NEAT-o-Games: Blending Physical Activity and Fun in the Daily Routine

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This article describes research that aims to encourage physical activity through a novel pervasive gaming paradigm. Data from a wearable accelerometer are logged wirelessly to a cell phone and control the animation of an avatar that represents the player in a virtual race game with other players over the cellular network. Winners are declared every day and players with an excess of activity points can spend some to get hints in mental games of the suite, like Sudoku. The racing game runs in the background throughout the day and every little move counts. As the gaming platform is embedded in the daily routine of players, it may act as a strong behavioral modifier and increase everyday physical activity other than volitional sporting exercise. Such physical activity (e.g., taking the stairs), is termed NEAT and was shown to play a major role in obesity prevention and intervention. A pilot experiment demonstrates that players are engaged in NEAT-o-Games and become more physically active while having a good dosage of fun.

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General Terms: Human Factors

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1. INTRODUCTION

1.1 Importance of NEAT

The importance of obesity to world health is without question. There are 1 billion people in the world who are overweight and 300 million with obesity [WHO 2007]. In the USA, data from two NHANES surveys show that among adults aged 20–74 years, the prevalence of obesity increased from 15.0% (in the 1976–1980 survey) to 32.9% (in the

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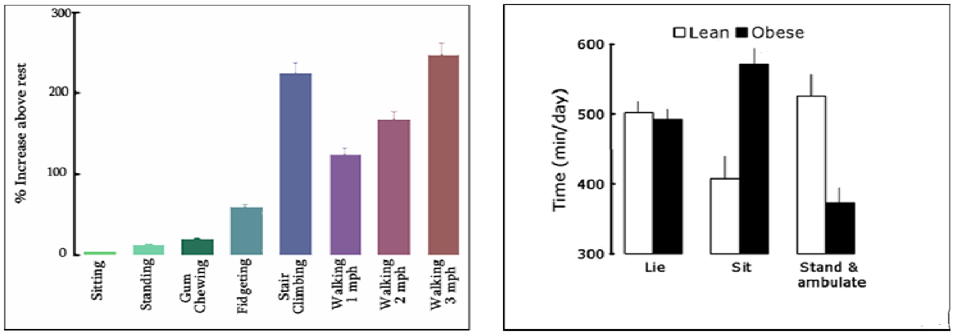

Fig. 1. *Left*: NEAT activities have higher energy expenditure than intuitively expected. *Right*: Obese people spend more hours in sitting than do lean people.

2003–2004 survey) [CDC 2007]. The health consequences of obesity are dire. It could lead to type II diabetes, heart disease, and even some types of cancers [National Cancer Institute 2007].

Recent work suggests that this is driven by a reduction in energy expenditure, rather than a rise in energy intake. In Britain where obesity has doubled since the 1980s, energy intake appears to have decreased on average [Prentice 1995]. Two major components of energy expenditure are *exercise activity thermogenesis* and *non-exercise activity thermogenesis* (NEAT). NEAT is the most variant portion of energy expenditure, and likely the culprit behind the obesity epidemic [Levine 1999 SCI].

NEAT is the energy expenditure of all physical activities other than volitional sporting-like exercise. It includes all the activities that render us vibrant, unique, and independent beings such as working, playing, and dancing. Contrary to conventional wisdom, NEAT activities expend a significant amount of energy (see Fig. 1, left). Even an activity as minute as sugar-free gum-chewing during waking hours could lead to a 20 pound loss per year, assuming all other factors remain unchanged [Levine 1999 BJM]. Recent research that used micro sensors for accurate activity measurement showed that obese participants were seated for 164 minutes per day more than lean participants (see

Fig. 1, right) [Levine 2006].

NEAT reduction is the result of evolving from the hunting/agriculturalist/industrial into a service-oriented society where computer work at the office is the norm and TV-watching/video-gaming the most widespread form of entertainment.

1.2 NEAT-o-Games

The ultimate goal of this research is to increase NEAT in the modern lifestyle. The most difficult and important part is how to motivate people to change something as fundamental as their everyday habits. Sedentariness is almost addictive and is reinforced by the specifications of the modern work and leisure environments. An important consideration here is that NEAT is omnipresent in our life (or should be anyway), in contrast to volitional sporting activities, which are bound to specific locations and times. Therefore, strong motivation and ubiquity are two key issues. We address the former by opting for games – that is, a successful form of entertainment throughout human history, which may be a potent motivator. We address the latter by opting for a game design that does not require the full attention of the player all the time, and is implemented using wearable gadgets, that is, accelerometers and cell phones.

The so-called NEAT-o-Games are envisioned as a collection of cell phone games where “activity points” may be earned and consumed across the game space. We implemented two games so far, the *NEAT-o-Race* and *NEAT-o-Sudoku* game. The *NEAT-o-Race* game could be viewed as the fundamental game of the set. Each player is equipped with a personal digital assistant/cell phone (PDA) and a wearable activity sensor (accelerometer). The data collected from the activity sensor us logged via Bluetooth connection to the player’s PDA. In the racing game, avatars are competing against each other, propelled by the physical activity data of real players participating in networked buddy lists. Winners are declared periodically (e.g., every day). In *NEAT-o-Sudoku* (a variation of Sudoku puzzle), players can spend activity points earned in the racing game to get a hint at a difficult juncture of the puzzle. This helps them in solving difficult puzzles, but it leaves them behind in the *NEAT-o-Race*. The only way to make-up for that is to increase their physical activity. Such an increase may stem from choosing a walking coffee break over a sitting one, or from taking the stairs instead of the elevator, or from any other activity falling under the NEAT category.

2. RELEVANT WORK

Various research efforts on serious gaming have been reported in the literature. The case of computer games that promote physical activity has received special attention. Computer games have an almost addictive effect that can potentially alter people’s behavior. In a recent article, Clarke et al. [2006] reported an exploratory interview-based study of computer gaming. They have found that aspects of gaming most salient to gamers were those perceived to be most behaviorally relevant to goal attainment. Brown [2006] identifies the role that video games play in the sedentary lifestyle of youth. At the same time, since video games are such a draw to young people (and people in general) he recommends the use of video games for healthful influence, not just for entertainment. For example, he suggests that dietetics professionals may add interactive, educational games to their ever-growing repertoire of dietetics knowledge, skills, and patient/client education.

