**Visual Scenario**	**Task/Instruction** **Sensor/key** **(Game action)**
04 **Jumping over MERCURY**	 **CD Keyboard** **Albert sensors**  	**Task/Instruction** Child makes “Moon” avatar jump over Mercury (one jump)/ “Jump over planet Mercury!” **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** “Space key” game action input. **Biosymtic device “Albert”** “Accelerometer, gyroscope and tilt sensor” game action input.
05 **From MERCURY to VENUS**	 **CD Keyboard** **Albert sensors**  	**Task/Instruction** Child makes “Moon” avatar move forward/ “ Go to Venus” **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** “Arrow pad” game action input. **Biosymtic device “Albert”** “Accelerometer, gyroscope and tilt sensor” game action input.
06 **VENUS**	 **CD Keyboard** **Albert sensors**  	**Task/Instruction** Child makes “Moon” avatar move from right to left to catch four CO_2 molecules present in the atmosphere of Venus/ “Catch the CO_2 molecules in Venus!” **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** “Arrow pad” game action input. **Biosymtic device “Albert”** “Accelerometer, gyroscope and tilt sensor” game action input.

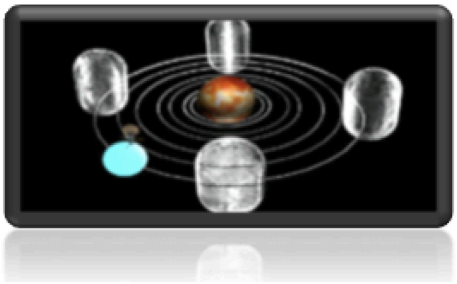
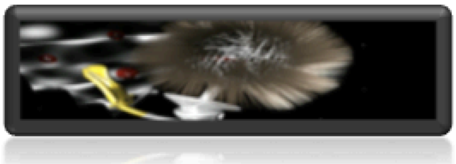
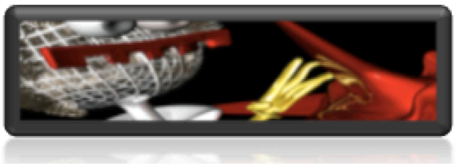
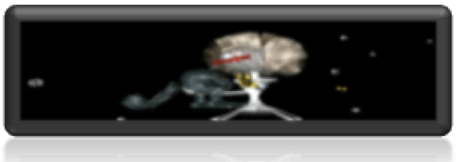
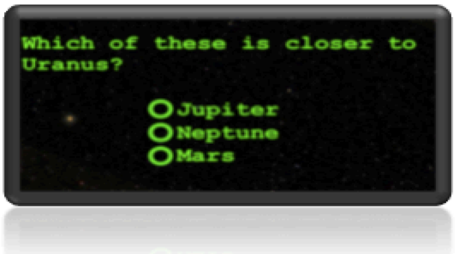
Scenario	Visual Scenario	Task/Instruction Sensor/key (Game action)
07 Multiple-choice Question 1	 How many CO2 molecules did you observe? ○ 6 ● 4 ○ 3 CD Keyboard Albert sensors  	**Task/Instruction** Child answers to multiple-choice question 1 **Traditional screen-based computer device (CD)** How many planets did you cross after the Sun? 1/2/0 **Biosymtic device "Albert"** How may CO_2 molecules did you observe? 6/4/3 **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Arrow pad" answer selection; "Space key" answer input. **Biosymtic device "Albert"** "Turn button" answer selection; "Airflow sensor" answer input.
08 From VENUS to EARTH	 CD Keyboard Albert sensors  	**Task/Instruction** Child makes "Moon" avatar jump twice/ "Jump and move to planet Earth!" **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Space key" game action input. **Biosymtic device "Albert"** "Accelerometer, gyroscope and tilt sensor" game action input.
09 EARTH	 CD Keyboard Albert sensors  	**Task/Instruction** Child makes "Moon" spin right and left in order to make the planet Earth rotate (Earth rotation movement)/ "One rotation corresponds to one day on planet Earth, the blue planet. Make planet Earth, the blue planet, rotate '2+2' times to the right; Make planet Earth, the blue planet, rotate '2+2' times to the left"). **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Arrow pad" game action input. **Biosymtic device "Albert"** "Accelerometer, gyroscope and tilt sensor" game action input.

