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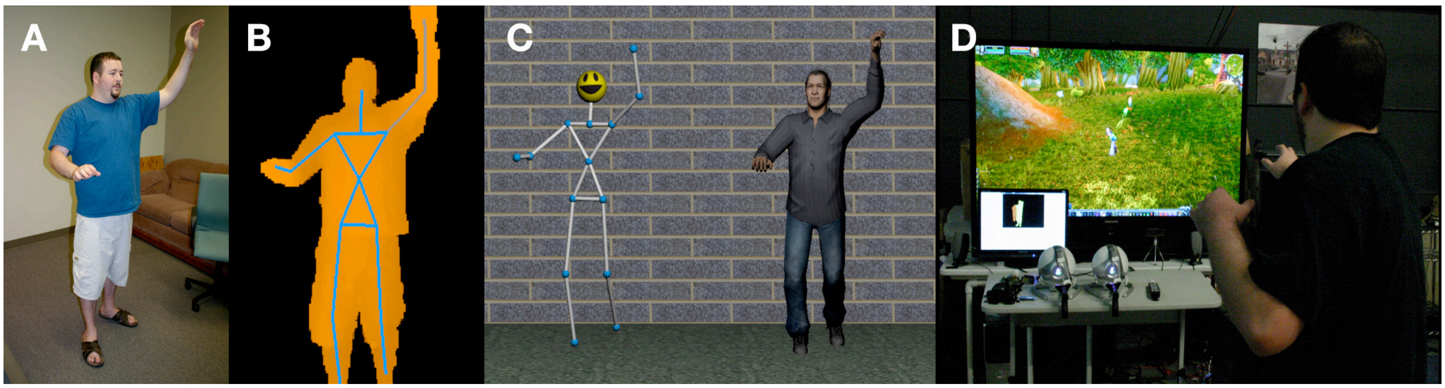
Albert "Skip" Rizzo, Ph.D., Belinda Lange, Ph.D., Evan A. Suma, Ph.D., and Mark Bolas, Ph.D.



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SYMPOSIUM

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Introduction

Since 1995, a virtual revolution has taken place in the use of virtual reality (VR) simulation technology for clinical purposes. Technological advances in the areas of computation speed and power, graphics and image rendering, display systems, body tracking, interface technology, haptic devices, authoring software, and artificial intelligence have supported the creation of low-cost and usable VR systems capable of running on a commodity-level personal computer. At the same time, a determined and expanding cadre of researchers and clinicians have not only recognized the potential impact of VR technology, but generated a significant research literature that documents the many clinical targets where VR can add value over traditional assessment and intervention approaches.[1–6] Such VR systems have been successfully used with adults with simple phobias[2,3,7,8]

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Abbreviations: (3D) three-dimensional, (ADHD) attention deficit hyperactivity disorder, (ASD) autistic spectrum disorder, (DDR) *Dance Dance Revolution*, (HMD) head-mounted display, (VE) virtual environment, (VR) virtual reality

Keywords: exergaming, interactive digital games, virtual environment, virtual reality

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(http://journalofdst.org/March2011/media/5-256-v1.html), posttraumatic stress disorder,[9–11] addictive behaviors,[12] acute pain reduction,[13,14] and cognitive and motor impairments following stroke, brain injury, and other forms of neurological disorders.[4,15–17] To do this, scientists have constructed virtual airplanes, skyscrapers, spiders, battlefields, social events populated with virtual humans, fantasy worlds, and the mundane (but highly relevant) functional environments of the schoolroom, office, home, street, and supermarket. This state of affairs now stands to transform the vision of future clinical practice and research in the disciplines of psychology, medicine, neuroscience, physical and occupational therapy, and the many allied health fields that address the therapeutic needs of children and adults with health care issues and clinical disorders.