The cultural phenomenon created by the *Dance-Dance Revolution* (DDR) game has been studied by Hoysniemi [2006]. The results showed that playing DDR had a positive effect on the social life and physical health of players. A successful test was carried out in public schools in West Virginia, where Konami DDR machines have been introduced against child obesity [Siesel 2007]. A few researchers have also developed immersive fitness computer games [Mokka et al. 2003; Mueller et al. 2006].

The powerful combination of physical activity gaming and ubiquitous computing has also been explored. Toscos et al. [2006] have developed a cell phone application that helps motivate teenage girls to exercise by exploring their social desire to stay connected with their peers. Maitland et al. [2006] developed a cell phone application in which graphic avatars give the player feedback regarding his/her activities. In *Fish’n’Steps* [Lin et al. 2005], the player can observe metamorphosis of a fish avatar based on his/her exercise. Consolvo et al. [2006] have developed a mobile phone application for encouraging activity by sharing step count with friends. Lee et al. [2006] developed *PmEB*, an application for mobile phones that allows players to monitor their caloric balance as part of weight management. *Treasure* [Chalmers et al. 2005] allows players to collect virtual coins that are hidden in the game area based on GPS information. *CYSMN* [Benford et al. 2006] combines pervasive gaming action in a real part of a city with online game-play in a virtual model of the game area. *Catch the Flag* [Xu et al. 2003] is a twist of a popular traditional game, in which smart phones are used as the main interface. *Human Pacman* [Cheok et al. 2004] allows players to play tag in a pacman-style virtual environment. Recently, N. Patel from Georgia Institute of Technology has developed a prototype handheld version of DDR [Mobile DDR 2007].

Although, our work is firmly embedded in the interactive game framework suggested by the aforementioned publications, it is also quite distinct. Overall, researchers have started identifying the potential role that ubiquitous devices, like cell phones, can play in an interactive gaming framework for promoting physical activity, battling obesity, and offering quality entertainment. The main characteristic that sets NEAT-o-Games apart is that they are not carried out in short bouts, but are being played continuously and are interwoven in the daily routine of the players minute by minute; still they remain unobtrusive.

3. METHODOLOGY

3.1 Design Principles

The NEAT-o-Games design is based on the following principles (see Fig. 2):

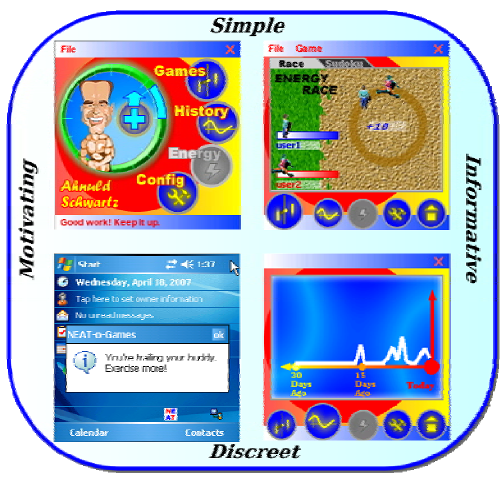

Fig. 2. NEAT-o-Games design principles as exemplified by characteristic screen shots.

- *Simple*. NEAT-o-Games' target population is the average consuming public. Therefore, the interfaces must be simple enough so that even PDA beginners can comfortably use them.
- *Informative*. The players should be able to understand easily all the game-related information.
- *Discreet.* NEAT-o-Games run for long periods (e.g., days) on the players' cell phones. Players carry PDA phones for reasons other than merely playing NEAT-o-Games. Therefore, the games should run mostly in the background and must not interfere with normal phone/PDA tasks.

- *Motivating.* The games should support behavioral change through strong motivation. Conventional methods for increasing physical activity rely on gym regimes. The great majority of people lose interest and abandon such regimes after a few weeks. Behavioral changes are hard to come by, and pervasive games may help more than righteous New Year resolutions.

Fig. 3. Two-player *NEAT-o-Race.* The two avatars race around the track and the overall standing is shown on the left. An annotated quantification in the center denotes relative lead or lag with respect to the opponent. The rate of avatar animation is commensurate to the level of each player's physical activity.

3.2 Game Design

NEAT-o-Games are envisioned as an expandable suite of games. For the moment it, comprises two games. One is *NEAT-o-Race*, a race game fueled by the player's physical activity. The other is *NEAT-o-Sudoku*, which is a variation of the Sudoku puzzle and benefits from consumption of physical activity points accrued in *NEAT-o-Race*.

3.2.1 NEAT-o-Race. *NEAT-o-Race* is indispensable in the NEAT-o-Games system. As we indicated in the Introduction (Section 1.2), the game rules are extremely simple. When the player moves, the corresponding avatar also moves, and activity points are accumulated. The player can select his/her opponent from the "buddy list" and compete for activity points. *NEAT-o-Race* bouts last typically 24 hours, although longer periods can be selected from the player interface.

One highly distinctive feature of *NEAT-o-Race* is the real-time feedback that it provides on the players' activities (see Fig. 3). If the game runs in the foreground and the player moves, he/she can see his/her avatar mirror his/her move instantly; when the player changes walking speed, he/she can also see an instant mirror change in the avatar's pace. Moreover, when the player's opponent moves, he/she can see it on his/her screen within 5-15 seconds depending on the network condition. This real-time feedback appears to "hook" players to the game. In the initiation of the pilot experiments, there have been many instances where subjects were running around watching the *NEAT-o-Race* screen. Hoysniemi's [2006] DDR research reveals that people are likely to be attracted by the novelty of player interface first and then continue playing the game for fun, exercise or challenge. In that sense, *NEAT-o-Race* is an ideal entry point to the game suite.