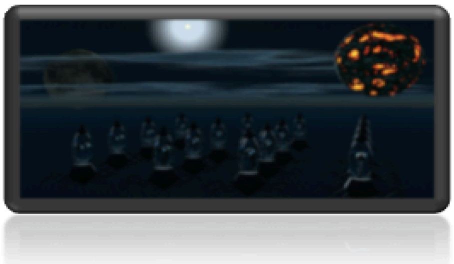
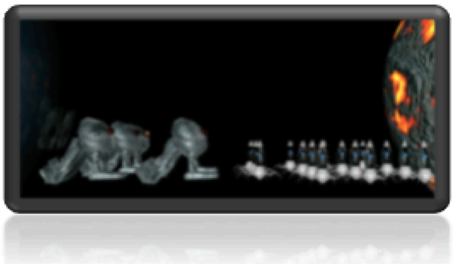
Scenario	Visual Scenario	Task/Instruction Sensor/key (Game action)
10 **Multiple-choice Question 2**	 Do they call this the blue planet? ○Maybe ○No ○Yes **CD Keyboard** **Albert sensors** 	**Task/Instruction** Child answers to multiple-choice question 2 **Traditional screen-based computer device (CD)** Do they call this the blue planet? Maybe/No/Yes **Biosymtic device "Albert"** Do they call this planet Venus? Yes/Maybe/No **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Arrow pad" answer selection; "Space key" answer input. **Biosymtic device "Albert"** "Turn button" answer selection; "Airflow sensor" answer input.
11 **From EARTH to MARS**	 **CD Keyboard** **Albert sensors** 	**Task/Instruction** Child makes "Moon" avatar move right/ "Fly to planet MARS!" **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Arrow pad" game action input. **Biosymtic device "Albert"** "Accelerometer, gyroscope and tilt sensor" game action input.
12 **MARS**	 **CD Keyboard** **Albert sensors** 	**Task/Instruction** Child makes trees grow/ "Help Albert create trees in Mars, to produce oxygen molecules and send it to Earth" **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Space key" game action input. **Biosymtic device "Albert"** "Airflow sensor" game action input.

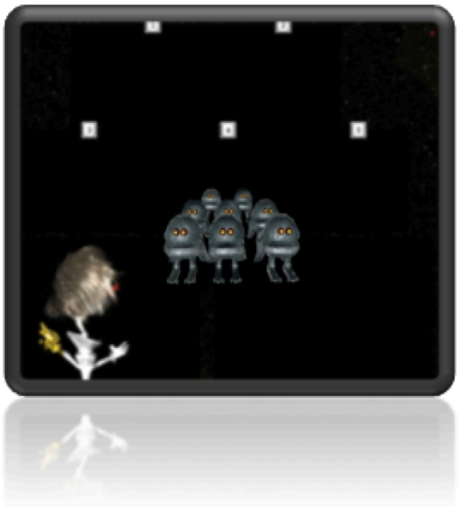
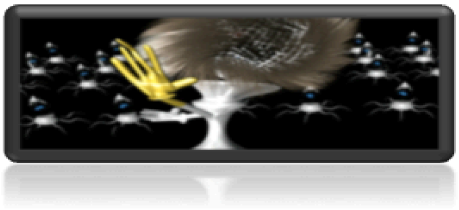
Scenario	Visual Scenario	Task/Instruction Sensor/key (Game action)
13 **From MARS to the SPACESHIP AEROBIAN** **O_2<-> CO_2**	 **CD Keyboard** **Albert sensors**  	**Task/Instruction** Child makes “Moon” and “Albert” move from right to left in between the trees/ “Catch the trees you have created and carry them to the Aerobian O_2<-> CO_2 spaceship to send them to Earth!” **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** “Arrow pad” game action input. **Biosymtic device “Albert”** “Accelerometer, gyroscope and tilt sensor” game action input.
14 **Multiple-choice Question 3**	 How big is Mars compared to Earth? ● Smaller ○ The same ○ Bigger **CD Keyboard** **Albert sensors**    	**Task/Instruction** Child answers to multiple-choice question 3 **Traditional screen-based computer device (CD)** Was there any oxygen before you planted Trees? No/Yes/Maybe **Biosymtic device “Albert”** How big is Mars compared to Earth? Smaller/The same/Bigger **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** “Arrow pad” answer selection; “Space key” answer input. **Biosymtic device “Albert”** “Turn button” answer selection;
15 **From MARS to JUPITER**	 **CD Keyboard** **Albert sensors**  	**Task/Instruction** Child makes the Aerobian O_2<-> CO_2 spaceship move forward in between meteorites/ “Fly to Jupiter! Watch out the meteorites!” **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** “Arrow pad” game action input. **Biosymtic device “Albert”** “Accelerometer, gyroscope and tilt sensor” game action input.