This convergence of the exponential advances in underlying VR-enabling technologies with a growing body of clinical research and experience has fueled the evolution of the discipline of clinical VR. This article will present a brief overview of methods for producing and delivering VR environments that can be accessed by users to address a range of clinical health conditions. Interactive digital games and new forms of natural movement-based interface devices will also be discussed in the context of the emerging area of exergaming along with some of the early results from studies of energy expenditure during the use of these systems. Developments in these areas have now driven the creation of engaging, low-cost interactive game-based applications designed to increase exercise participation in persons at risk for obesity, and this trend is expected to continue and evolve with new advances in interactive digital game technologies.

Virtual Reality Formats

Virtual reality is not defined or limited by any one technological approach or hardware setup. The creation of a VR user experience can be accomplished using combinations of a wide variety of interaction devices and sensory display systems and in the design of content presented in a computer-generated graphic world. For example, immersive VR combines computers, head-mounted displays (HMDs), body-tracking sensors, specialized interface devices, and real-time graphics to immerse a participant in a computer-generated simulated world that changes in a natural way with head and body motion. In these systems, one of the key aims is to replace the outside world perceptually with that of a simulated environment (delivered within a HMD) to create a specific user experience. Immersive VR has been most commonly employed in applications where a controlled stimulus environment is desirable for constraining a user's perceptual experience within a specific synthetic world. This format has been used often in clinical VR applications for anxiety disorder exposure therapy,[2,3,7–12] in analgesic distraction for patients suffering from acutely painful medical procedures,[13,14] and in the cognitive assessment of children with attention deficit hyperactivity disorder (ADHD) within a virtual classroom to measure attention performance under a range of systematically delivered task challenges and distractions.[18,19]

By contrast, *nonimmersive* VR is commonly experienced using modern computer and console game systems. This format presents a three-dimensional (3D) graphic environment on a flatscreen monitor or television (no real-world occlusion), within which the user can navigate and interact. Albeit delivered on a less immersive display, such graphic worlds are still essentially a VR *environment*. Virtual environments (VEs) presented on these widely available commodity display systems have the capacity to provide the user with significant options for interaction with dynamic digital content using traditional computer and game interface devices (e.g., keyboard, mouse, game pads, joysticks). The use of such ubiquitous display and interface devices has promoted widespread access to this form of nonimmersive interactive media, mainly in the domain of entertainment. Moreover, researchers have investigated the value and usability of commercially available interaction devices and methods that can be used with flatscreen-delivered VEs that can allow users to interact with digital content using more naturalistic body actions beyond what is possible with traditional game interfaces (e.g., Konami *Dance Dance Revolution* (DDR), Sony Eyetoy, Nintendo Wii, Microsoft Kinect).[20,21] Regardless of the hardware format, the capacity of VR technology to create controllable, multisensory, interactive 3D stimulus environments within which human performance can be motivated, recorded, and measured, offers clinical assessment and intervention options that are not possible using traditional methods.[1,4,6,15] Much like an aircraft simulator can serve to test and train piloting ability under a variety of controlled stimulus conditions, VR can be used to create relevant simulated environments that allow for the assessment and treatment of cognitive, emotional, and motor functioning. Such VR simulations can afford many assets to both clinical and research methods that are not available with traditional approaches. A full detailing of these assets (e.g., ecological validity, controlled stimulus environment, naturalistic performance recording, safety, tailored feedback) are published elsewhere.[15]

The Intersection of Virtual Reality and Interactive Digital Game Technology

Concurrent with the emerging acknowledgement by scientists and clinicians of the unique value of clinical VR is a growing awareness by the general public of the potential relevance and impact of new digital media technology. While public consciousness has been occasionally exposed to popular media reports of clinical and research VR applications, popular awareness has been more significantly bolstered by the high visibility of interactive digital 3D games, the growing use of massive shared Internet-based virtual worlds where many users can gather and interact via an avatar representation of themselves regardless of their physical location (e.g., *World of Warcraft*, *Halo*, and *Second Life*), and the release of the Nintendo Wii motion-sensing interface. Moreover, the growth of the interactive digital game industry juggernaut is evidenced by the fact that, as of 2002, its total entertainment market share was second only to the Hollywood film industry, and in 2009, sales of game software reached 10.5 billion dollars with a 67% penetration rate in American households.[22] This digital "gold rush" has increased public awareness, driven advances in underlying enabling technologies, and ignited social changes that have gone well beyond the early expectations of behavioral health scientists.