The home screen of the *NEAT-o-Games* suite features along with access buttons to the various functions (i.e., game screens, activity history, and configuration management), information about the current status of the race with a motivational twist (see Fig. 4). A dial with an up or down arrow communicates winning or losing status of the player,

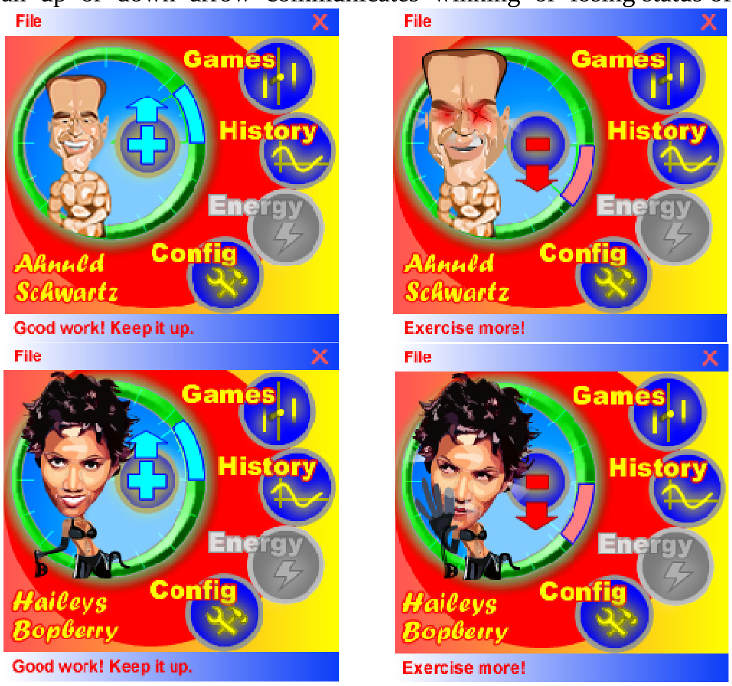

Fig. 4. Race monitoring avatars in home screens. If the player's overall activity level is higher than the opponent's, a pleased avatar shows (left screens). If the player's activity level is lower than the opponent's, an unpleased avatar shows (right screens).

respectively, along with a graphical quantification of the lead or lag amount. A static monitoring avatar in the center of the dial appears to be the information underwriter. One can view the monitoring avatar as a couch figure. When a player is ahead of the opponent, a pleased couch avatar is depicted in the home screen along with an occasional congratulatory message. If the player is trailing his/her opponent, a frustrated avatar appears in the home screen alongside with a call for more effort.

Couch avatars are caricatures of well-known athletes, politicians, and actors. A couch avatar depicted in Fig. 4 is a caricature of Arnold Schwarzenegger, an ex-athlete turned politician, and for this reason not only well-known but also semantically relevant. Another monitoring avatar depicted in the same figure is a caricature of Halle Berry, the famous Oscar-winning actress with athletic physique. The player can choose from a gallery of couch avatars his/her favorite one through the **Config** function.

3.2.2 NEAT-o-Sudoku. Sudoku is a logic-based number placement puzzle. The objective is to fill a 9x9 grid so that each column, each row, and each of the nine 3x3 constituent blocks contains the digits from 1 to 9. The puzzle setter provides a partially completed grid. This logic-based game has first gained popularity in Japan, then in England as a newspaper puzzle, and later in U.S. and across the world.

There are many reasons for which a variant of the Sudoku puzzle was introduced in the NEAT-o-Games suite. First, it blends a mental game into a suite of activity games, hence attracting more "brainy" players. Second, it is easy to use such a game as an acti-

Fig. 5. *NEAT-o-Sudoku*. The left image shows a Sudoku board, in which a yellow ball under the **Hint** button indicates that the player has available activity points to spend for hints. The right image shows the board after spending the points (the yellow ball has disappeared) and getting the hint (red 5).

vity point consumer, thus increasing the intensity of the racing game. Third, Sudoku is probably the most popular mental game; and fourth, it is a health game itself, so it blends well with the NEAT-o-Games concept. Sudoku is recommended for education [McCormack 2005] and even for Alzheimer prevention [Critser 2006]. As many puzzle games, Sudoku may become frustrating at times, that us, when the player hits a stumbling block and cannot see a way forward. In *NEAT-o-Sudoku*, a convenient "hint function" is provided that can rescue the player from this situation as long as he/she has been active enough and has some points "in the bank" from the racing game.

Fig. 5 shows the "hint function" of *NEAT-o-Sudoku*, which fills out one random slot upon tapping the **Hint** button. This hint operation requires a certain amount of activity points to be subtracted from the player's activity account. Deposits in this account are being realized through the racing game and can be consumed in the *NEAT-o-Sudoku* game. Of course, consumption of activity points lowers the standing of the player in the competitive race. For the player to maintain his/her competitive racing position, he/she has to get more active.

3.2.3 Discreet Design and Messaging. Even when NEAT-o-Games are run in background mode, they use occasional messaging to inform players about major events in the race. For example, they send an alert to the player when the opponent has built too much of a lead in the race (see Fig. 6). In the contrary situation, when the player is far ahead in the race, a congratulatory message is sent.

Fig. 6. Messaging when NEAT-o-Games are run in background mode. The left screen shows a rallying message that alerts the player who is being left behind. After pressing **ok**, the NEAT-o-Games home screen will be restored. The right screen shows a congratulatory message to the winner of the race in the previous day.

A message also announces the winner (or loser) of the *NEAT-o-Race* session. A typical race session lasts 24 hours from 12:00 am to 12:00 am next day. At the first login after a session, the player will see a message that declares him/her as winner or loser of the last session (see Fig. 6). The record of the session is stored in the database table and can be used for future reference.

3.3 Technology

3.3.1 System Architecture. We use a custom sensor package developed in-house to measure physical activity. Its form factor is similar to a mobile phone and it is typically attached to the waist of the player (see Fig. 7). It communicates with a Palm Treo 700w/wx phone [Palm 2007] through Bluetooth connection. Measurements are recorded four times every second and are correlates of the energy expended by the player due to motion at the time.