Scenario	Visual Scenario	Task/Instruction Sensor/key (Game action)
16 **JUPITER**	 **CD Keyboard** **Albert sensors**  	**Task/Instruction** Child makes "Albert" move forward/ "Cross the gaseous atmosphere of planet Jupiter!" **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Arrow pad" game action input. **Biosymtic device "Albert"** "Accelerometer, gyroscope and tilt sensor" game action input.
17 **JUPITER CHALLENGE**	 **CD Keyboard** **Albert sensors**  	**Task/Instruction** Child is asked to put the planets in order in 40 seconds, according to the game scenarios experienced previously - Mercury, Venus, Earth, Mars and Jupiter/ "Remember the planets crossed after the sun. Put the planets in order. Which planet follows the sun?" **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Arrow pad" planet selection; "Space key" planet input. **Biosymtic device "Albert"** "Turn button" planet selection; "Airflow sensor" planet input.
18 **From JUPITER to SATURN**	 **CD Keyboard** **Albert sensors**  	**Task/Instruction** Child makes "Moon" move forward to Saturn/ "Go to planet Saturn!" **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Arrow pad" game action input. **Biosymtic device "Albert"** "Accelerometer, gyroscope and tilt sensor" game action input.

Scenario	Visual Scenario	Task/Instruction Sensor/key (Game action)
19 **SATURN**	 **CD Keyboard** **Albert sensors** 	**Task/Instruction** Child makes "Moon" and "Albert" jump over the Saturn ring"/ "Jump over the Saturn ring 2+2 times; 6+2; 10 - 4 times; etc" **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Arrow pad" and "Space key" simultaneously. **Biosymtic device "Albert"** - "Accelerometer, gyroscope and tilt sensor" and "Airflow sensor" simultaneously.
20 **Multiple-choice Question 4**	 Does Saturn have a ring? ○ Yes ○ No ○ Maybe **CD Keyboard** **Albert sensors** 	**Task/Instruction** Child answers to multiple-choice question 4 **Traditional screen-based computer device (CD)** Does Saturn has a ring? Yes/No/Maybe **Biosymtic device "Albert"** You jumped over… 3, 1 or 5 rings in Saturn? **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Arrow pad" answer selection; "Space key" answer input. **Biosymtic device "Albert"** "Turn button" answer selection; "Airflow sensor" answer input.
21 **Space-time traveling to URANUS**	 **CD Keyboard** **Albert sensors** 	**Task/Instruction** Child makes "Moon" and "Albert rotate through the space-time portals/ "Go through the space-time portals, rotate to arrive to planet Uranus!" **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Arrow pad" game action input. **Biosymtic device "Albert"** "Accelerometer, gyroscope and tilt sensor" game action input.

Scenario	**Visual Scenario**	**Task/Instruction** **Sensor/key** **(Game action)**
22 **URANUS** **Task/Instruction** **First space-time capsule: touch a cosmic tree** **Second space-time capsule: touch a cosmic satellites** **Third space-time capsule: hug a water mutant friend** **Fourth space-time capsule: hug a tree**	     **CD Keyboard Albert sensors** 	**Task/Instruction** Child makes "Albert" move on the top of the planet Uranus – performing an orbit around the Sun, while passing through four space-time capsules; first capsule action - touch a cosmic tree; second capsule action - touch a cosmic satelitte; third space-time capsule – hug a water mutant friend; fourth space-time capsule - hug a tree/ "Make Uranus perform a complete orbit around the Sun. Create a circle. What mystery lies inside the space-time capsules?" **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Arrow pad" move game action input; "Space key" touch game action input. **Biosymtic device "Albert"** "Accelerometer, gyroscope and tilt sensor" game action input; "Touchglove sensor" game action input.
23 **Multiple-choice Question 5**	 Which of these is closer to Uranus? ○Jupiter ○Neptune ○Mars **CD Keyboard Albert sensors** 	**Task/Instruction** Child answers to multiple-choice question 5 **Traditional screen-based computer device (CD)** Where were you before crossing Uranus? Earth/Jupiter/Saturn **Biosymtic device "Albert"** Which of these planets is closer to Uranus? Jupiter/Neptune/Mars **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Arrow pad" answer selection; "Space key" answer input. **Biosymtic device "Albert"** "Turn button" answer selection; "Airflow sensor" answer input.

Scenario	Visual Scenario	Task/Instruction Sensor/key (Game action)
24 **From URANUS to NEPTUNE**	 **CD Keyboard** **Albert sensors**  	**Task/Instruction** Child makes "Albert" move forward, to planet Neptune/ "Go to planet Neptune. The last planet of our Solar System!" **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Arrow pad" game action input. **Biosymtic device "Albert"** "Accelerometer, gyroscope and tilt sensor" game action input.
25 **NEPTUNE**	  	**Task/Instruction** Child makes the "Water mutant" creatures move forward, to face a battle with "Vankalo's" creatures – "Takle K's – symphonic lava troop"/ "Prepare for battle! Bring the 'Water mutant' creatures. Face the 'Vankalo's' troop, the 'Takle K's, symphonic lava troop'!" **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Arrow pad" game action input. **Biosymtic device "Albert"** "Accelerometer, gyroscope and tilt sensor" game action input.