One of the important developments to emerge from this convergence of VR with interactive digital games is what has been termed the "games for health" movement.[23] One of the basic tenets of the games for health movement is the view that a person will become more engaged in a testing, treatment, or training activity if he/she is motivated to participate by some form of embedded digital gameplay in a VE. This perspective has encouraged clinical and research efforts to investigate how these technologies could be applied usefully to pediatric health care issues and disorders. From this, clinical researchers and game developers alike have been driven to explore novel VR game-based opportunities for addressing the health care needs of this segment of the population in ways that were undreamed of back in the bygone days of the 20th century. Although the vision of a "digital generation" of children, who are more at home with a mouse and gamepad than with a book or a bicycle, raises many serious concerns; there is no denying the attractive, compelling, and motivating nature of these new forms of information technology and interactive media. A reasonable case can be made that such technology, if harnessed thoughtfully, could be used to engage children in a wide range of positive behavioral health activities. This view makes intuitive sense and hits close to home when parents notice their children exhibiting Herculean focus when playing a video game on their Xbox while teacher reports indicate chronic inattention and distractibility in the classroom.

One early example of research and development with VR systems to address childhood disorders can be seen in the development of a virtual classroom simulation that has been used for testing attention processes in children with ADHD.[18,19] Children are tested in this system by donning a motion-tracked VR HMD and are whisked away into a simulation of a typical classroom where they can look ahead at the blackboard and follow a virtual teacher's instructions or choose to turn their head to look out the window at a passing car (or at other distractions). It is possible within this controlled stimulus environment to measure precisely how well a child can pay attention to the directed test activities at the front of the VR classroom while audio and visual distractions are delivered systematically (e.g., cars driving by the window, hall sounds, a paper plane floating across the room). In this manner, it becomes possible to measure how susceptible a child is to different types and levels of distraction that might commonly occur in a real classroom. Such information can be used to document performance for diagnostic purposes, inform treatment planning, or help in determining the impact of medications via the measurement of performance in this ecologically relevant and consistently delivered virtual classroom test setting/simulation.

Other researchers have embraced the logic of the VR/aircraft simulation metaphor in the creation of virtual homes, public spaces, and traffic-filled streets to teach fire safety skills[24] (*http://journalofdst.org/March2011/media/5-256-v2.html*), social skills,[25] safe street crossing,[26,27] and earthquake safety procedures[28] to children with autistic spectrum disorder (ASD) and other developmental disorders. Even a virtual obstacle course has been created to determine if a child is capable of using a motorized wheelchair safely and effectively.[29] Game-based flat-screen-delivered VR applications have also demonstrated efficacy in engaging children with cerebral palsy to better perform tedious motor rehabilitation exercises for ankle dorsiflexion and other important motor movements.[30,31] Such results in children directly follow from research targeting adults where game-based VR training was reported to enhance motivation to participate in rehabilitation, leading to improvements in hand function[32–34] and locomotor activity in individuals with chronic stroke[35] and in decreasing akinesia for individuals with Parkinson's disease.[36]

Games are also being used successfully to promote health behaviors in children undergoing chemotherapy[37] (reducing pain perception and discomfort by distracting children's attention away from common, yet anxiety-provoking medical procedures, e.g., intravenous insertions, spinal taps[13]) and to promote eye contact in children with ASD,[38] interactive story telling,[39] turn taking, and social awareness.[40]

These initiatives represent early and encouraging first steps in using new VR simulation and interactive digital game technologies to make a positive difference for children with special needs. The key challenge now for the games for health community is to find ways to translate important testing, treatment, and training activities into game activities that are engaging to children who have grown up "digital," while still being able to make the case that relevant therapeutic or health care objectives are being measured and improved.