Concurrently, this data is transmitted to an SQL Server database through cellular broadband or Wi-Fi. Thus, the systems of other NEAT-o-Games players can access this data and make competitive real-time racing possible.

3.3.2 Sensor. We developed a lightweight sensor package that can be mounted almost anywhere on the body (foot, leg, arm, or waist). It is comprised of a tri-axial accelerometer, microcontroller, and a Bluetooth communication module (see Fig. 8). The accelerometer reading correlates better with the player's overall aerobic activity if the sensor package is placed close to the body's center of mass. Most of the work regarding caloric calculation using accelerometer has been done with the sensor attached to the waist [Choi et al. 2005; Bouten et al. 1996].

The Parallax propeller microcontroller [Parallax 2007] was chosen because it supports highly parallel processing, which is vital to the real-time nature of the application. The sensor package is driven by a rechargeable Lithium Polymer (Li-Poly) battery that lasts up to 6 hours when the device is active and transmission of data is continuous at 4 times/sec (default rate).

Fig. 7. Player wears activity sensor at his waist and holds a Palm Treo PDA phone at his palm. The devices are indexed in the right panel where the connectivity architecture is also shown.

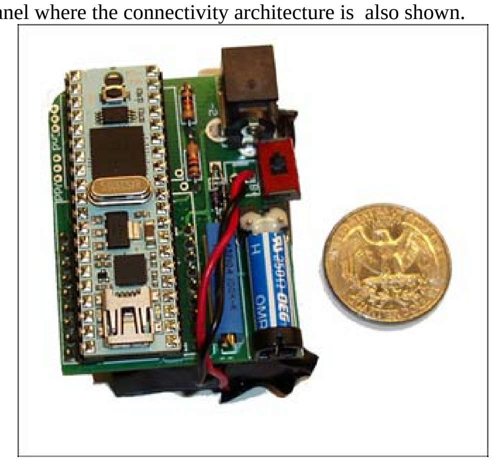

Fig. 8. Custom telemetry device, which consists of accelerometer, microcontroller, and transmitter. Battery is attached to the rear side of the board. Dimensions are 5.1 cm x 4.2 cm x 2.0 cm.

3.3.3 Database and Network Connectivity. We use a relational database instance of SQL server 2005 to store player information and his/her activity record. This is the central hub of the system where all information is stored and postprocessed. For example, everyday at 12:00 am, a scheduled server program searches the database, calculates everybody's activity points of the day passed, and stores the results into the "game statistics" table. On next day's first login by the players, each NEAT-o-Games instance will refer to the table and receive winner/loser information.

A typical problem in cellphone-based systems is intermittent network failure. Even if the player lives in an urban area where coverage is strong, intermittent network failure is still unavoidable (e.g., the player goes into an underground library floor). NEAT-o-Games manage intermittent network failures in an effective manner, highly transparent to the player. When network connection is down, NEAT-o-Games store the player's activity record to a local file system, which acts like a cache and is flushed to the server database after the network connection is back. At the same time, NEAT-o-Games automatically try to reconnect to the network so that players do not have to engage in any restorative action.

4. EXPERIMENTAL STUDY

We conducted two experiments to evaluate NEAT-o-Games. One was conducted at the University of Houston and the other at the Texas Medical Center. The former was a short-term pilot experiment meant to test smoothness of operation and initial perceptions. The latter was a longer-term experiment meant to investigate trends in behavioral change.

4 .1 Experimental Study at the University of Houston (UH)

4.1.1 UH Experimental Procedure. A pilot experimental study for an initial evaluation of NEAT-o-Games was conducted after the approval of the local Institutional Review Board. Eight participants (7 males, 1 female) were recruited from the University of Houston (UH) campus. Prior to beginning the experiment all participants were requested to sign a consent form, read the NEAT-o-Games manual, and fill in a pre-test questionnaire form, which asked questions about height, weight, and % body fat measured. During the experiment, participants' activity levels sensed with the NEAT-o-Games telemetry devices were recorded in the SQL server. At the end of the experiment, all participants were requested to fill in a post-test questionnaire.

The experiment consisted of four sessions; each session included one weekday and one weekend day.

Session 1: *Baseline Session.* During this session, the participants were asked to carry around the NEAT-o-Games set (PDA + sensor). The system recorded their usual physical activity levels and the baseline was established.

Session 2: *Emulator Session.* The NEAT-o-Race simulated avatar option was activated. The player was represented by an avatar competing with a computer-animated avatar in a virtual race. The rate of animation of the player's avatar was controlled by accelerometer data. The more the player moved, the higher the rate of animation for the avatar that represented him/her in the virtual race. The pace of the simulated avatar was set to a level slightly lower than the recommended daily physical activity for an average person. Therefore, for the player to win the race, he/she had to complete at least the average daily physical activity quota.

Session 3: *Energy Race.* The human to human competitive option was activated. In that session the competitive avatar in the virtual race represented an actual player ("buddy") from the player pool that participated in the study. For each duo, a daily winner was proclaimed based on the activity scores logged by the corresponding players.

Session 4: *Sudoku.* In that session, each participant played competitively against his/her buddy. However, the player had the option of spending activity points gathered during the daily race in exchange for help in the PDA-based Sudoku game. This helped the player to solve difficult Sudoku puzzles, but to make up spent points he/she had to be more physically active.

4.1.2 UH Pre-Test Information. Useful information about the profile of the participants was gathered from the consent form and pre-test questionnaire. Specifically, the statistical mean and standard deviation of age, height, weight, percentage of fat, and body mass index (BMI) for the participants were collected and computed (see Table I). The population sample was composed primarily of young people who were bordering the overweight category. According to WHO I classification [WHO 2007], people with $19 < BMI < 25$ are normal, while those with $25 < BMI < 30$ are overweight.