Scenario	Visual Scenario	Task/Instruction Sensor/key (Game action)
25 **NEPTUNE**	 **CD Keyboard** ☐1 ☐2 ☐3 ☐4 ☐5 **Albert sensors** 	**Task/Instruction** Child makes the "Water mutants" repeat a orderly sequence of sounds – five sounds produced by the "Takle K's" (e.g., animals, musical instruments, spacesounds, phrases)/ "Repeat the symphony produced by the 'Takle K's' to put and end to 'Vankalo´s' plans and save our Solar System! Try not to go out of tune!" **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** "Numbers pad" from "1" to "5" game action input. **Biosymtic device "Albert"** "touchglove sensor" (using the five fingers) action input.
26 **GAME CONCLUSION/ CLASSIFICATION**	   	**Instruction** "Albert", the cosmic maestro, puts and end to the evil "VanKalo´s" plans, after conducting a grand symphony!" "Incoming message from planet Earth: Our Solar System is still operational! You got It!" **Traditional screen-based computer device (CD)** Average motion intensity values obtained throughout the game are displayed to the child, as well as scores related to game scenarios, questions, time spent playing the game and total game score. **Biosymtic device "Albert"** Average heart rate/motion intensity values obtained throughout the game are displayed to the child, as well as scores related to game scenarios, questions, time spent playing the game and total game score.

BIOSYMTIC DEVICE ALBERT/TRADITIONAL SCREEN-BASED COMPUTER DEVICE

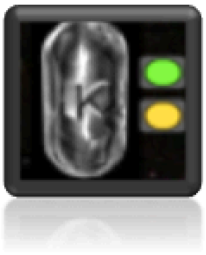
OPEN NARRATIVE

In the *open narrative* version, the child selects the video game chapter that she wants to complete (from Moon to Venus, from Venus to Earth, from Earth to Mars, from Mars to Saturn and from Saturn to Neptune). The child receives visual and verbal instructions throughout the video game (which goal to accomplish in each game scenario, including where she is located in the game; which sensor to use in each game scenario; which "keys" to use in each game scenario). While using the Biosymtic device "Albert", the child controls her physical activity levels according to will, via the "bar-sensor" (before each game chapter in a menu to select the inertial forces – "Easy" corresponding to low intensity, "Medium" corresponding to medium intensity and "Hard" corresponding to high intensity). While using the traditional screen-based computer device, the child controls the inertial forces of the avatar through a "keyboard" interface (before each game chapter in a menu to select the inertial forces – "Easy" corresponding to low intensity, "Medium" corresponding to medium intensity and "Hard" corresponding to high intensity). The child is presented with multiple-choice questions between game chapters – different questions from those presented in the closed narrative.

In this version, the child selects the video game chapter to complete – selecting a virtual "capsule" from five capsules (the five game chapters - from Moon to Venus, from Venus to Earth, from Earth to Mars, from Mars to Saturn and from Saturn to Neptune) in a main menu in the game (each capsule with a letter in it, e.g., "Y", "X", etc.). After finishing a capsule/game chapter the child returns to the main menu to select another capsule. The child has to pass through all the capsules/game chapters to end the game. The game scenarios are analogous to the scenarios in the first version (same visual content), closed narrative – including visual and verbal instruction throughout the video game.

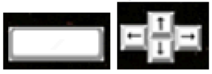
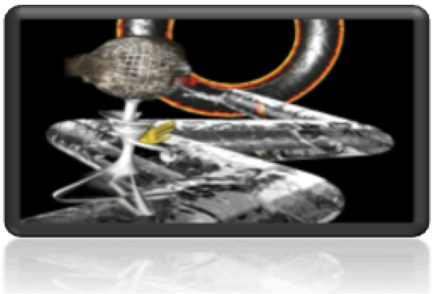
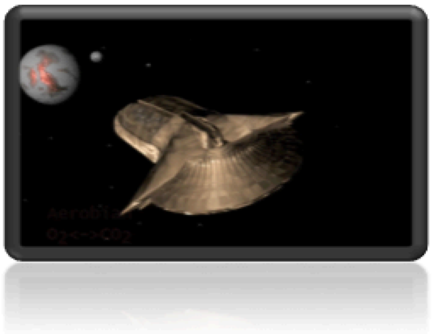
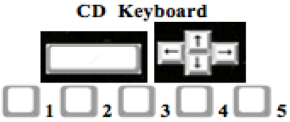
The child has to move through the video game scenarios in order to score - scores automatically after accomplishing each game scenario (e.g., Venus, Mars, Saturn, etc.; from 0 to 21 points according to the game scenario difficulty; total game score 56 points). The child also scores if she is able to answer the multiple-choice questions at the end of each game chapter (from Moon to Venus; Venus to Earth; to Mars; to Saturn; Saturn to Neptune) – five questions presented at the end of each game chapter, each with three answer choices (for each correct/incorrect answer the child gained 3 or 0 points respectively; total game score regarding episodic memory between 0 and 15 points). The multiple-choice questions presented in the Biosymtic device "Albert" are different from those presented in traditional screen-based computer device.