Exergaming

Exergaming has drawn both popular media and scientific attention as a potential remedy to the growing societal health problem of childhood obesity and diabetes. The core concept of exergaming rests on the idea of using vigorous body activity as the input for interacting with engaging digital game content with the hope of supplanting the sedentary activity that typifies traditional game interaction that relies on keyboards, gamepads, and joysticks. In this format, increased motivation to participate in calorie-burning cardiovascular exercise activities is postulated to occur by creating compelling digital game content that can only be interacted with via body activity. Also known as kinetic games,[41] exergaming is not a new idea, and the reader is directed to the Wikipedia entry for a concise review of the history in this area. Initially, VR and computer game-based exergaming applications were hamstrung both by the cost of equipment and by the complexity involved in tracking the movement activity of users. Such applications required 3D user interface devices[42] that sensed and captured vigorous body activity as a usable input signal for meaningful interaction with game content. Thus, complex and costly sensing systems capable of high sampling rates and with full six-degree-of-freedom motion capture, such as magnetic or high-end optical tracking systems, were often used to capture the movement data needed to drive exercise and rehabilitative interaction in game environments. Alternatively, many commercial entities took the approach of adapting standard exercise equipment (e.g., lifecycles, treadmills, recumbent bikes, stair steppers) to interact with digital content via the use of analog to digital conversion systems.[43] Such systems have been typically employed in fitness clubs that have good economic resources and the financial incentives to justify the significant infrastructure costs. However, to promote better accessibility and widespread use by children, home-based systems are needed that are affordable and easy to deploy and maintain while still providing the movement-sensing fidelity required to drive engaging interaction within the game content. High-end location-based fitness club systems do not meet these cost and deployability requirements for widespread use in the home.

To address this challenge, some researchers have created low-cost optical motion tracking systems that employ off-the-shelf cameras (e.g., Logitech webcam). These types of cameras can track activity from the movement of light-emitting diodes or retroreflective markers (using infrared cameras) attached to strategic points of interest on the body or to relevant objects such as handheld jogging weights and plastic swords.[44] These systems have been found to be useful for rehabilitation purposes, where the capture of a small number of constrained movement points is sufficient for the needs of upper/lower extremity and general balance-focused applications. However, a low-cost system for capturing vigorous full-body activity for game interaction required for cardiovascular fitness and weight loss applications has yet to appear with this technological approach.

Some researchers have tackled this problem by implementing off-the-shelf game console systems, such as with the Sony Eyetoy, Konami DDR, and the Nintendo Wii games.[21,31] In addition to the intuitive appeal that this concept has, energy expenditure studies have provided initial support for this direction. For example, Lanningham-Foster and associates[45] reported that, "Watching television and playing video games while seated increased energy expenditure by 20 ± 13% and 22 ± 12% above resting values, respectively. When subjects were walking on the treadmill and watching television, energy expenditure increased by 138 ± 40% over resting values. For the activity-promoting video games, energy expenditure increased by 108 ± 40% with the EyeToy (Sony Computer Entertainment) and by 172 ± 68% with *Dance Dance Revolution* Ultramix 2." The authors concluded that energy expenditure more than doubles when sedentary screen time is converted to active screen time and that such interventions might be considered for obesity prevention and treatment. Other research has also shown the DDR system to be effective for increasing energy expenditure[46] and heart rate.[47] An increased energy expenditure advantage has also been reported from playing the various *Wii Sports* games compared to traditional sedentary games.[48] In a study that tested five girls and six boys aged 13–15 years, Graves and coworkers[48] reported mean (standard deviation) predicted energy expenditure levels for playing *Wii Sports: Bowling* (190.6 (22.2) kJ/kg/min), compared to *Wii Sports: Tennis* (202.5 (31.5) kJ/kg/min), and *Wii Sports: Boxing* (198.1 (33.9) kJ/kg/min). These values were significantly greater than when playing sedentary games (125.5 (13.7) kJ/kg/min; $p < .001$). As well, another research group tested a similar sample age (14 boys and 9 girls; ages 10–13 years) and found energy expenditure relative to body mass with the DDR Level 2 and the *Wii Sports: Boxing* games to be higher than watching television and equivalent to treadmill walking at a 5.7 km/h pace.[46] However, while these results suggest that playing currently available active exergames uses significantly more energy than sedentary activities and is equivalent to a brisk walk, they do not reach the level of intensity that would match playing the actual sport, nor do they deliver the recommended daily amount of exercise for children.