Tabulation of other profile information from the participants' answers in the pre-test questionnaire is shown in Table II, including information about computer savviness, computer game preferences, active/inactive lifestyle, work breaks, and initial attitude to

Table I. Statistics of Physical Attributes for UH Participants

Physical Attribute	**Statistics (** $n = 8$ **)**
Age (yr)	$\hat{\mu}_a = 28.1, \quad \hat{\sigma}_a = 7.3$
Height (in)	$\hat{\mu}_h = 72.9, \quad \hat{\sigma}_h = 2.7$
Weight (lbs)	$\hat{\mu}_w = 178.9, \; \hat{\sigma}_w = 29.3$
% fat	$\hat{\mu}_f = 21.2, \quad \hat{\sigma}_f = 5.0$
BMI (kg/m)	$\hat{\mu}_i = 24.3, \quad \hat{\sigma}_i = 3.9$

Table II. Profile of UH Participants

1. 88% of the participants knew what a Smartphone/PDA was.
2. Favorite computer games included: solitaire, minesweeper, snake, bowling, and Baldur's gate.
3. The average time that the participants devoted to exercise was around 5 hours per week.
4. 75% of the participants had started an exercise plan in the past. Out of those, 67% stopped within a month and the remaining within a year.
5. The main reason for abandoning the plan was motivation to keep up.
6. 88% of the participants had lunch around noon, and the remaining around 01:00 pm.
7. All participants went back to work after lunch.
8. 75% of the participants left their work place around 06:00 pm.
9. 75% of the participants had dinner around 07:00 pm.
10. 60% of the participants relaxed in their homes before dinner.

the NEAT-o-Games concept. The participants were computer literate and played computer games occasionally. They also had a moderately active lifestyle, a normal working schedule, and a positive attitude towards NEAT-o-Games.

4.1.3 UH Results. In the pilot experiments, two questions for which we sought quantified answers were the following:

- Do NEAT-o-Games motivate people to devote more time in physical activity?
- Do NEAT-o-Games contribute to intensifying people's physical activity (e.g., from leisure to high-pace walking)?

First, we had to determine the threshold that separates typical NEAT activity (e.g., walking) from inactivity (e.g., sitting). To be true to the continuous nature of the activity-intensity axis, we termed regular NEAT activity, *high activity* and inactivity, *low activity*. A person is considered to be inactive when the output from the NEAT-o-Games sensor

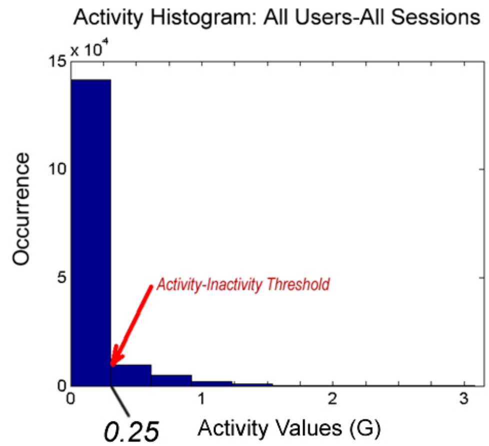

Fig. 9. Histogram of sensor values.

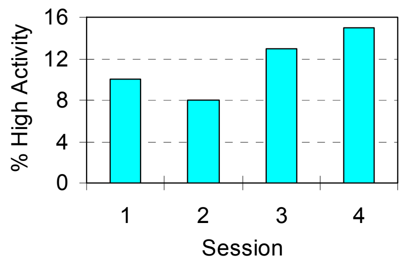

Fig. 10. Percentage time of high activity during the UH experiment.

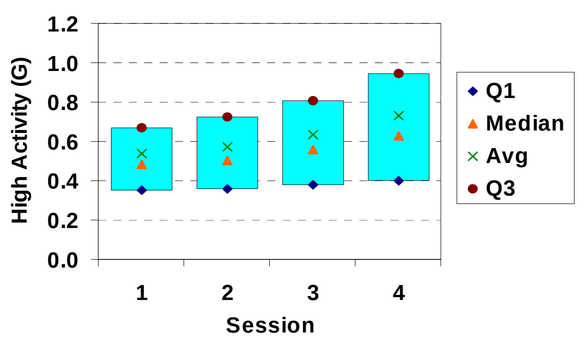

Fig. 11. High activity box plot for the UH experiment.

has a value lower than 0.25 G. We determined this threshold from the histogram of all sensor values recorded during the experiment (see Fig. 9). Quantitative analysis was conducted on both the UH and TMC datasets on the basis of this threshold.

Based on the intensity threshold between low and high activity, we counted the time players exhibited high activity in every session and plotted the relative results in the graph of

Fig. 10. High activity time as a percentage of the total time increased in Sessions 3

and 4, where the competitive human to human race game was played, with respect to the baseline Session 1. Session 2, where the competitive human to machine race game was played, appears to contradict this trend. In part, this shows that the human element may act as a stronger motivator. Nevertheless, one has to take into account that Session 2 was the first time ever players had the chance to play some form of the NEAT-o-Games (emulator mode). A sort of "cultural shock" may have contributed to a less than spectacular start. It is also likely that the current design of the emulator contributed to boredom, as the computer avatar maintained a constant speed throughout the session, which was the amortized value of an average daily activity.

Based on the intensity threshold, we also computed the descriptive statistics for low and high activity values in the various experimental sessions (see Fig. 11). It appears that the intensity of high activity progressively increased as NEAT-o-Games options were added in the experiment, including the human to human race (Session 3) and *NEAT-o-Sudoku* (Session 4). The mean increase of high activity values was accompanied by a widening spread. In other words, while players maintained some of the regular NEAT activities (e.g., walking at a normal pace), as the experiment unfolded they also exhibited more intense activities (e.g., walking at a forced pace); the intensity of low activity remained relatively stable throughout the experiment.