We will now describe the multiple-choice questions included in the open video game narrative, corresponding to each game chapter – a multiple-choice question for each virtual "capsule" on a main menu to be selected by the child. Content regarding the game scenarios and visual and verbal instruction throughout the video game was previously described in the closed video game narrative.

Scenario	CAPSULE	Multiple-choice Questions
From MOON to VENUS		**Traditional screen-based computer device (CD)** How big is Mercury compared to Venus? bigger/smaller/the same size **Biosymtic device "Albert"** Mercury is closer to the Sun, Venus or Earth?
From VENUS to EARTH		**Traditional screen-based computer device (CD)** Earth is closer to Mercury, Venus or the Sun? **Biosymtic device "Albert"** How big is Earth compared to Venus? Smaller/bigger/the same size
From EARTH to MARS		**Traditional screen-based computer device (CD)** How many trees did you carry to the Aerobian spaceship? 6/2/7 **Biosymtic device "Albert"** How many trees did you planted? 2/3/4
From MARS to SATURN		**Traditional screen-based computer device (CD)** How big is Jupiter compared to Saturn? The same size/smaller/bigger **Biosymtic device "Albert"** Jupiter was closer to Earth, Mars or Saturn?
From SATURN to NEPTUNE		**Traditional screen-based computer device (CD)** Did you hug a cosmic tree inside the second capsule? No/yes/maybe **Biosymtic device "Albert"** Did you touch a cosmic satelitte inside the first capsule?