Although these results provide some support for the use of digital exergames using the current state of technology, this activity should be viewed as a complement to, rather than a replacement, for regular exercise. These results may be due, in part, to the limitations regarding the movement activity required for interaction with these console games. For example, the Eyetoy is restricted to the capture of unnatural single plane two-dimensional activity, and while the *DDR* can certainly provide a fairly energetic workout, the dancing game component may not appeal to and engage some children who would otherwise benefit from such game-based exercise activities. The functionality of the Nintendo Wii gaming console and the variety of sport and fitness game offerings seems on the surface to be closely aligned with the needs of exergaming. The interface for the Wii employs a camera-based and inertial tracking hybrid system that is inexpensive and can be used to interact with compelling and engaging exercise games. Unlike the Sony Eyetoy, user groups have now been able to adapt the Wiimote controller to interact with novel applications that can be created on a basic personal computer and even outside the digital spectrum to drive radio-controlled cars.[49] This supports the potential for flexible development of activity-specific game content that may appeal to a variety of user interests for engaging participation beyond the standard Nintendo offerings. However, frequent users of some of the Wii games have learned various "cheats" with using the hand held Wiimote controller that, while producing the desired game result, do so with much less actual naturalistic and energetic movement. This issue, in addition to anecdotal reports from users regarding discouraging comments that are sometimes made by the avatar "coach" on the Wii Fit, may make this system less regarded in the future for inspiring motivation to exercise; in contrast to its place in history as an innovative product that moved the epicenter of game interaction from the thumbs to the larger body as a whole.

One of the more exciting new developments involves the new Xbox Kinect system by Microsoft, which, by its design, could motivate user activity to energy expenditure levels that will more closely emulate daily exercise recommendations. This revolutionary game platform uses an infrared "depth-sensing" camera (produced by an Israeli company, Primesense) to capture the user's full body movement in 3D space (*http://journalofdst.org/March2011/media/5-256-v3.html*) for interaction within game activities. The system does not rely on the user's holding an interface device or moving on a pad as the source of interaction within the game. Instead, the user's body is the game controller operating in 3D space and multiple users can be tracked in this fashion for both cooperative and competitive exergaming activities. Another attractive feature is that while, the Primesense camera provides the tracking functionality for the Kinect, it will soon be available as a low-cost stand-alone USB depth-sensing camera. This option will allow homegrown developers and researchers to produce game software and content that is specifically designed to promote exercise (and rehabilitation activity) beyond what the Xbox console games may offer. Our group at the University of Southern California Institute for Creative Technologies is currently testing this camera system and building software around its functionality to promote the creation of home-based rehabilitation and exergame applications (see **Figure 1**). We have thus far integrated the Primesense movement-tracking system (*http://journalofdst.org/March2011/media/5-256-v4.html*) with associated software that allows it to drive any personal-computer-based computer game by emulating standard mouse and keyboard commands, all based on the designated physical activity of the user.[50] This will provide a new dimension for interactive exergaming in many ways by opening up a multitude of existing game content for full-body interaction. For example, if a child is obsessed with *World of Warcraft*, playing every day for hours at a time, it could be possible for a parent to require that the child use the Primesense tracking system for a certain portion of that time to