Table III. Summary of Qualitative Analysis from the UH Experiment

Strengths of NEAT-o-Games
The players felt that the competitive yet friendly character of the game was innovative.
The telemetry devices were easy to use; but on some occasions uncomfortable.
All players suggested that they could incorporate NEAT-o-Games to their everyday lives.
Players felt that a few minutes of training were enough to start using NEAT-o-Games.
All players liked the interface of NEAT-o-Games.
The players enjoyed the ubiquitous nature of NEAT-o-Games. They could use it wherever and whenever, and compete against whoever they desired.
All players enjoyed the energy race game and found the introduction of a mental game (Sudoku) very appealing.
All players stated that they could use NEAT-o-Games through the day.
Weaknesses of NEAT-o-Games
There were occasional technical problems; the sensors did not charge at times.
More games for different age groups should be added.
The sensor should become smaller and more stylish to accommodate female players.
The sensor was a bit uncomfortable when it was worn at the waist (especially by females); perhaps another spot (arm or wrist) would be better.
Energy expenditure should be depicted in terms of Kcal not raw accelerometer units.
The emulator should be made more challenging by dynamically adjusting its speed according to player activity.
Battery life time for both components should be more than 12 hours.

More than two players in the race game should be allowed.
The sensor and PDA phone should be combined into one device.
According to one participant, NEAT-o-Games need more pop-up motivational statements geared to females, such as “You look fabulous,” “Keep drinking water,” “Keep eating the right things.”

Table IV. Selected Verbatim Participant Comments in the UH Experiment

“NEAT-o-Games will help me exercise more! Now when I play NEAT-o-Games I take the stairs to go to the 5th floor where my office is, instead of an elevator. I want to beat my opponent!”
“When using NEAT-o-Games I want to stand up and keep moving while I work! This concept is truly innovative!”
“NEAT-o-Games are ok. When the games go on without any software or hardware bugs it is a real pleasure! Sometimes, though, when bugs occur I just want to throw the system out my window.”

The post-test questionnaire responses were analyzed qualitatively to extract NEAT-o-Games’ strengths and weaknesses. The summary is shown in Table III; characteristic comments from players are shown in

Table IV. Although, the players had difficulty with the somewhat crude implementation of that time, they enjoyed the intriguing concept of NEAT-o-Games. This can be observed in the quantitative results, too.

4.2 Experimental Study at the Texas Medical Center (TMC)

4.2.1 TMC Experimental Procedure. To assess the impact of NEAT-o-Games in more realistic terms, another experimental study (per the approval of the local Institutional Review Board) was conducted in the newly founded National Center for Human Performance of the Texas Medical Center. Ten participants (N=10, eight females and two males) were recruited through flyer and e-mail advertisement. Each participant was assigned one “buddy” with a similar body mass index (BMI), against whom he/she would compete. Thus, there were five game groups; the study ran for four weeks.

In the TMC experiment, a single session approach was adopted to observe the naturally evolving use of the system. Players were provided with a NEAT-o-Games set and left free to experience and use the system at will. Application logs allowed later analysis of user operation.

We used three metrics in order to monitor and evaluate the participants’ physical and behavior modification over the duration of the study:

(a) Physical activity record of each participant logged by the application to the central SQL server database, as well as user operation history logged to the phone’s local file system.
(b) Usability testing and player interviews that were meant to reveal positive and negative feedback points.
(c) Trend explanation focus groups [Krueger 1997] that assisted in spotting behavioral trends during and after the study.

A usability test session was conducted for all participants to confirm that the interface of NEAT-o-Games did not present any serious problems. The participants were asked to complete a set of 13 tasks designed to evaluate the system's interface and interactivity. The usability test was conducted in a closed room with the discreet presence of a moderator and a note-taker. Participants were urged to talk on an audio recorder while they were completing each task. The moderator did not intervene at all during the test, unless requested by the participant. Time was recorded upon the completion of each task and the metrics were extracted. Each task had an ideal completion time set by the experts. The ideal time was determined as follows: First, the two main developers of the system were requested to complete the usability test two times; then the extracted mean times were multiplied by a factor of 3 to 10, based on the difficulty of the task [Dumas et al. 1999].

Based on their physical activity record, participants were classified into consistent (*Nc*=4); average (*Na*=3); or below-average (*Nb*=3). Consistent players were those who played NEAT-o-Games at least 80% of the total study time (24 days); average players were those who played for at least 50% of the total study time (15 days); and those below-average played for fewer than 15 days.

Three focus groups were conducted, one for each activity level; refreshments were provided; and conversations were recorded for post-analysis.

4.2.2 TMC Pretest Information. The statistics of the physical attributes for the TMC participants are given in Table V. The participants' average age was above 30, and 80% of them were overweight or obese.

Tabulation of other profile information from the participants' answers in the pretest questionnaire is shown in

Table . The participants were computer literate, but less sophisticated than UH participants. They also had a sedentary lifestyle, normal working schedules, and positive attitudes towards NEAT-o-Games.

4.2.3 TMC Experimental Results. The mean physical activity level per player for the different focus groups is shown in Fig. 12. The Y-axis indicates the intensity of the activity during valid playing time. Valid playing time is the time during which NEAT-o-Games is on and functioning properly (i.e., the sensor-to-phone Bluetooth communication is active and working correctly).

Table V. Statistics of Physical Characteristics for TMC Participants

Physical Attribute	**Statistics (*N*=10)**
Age (yr)	$\hat{\mu}_a = 37.9, \quad \hat{\sigma}_a = 7.5$
Height (in)	$\hat{\mu}_h = 66.3, \quad \hat{\sigma}_h = 3.7$
Weight (lbs)	$\hat{\mu}_w = 183.9, \quad \hat{\sigma}_w = 38.5$
BMI (kg/m)	$\hat{\mu}_i = 30.5, \quad \hat{\sigma}_i = 6.4$

Table VI. Profile of TMC Participants

1. 60% of participants knew what a Smartphone/PDA was.
2. No participant had much exercise with computer gaming.
3. The average time that participants devoted to exercise was less than 4 hours per week.
4. 70% of participants had started an exercise plan in the past. All stopped in less than 2 months.
5. The main reason for abandoning the plan was motivation to keep up.
6. Participants had lunch break at around 12pm.
7. Participants left work between 5pm and 6pm.
8. Participants' dinner time ranged between 7:30 pm to 9pm.
9. 80% of participants went back to work after lunch.
10. 70% of participants relaxed in their homes before dinner. Among the rest, one participated in her kids' activities and another went to a second job.
11. All participants had a positive attitude towards technology and NEAT-o-Games. It is characteristic that 8 participants stated that they never forgot their cell phones wherever they went.
12. Most participants (9/10) stated that they were trying to have a healthy lifestyle.