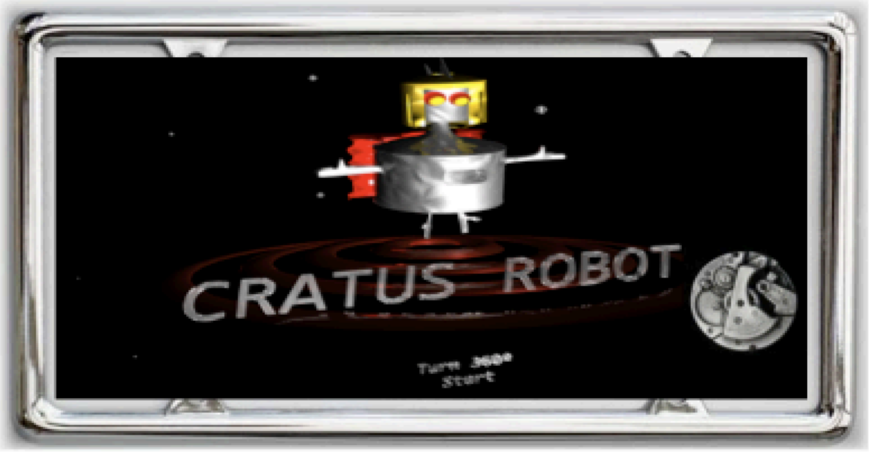
ADAPTATION SESSION VIDEO GAME SOFTWARE

BIOSYMTIC DEVICE ALBERT/TRADITIONAL SCREEN-BASED COMPUTER DEVICE

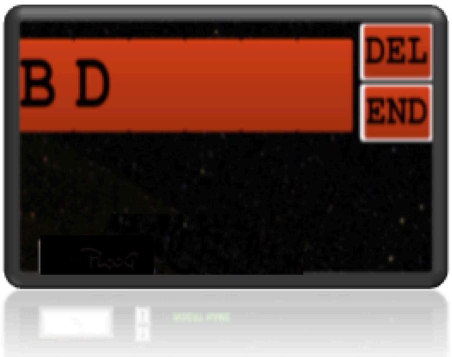
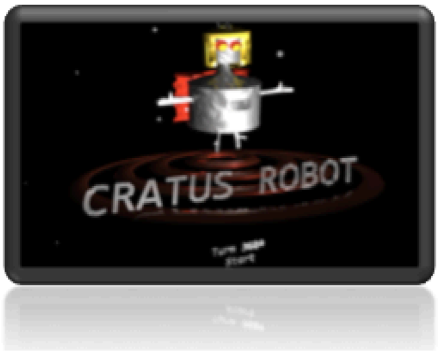
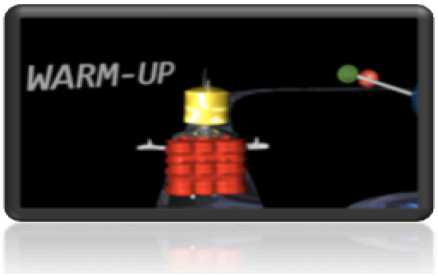
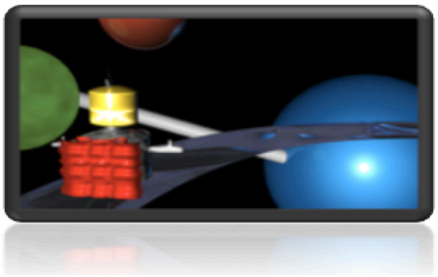
Scenario	Visual Scenario	Task Sensor/key (Game action)
01 **Name/Age input**	 **CD Keyboard**  **Albert sensors** 	**Task** Name and age input/ "Insert name; Insert age" **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** - "Arrow pad" letters/numbers selection; - "Space key" letter input. **Biosymtic device "Albert"** - "Turn button sensor" letters/numbers selection; - "Airflow sensor" letters/numbers input.
02 **Albert moves over a cosmic road/spaceship moves to a planet**	  **CD Keyboard**  **Albert sensors** 	**Task** Child makes "Albert" move over a cosmic road; drives a spaceship to a planet. **Sensor/key** **(Game action)** **Traditional screen-based computer device (CD)** - "Arrow pad" game action input – "move forward"/"back"/"left"/"right"/"rotate"; - "Space key" game action input –"jump"; "Numbers pad" from "1" to "5" game action input - "move "forward"/"back"/"left"/"right"/"rotate". **Biosymtic device "Albert"** - "Airflow sensor" game action input – "move forward"; - "Accelerometer, gyroscope and tilt sensor" game action input – "move forward"/"back"/"left"/"right"/"rotate"/ "jump"; - "Touchglove sensor" (using the five fingers) game action input - "move "forward"/"back"/"left"/"right"/"rotate".

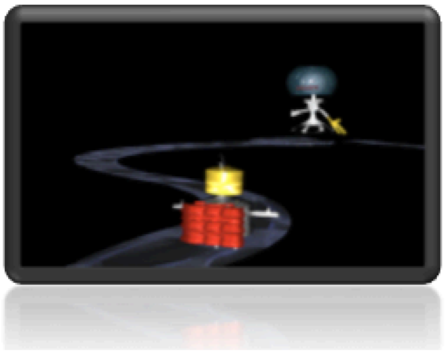
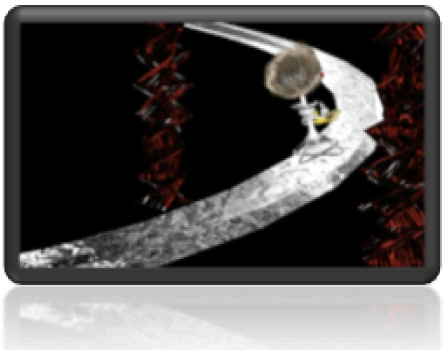
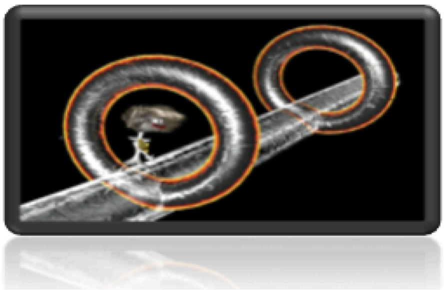
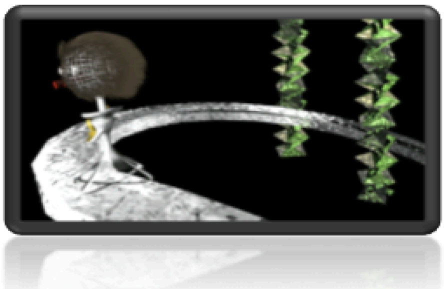
VIDEO GAME SOFTWARE “CRATUS ROBOT. THE SPACE TRAVELLER”

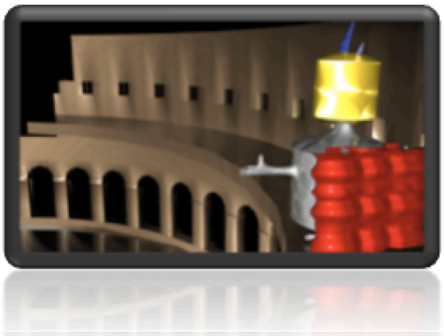
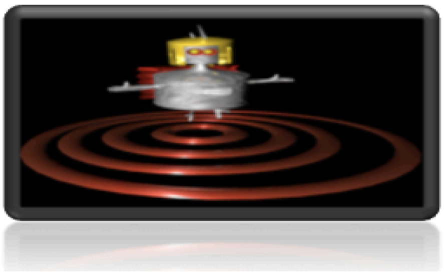
“Cratus” is an old Roman inventor from the XIX century. This inventor reinvented his own body to become a time traveller. The “wheeled teleportation system” is one of his great inventions. This system allows “Cratus” to travel at the speed of light in the Universe. “Cratus” begins a journey throughout the Universe to discover the ancient architectural epochs of the planet Earth (Classical periods). At the beginning of his adventure, “Cratus” discovers that its “wheeled teleportation system” has technical flaws – somehow “Cratus” has endowed the mechanism with some sort of intelligence that does not obey to its commands. Due to this technical flaw, it becomes very difficult to coordinate his body together with the “wheeled teleportation system”. The main goal of the game is to help “Cratus” control his “wheeled teleportation system” while exploring a variety of 3D scenarios in the game. The child is encouraged to move, as fast as possible, in each game scenario so as to score (complete each game scenario – race tracks - in the shortest time possible).