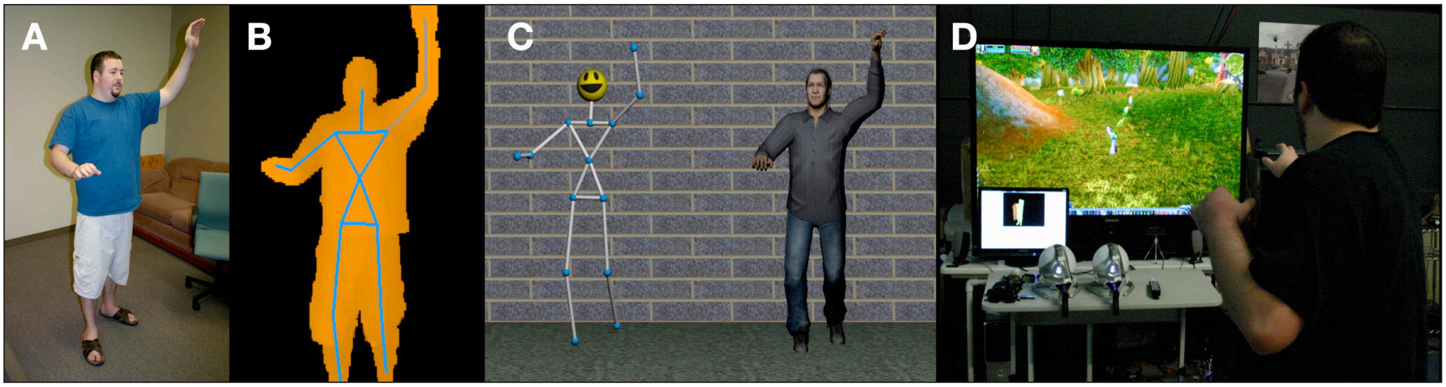

Figure 1. (A) Example user strikes pose. **(B)** Primesense depth-sensing camera and software identifies and segments the user from the background depth image and fits articulated skeleton. **(C)** Articulated skeleton can be used to actuate a digital "puppet" for interaction. **(D)** User can interact with computer games by emulating keyboard controls with body action, in this case, in the *World of Warcraft* game.

engage in the game and actuate their avatars with body activity rather than keystrokes. Although the Primesense camera is not publicly available at the time of this writing, we have access to the system and have set up an open source software development group to create software tools that we expect will motivate and support the creative development of new rehabilitation/exergame content and strategies. This will likely promote health care research and application development using this system, which can be widely disseminated at a low cost.

Conclusions

Revolutionary advances have occurred in the areas of VR and interactive digital game technology, and this has supported research and development that has targeted important societal-level health care challenges in ways not possible in the past. As well, the infrastructure is certainly in place in the home to drive further digital efforts at fostering positive health attitudes and behavior change. It is no longer a stretch to consider that powerful VR and interactive digital game systems will soon become routine hardware in the "digital homestead." The beginnings of this now exist in the form of modern game consoles and stereo televisions that can be networked with massive numbers of remote users. Such computing, display, and interaction horsepower could serve to promote health-relevant activities that leverage social engagement and interaction and thereby provide another essential ingredient for positive attitude and behavior change. Deriving from these advances in infrastructure and access, the concept of exergaming may now provide digital options for motivating healthy physical activity in an increasingly sedentary population of children at risk for obesity and diabetes.

However, a significant research effort is still required to determine the efficacy and added value of VR and exergame applications for reducing weight and improving the management of diabetes. As noted previously, early results suggest that playing currently available active exergames uses significantly more energy than sedentary activities, yet this activity does not reach the level of intensity that would match playing the actual sport, nor does it deliver the recommended daily amount of exercise for children. At least two major directions for future research are suggested to test the efficacy of next generation VR games for weight loss and diabetes management. These directions focus on engagement and energy expenditure.