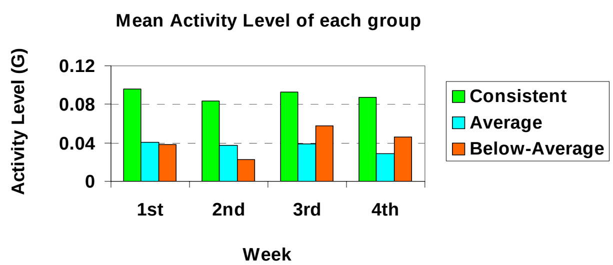

Fig. 12. Mean activity levels per player for the different groups, derived by dividing cumulative activity points with valid playing time (seconds).

Consistent group players showed higher activity levels than other group players throughout all four weeks. In fact, two of the players reported that they lost weight. This result is an indication that NEAT-o-Games could be an effective physical activity incentive to office workers.

Fig. 13 shows the mean physical activity levels of participants during specific times of the day. Activity levels go up in the morning and remain about the same until participants come home. The high activity hours correspond to the participants' lunch-break and commuting time, which brings the NEAT-o-Games' unobtrusive, yet effective, interaction mode to the fore. Unlike other pervasive games, like *Majestic* [Szulbroski 2005; Wikipedia: Majestic 2007], NEAT-o-Games allow players to engage on their own volition in game-relevant activities (i.e., physical activities) compatible and not in conflict with their daily routines. For example, several participants developed a walking-break behavior in the office.

In the usability test, all participants managed to complete all tasks under the time threshold (Fig. 14). Six tasks and their ratios are depicted in Table VII. The first three tasks have the lowest ratio to expert time, whereas the last three have the highest ratio. Frequently used functions were apt to be finished faster, whereas rarely used functions required more time.

Focus groups revealed interesting player responses, including group-specific as well as unanimous ones. All participants in all groups agreed that the concept was motivating and encouraged them to be more physically active than they used to be. The element of real-time competition was very appealing to them. Most of the participants felt that the system made them more "conscious of their everyday activity levels" and gave them a very good understanding of how sedentary they were prior to the study. For example, one

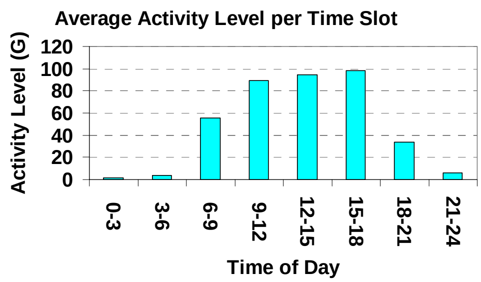

Fig. 13. Average activity level per time slot.

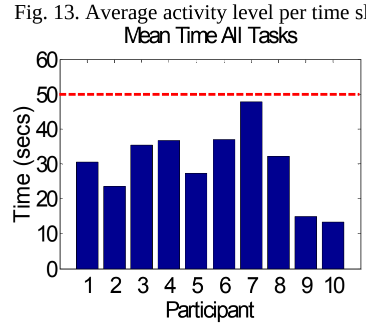

Fig. 14. Mean completion time for all tasks by the set of participants. The red line represents the threshold.

Table VII. Tasks with the Lowest and Highest Ratios to Expert Time

Tasks	Ratio to Expert Time
Start Application	1.318
Play NEAT-o-Race	1.386
Choose Real Life Opponent	1.414
Choose Emulator Opponent	2.45
See History	3.025
Change Avatar	3.838

participant used to ask her son to bring her water at home, but now she went to get it herself. Another participant remembered that she was motivated to be active when she woke up and saw her buddy's avatar running ahead of her. Qualitatively, the ubiquitous nature of the system appeared to have quite an impact.

The drawback of ubiquity is that users would sometimes feel annoyed. Such a reaction has been observed in an ambitious trial of *Majestic* [Kushner 2002], in which players did not appreciate the way their lives was interrupted by the game; for example, players received frequent calls with clues to solve a mystery. This was quite a persistent approach.

NEAT-o-Games have a much more discreet game design, hence only two of the ten TMC participants expressed some annoyance at the game's interaction. NEAT-o-Games mostly run in the background and interact with the player only when the player is far behind or far ahead in the race game. Even then, the interaction is minimal and nonpersistent (i.e., a single message). There are no obnoxious calls that, in essence, ask the player to perform this or the other task. NEAT-o-Games "bet" that most players will check (at least out of curiosity) the status of the race from time to time. Eventually, they will get motivated to do something small or big, which may become a habit. This bet has appeared to work with most players so far. Based on the system log, players were checking the status of the race every 10-25 min. Thus, they took a real interest on the game. Many of them developed new behaviors, such as taking walking breaks at work (see Fig. 13) and happily doing chores that they had previously tended to avoid (e.g., fetching their own water). These were sure signs of volitional engagement in the game.

All participants complained that the battery life of the Smartphone and sensor was too short. In its current version, NEAT-o-Games can continuously capture/transmit activity data for approximately 6 hours without recharging. Participants were given one spare battery so that they could use the system for about 12 hours per day; but this was still not a true 24/7 system. Participants also uniformly stated that charging everyday was a problem. When they had some irregular event (e.g., travel), carrying chargers with them was not convenient. All participants commented uniformly on the wear ability of the sensor. Currently, the sensor size is 5.1 x 4.2 x 2.0 cm, and is attached to the waist. Participants want a smaller sensor, and female players expressed a strong desire for a sensor they could wear on their arms like a watch or a bracelet.