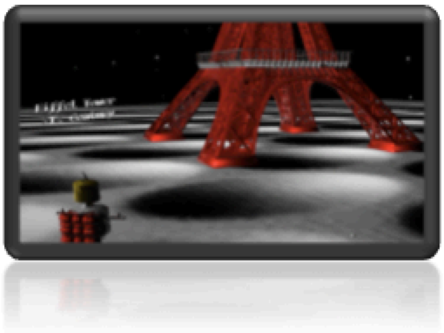
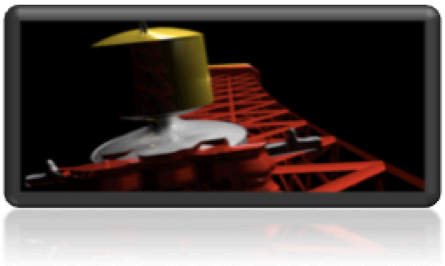
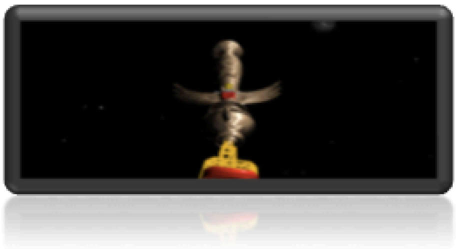


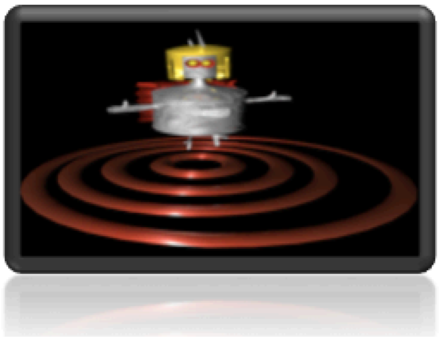
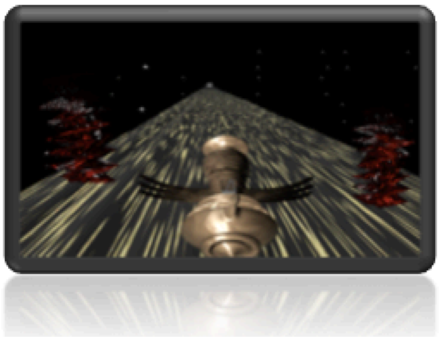
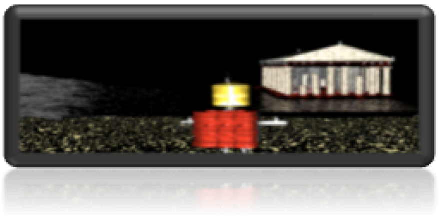
Cratus” gives visual instruction to the child (software) - necessary angles and rotation velocity in three-dimensional space (demonstrating the directions to be taken in a slider, in order to facilitate spatial orientation skills), as well as verbal instructions – e.g., “Straight ahead!”, “Turn right!”, “Turn backwards!”, “Rotate 45 degrees to the right!”, “Rotate 360 degrees to the left!”. The system calculates the child’s average heart rate values obtained throughout the game and displays them to the child at the end of game, as well as the game scores related to each scenario (time taken to cross each scenario; the latter compared to a “top time” obtained by previous players). The video game includes the following scenarios: “The teleportation portal 01”; “Finding the cosmic map”; “Rome Coliseum - IV century”; “The teleportation portal 02”; “Eiffel Tower - XIX century”; “The teleportation portal 03” “V-O-VOX Vortex in the cosmic pathway”; “Parthenon - V century”.