It must first be demonstrated that exergame activities are engaging enough to promote their use on a regular basis, not only with children who already get sufficient exercise, but also with users who are overweight. Will such children opt instead to play traditional games that require less physical exertion? As well, will users consider games that convey messages that promote a healthy diet and other health management strategies as "uncool," leading to those games being abandoned by those who may need them most? Our laboratory posted a video on YouTube demonstrating how the Microsoft Kinect could be used to play the popular *World of Warcraft* computer game with body activity rather than keystrokes, along with some video commentary about the value of exergaming for reducing obesity and the potential for developing diabetes. It was somewhat disheartening to observe that, out of the 2051 comments posted mainly by *World of Warcraft* gamers (from 1.3 million views), nearly half contained statements disparaging the idea (http://www.youtube.com/watch?v=62wj8eJ0FHw). Although hardly a scientific analysis, the less than universal excitement for playing *World of Warcraft* by this group of current gamers underscores the challenge for creating exergames that are engaging to the wide variety of users who could potentially benefit from this activity. However, *World of Warcraft* was originally designed to take advantage of the orchestration of a near infinite set of keystroke combinations for successful gameplay. Thus, with its traditional keyboard interaction format so culturally entrenched due to its history of literally billions of hours of play already logged by users, it was likely not the optimal choice for conversion to an exergame activity that would inspire exercise via a novel physical interaction method. Perhaps specifically tailored online team-based competitive or collaborative exergames might provide a solution that would motivate engagement, especially in users who may have limitations in their social behavior that preclude their ability to participate in and enjoy in-person team sports. The perceived "comfort" of this remote access to digital team interaction from the safety of the home could be investigated to determine if it serves to motivate engagement and increase exercise activity. Thus research that drives a better understanding of the design issues that underlie both social and solo games that can be played with full-body interaction might lead to the creation of exergames that will promote more vigorous adoption and engagement.

The second research direction necessarily involves the continued evolution of the literature that aims to determine the caloric expenditure rates of new exergames that may be candidates as part of a weight reduction strategy. We have noted that the early research with current commodity game systems indicates that they fall short of providing recommended daily levels of exercise. Can the technical advances that now exist in capturing full-body activity for interaction with digital game content lead to the design of exergames that, when actively engaged with, could provide a meaningful substitute for traditional exercise? And if not, could some complementary positive outcome be achieved with lesser amounts of participation? Related to this would be investigations that assess attitude and behavior change regarding daily exercise and health-related activities that might be affected or inspired by engagement in exergames.

In addition to the approaches detailed in this article, and as underscored by the other technology-focused articles in this issue, there are other forms of digital technology that could be marshaled to generate a more far-reaching solution for this significant public health challenge. Interactive digital games can be created that address health care education and health-related behavior change as part of engaging gameplay, as has been seen with the Hope Lab's *Remission* game for children with cancer.[37] Social networking activities (e.g., *Second Life*, *Club Penguin*, Facebook) could provide new options for dissemination of health care information, peer group support, and other relevant health-related activities that may affect attitude and behavior change. Virtual reality simulations can provide opportunities for creative 3D visualizations of users' body types and provide feedback from that source to help inform a rational and intuitive view of the interaction between behavior and physical outcomes. And not far off in the future, VR online digital worlds will be created that are populated by supportive artificially intelligent virtual human agents (perhaps "virtual buddies") that users will be able to interact with and receive support and guidance from to develop more positive health-related thinking and behavior (*http://journalofdst.org/March2011/media/5-256-v5.html*). Exergaming is simply one part of a larger, more comprehensive approach to this problem, and despite the encouraging outcomes thus far, a larger context of societal effort will be required to reach the level of behavior change desired. While the usual suspects will naturally include approaches that leverage everyday real-world activities and experiences, the emergence of digital technology will likely play a significant part of a larger solution—as it should—in view of its widespread appeal and access. As these technologies continue to advance, the boundaries for creating positive health applications will be governed only by the limits of our imagination.

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