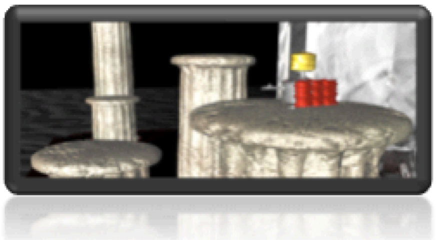
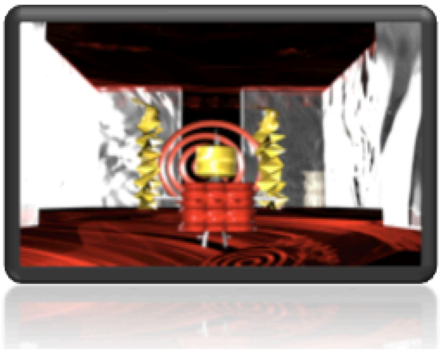
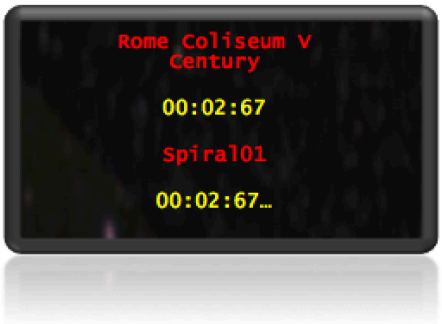
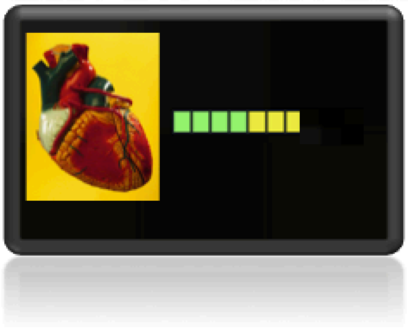
Scenario	Visual Scenario	Task/Instruction Sensors (Game action)
01 **Name/Age input**	 **sensors** 	**Task/Instruction** Name and age input/ "Insert name; Insert age". **Sensors** **(Game action)** "Turn button" letter selection; "Touch button" letter input.
02 **"The teleportation portal 01"**	 **sensors** 	**Task/Instruction** Child makes the "Cratus Robot" apparatus (avatar in the video game) rotate 360º degrees to start the game/ "Rotate 360º degrees to start your adventure!" **Sensors** **(Game action)** "Accelerometer, gyroscope and tilt sensor" game action input.
03 **"Finding the cosmic map"**	 	**Task/Instruction** Child makes the "Cratus Robot" move forward, right and left and rotate over the cosmic racetrack/ "Start moving over the cosmic pathway and ask help from Albert to find the cosmic map!" **Sensors** **(Game action)** "Accelerometer, gyroscope and tilt sensor" game action input.

	     **sensors** 	

04 **“Rome Coliseum – IV Century”**	    **sensors** 	**Task/Instruction** Child makes the “Cratus Robot” explore the Rome Coliseum – making the apparatus move forward, right and left and rotate over the racetracks outside and inside the Rome Coliseum/ “Explore the Rome Coliseum, IV Century!Finish this race track as fast as possible” **Sensors** **(Game action)** “Accelerometer, gyroscope and tilt sensor” game action input.
05 **“The teleportation portal 02”**	 **sensors** 	**Task/Instruction** Child makes the “Cratus Robot” rotate over a “teleportation portal”/ “Make ‘Cratus´rotate 360º to the right and left over the teleportation portal and move to the next cosmic race track!” **Sensors** **(Game action)** “Accelerometer, gyroscope and tilt sensor” game action input.

06 **“Eiffel Tower XIX century ”**	      	**Task/Instruction** Child makes the “Cratus Robot” explore the Eiffel Tower – making the apparatus move forward, right and left and rotate over the racetracks outside and inside the Eiffel Tower/ “Explore the Eiffel Tower, XIX Century!Finish this race track as fast as possible!” **Sensors** **(Game action)** “Accelerometer, gyroscope and tilt sensor” game action input.

07 **“The teleportation portal 03”**	 **sensors** 	**Task/Instruction** Child makes the “Cratus Robot” rotate over a “teleportation portal”/ “Make ‘Cratus´rotate 360º to the right and left over the teleportation portal and move to the next cosmic race track!” **Sensors** **(Game action)** “Accelerometer, gyroscope and tilt sensor” game action input.
08 **“V-O-VOX Vortex in the cosmic pathway”**	 **sensors** 	**Task/Instruction** Child takes the “V-O-VOX Vortex” over the cosmic pathway/ “Explore the cosmic pathway! Drive the ‘V-O-VOX Vortex’ through the race track and finish it as fast as possible!” **Sensors** **(Game action)** “Accelerometer, gyroscope and tilt sensor” game action input.
09 **“Parthenon - V century”**	  	Child makes the “Cratus Robot” explore the Parthenon – making the apparatus move forward, right and left and rotate over the racetracks outside and inside the Eiffel Tower/ “Explore the Parthenon, VCentury!Finish this race track as fast as possible!”

	  sensors 	
09 “GAME CONCLUSION/ CLASSIFICATION”	 Rome Coliseum V Century 00:02:67 Spiral01 00:02:67… 	**Instruction** Game scores (race tracks). Average heart rate values obtained throughout the game displayed to the child.