The degree of displeasure on the perceived negative points of the application were different for different groups. Below-average and average players commented that the difficulty of using the system reduced their motivation to play from time to time. In contrast, most of the consistent players adjusted to those drawbacks. Here is a quantitative example that depicts this phenomenon. The sensor-to-phone communication is valid as long as a user: (1) keeps the sensor battery charged; (2) keeps the sensor switch on; and (3) carries the sensor and phone in proximity (100 ft). But depending on the player, these tasks are not as easy to do as they sound. In

Fig. 15 we compare the cumulative NEAT-o-Games running hours among different groups to see how well the

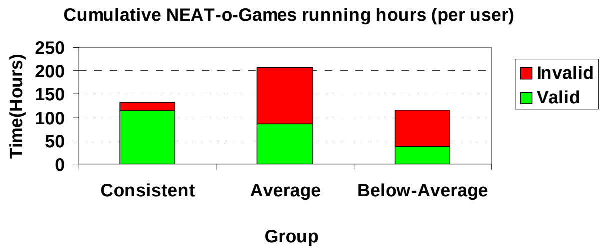

Fig. 15. NEAT-o-Games running hours per player in different groups. Green represents valid playing time and red represents invalid playing time (either the sensor is off or too far from the phone to establish communication).

Table IIX. Selective Verbatim Comments from Participants in the TMC Experiments

"I love the challenge that the system gives me. The concept is perfect, I am more conscious of my activity right now."
"We are both more conscious of our everyday lives right now. I did not realize one month ago how much I sat!"
"The system is absolutely wonderful and fun when it works. Sometimes, though, the battery will die after only 6 hours!"
"There is too much maintenance to do. Charging all the time and carrying spare sensors… Our life is not hooked with power plug!"
"When I realize the phone battery is dead and notice that my recent activity was not registered, I feel very discouraged to continue. "
"I had a hard time carrying a sensor and a phone at the same time. It would be better if you combine them together."

players maintained valid communication, and it appears that average/below-average groups had hard time doing so. Participants' comments (Table) suggest that with further improvements in usability average and below-average players were likely to become consistent players.

5. CONCLUSIONS

This article presents a new game paradigm to attack the behavioral aspects of a sedentary lifestyle, which is the major culprit in the obesity epidemic. The article introduces NEAT-o-Games where characters compete on the basis of energy counts recorded by accelerometer sensors that players wear alongside their cell phones. Typically, games are diversions of short duration from everyday life; but NEAT-o-Games, unlike others, run for hours, days, *or for life*. They are meant to become part of people's everyday routines.

In a pilot experiment conducted with participants from the University of Houston, the games were well received by the players and appeared to increase both the time and intensity of the players' engagement in mild aerobic activities. Although, this is highly encouraging, it should be interpreted with caution, as the duration of the experiment was short (a few days).

A longer-term experiment that ran for four weeks was conducted with participants from the Texas Medical Center. Valuable experience was gained about problems that manifest themselves when the game goes on for a long time in realistic conditions.

Participants' physical activity records indicate that a good percentage of them sustained an elevated level over the four weeks, suggesting that this approach will be viable for long-term activity modification. Usability tests showed that the game interface was adequately designed. Focus groups revealed that the NEAT-o-Games concept was appealing to everybody after four weeks of usage. Although the system is still evolving and longer experiments are planned with more participants, analysis of the recent, rather realistic, experiment suggests that NEAT-o-Games is a step in the right direction.

The participants were not complete strangers as they were colleagues working in the same organizational unit. Almost none of them were avid computer gamers. It is to the credit of NEAT-o-Games that it managed to engage a difficult demographics, that is, nongamers. The effect of using complete strangers and/or avid gamers as co-players remains to be seen.

6. FUTURE WORK

Despite progress and encouraging initial results, a lot remains to be done. Focus groups revealed that players belonging to the average/below-average groups felt that the maintenance effort required by the system was too much. To ameliorate this discouraging effect, we need to extend the battery lifetime and minimize the size of the sensor. Alternatively, we are looking to migrate the games into a phone platform that has a built-in accelerometer, like the iPhone. This will solve many usability problems, but its effect on the accuracy of the measurements of physical activities needs to be studied carefully.

Transformation of raw accelerometer values to calories appears to be important to players as they correlate to units that they can understand. The motivational effect of this should not be underestimated. Choi et al. [2005] did some research on deriving calories from triaxial accelerometer values, on which a future effort should be based. Weighting the accelerometer values for different body positions is also essential for accuracy and fair game-play. This is in response to feedback from female players who would prefer to wear the accelerometer on their arms rather than attaching it to their waists.

Reliability and battery life are challenging problems. Currently, the PDA phone lasts only 6 hours when NEAT-o-Games run continuously. Energy-scavenging technology can address this issue. Konarka [2007] is developing a wearable solar panel that can charge small devices and may be of help in a future effort.

The choice of *Sudoku* as the second game of the suite had to do in part with the discreet persuasive philosophy of NEAT-o-Games. Many people use puzzle games to "kill" time while they wait at airports or in other such places. We wanted to use this natural habit to make the connection with the *NEAT-o-Race*, which epitomizes the urgency for physical activity (e.g., take a walk around the terminal). As the experiments show, however, not all games may appeal to all people. The UH participants (scientists) appeared to engage in *NEAT-o-Sudoku* much more than the TMC participants (office staff), who found it somewhat difficult. A future addition of *NEAT-o-Solitaire* may be more appealing to the latter demographic. Therefore, more innovative games that can produce or consume activity points need to be added to the NEAT-o-Games suite, not only to keep the players' motivation from sinking in the long run but also to satisfy different tastes.

As with every game, cheating is a concern. The best-known form of cheating in NEAT-o-Race is for the player to shake the sensor with his/her hands. In the experiments so far, no such cheating activity appears to have occurred. We can say this with some confidence, as shaking produces a characteristic signal, which is very different from the signals of other NEAT activities, like walking. In careful signal analysis of the players' records we found no suspicious signal segments. Most participants were of a certain age and motivated to change lifestyles – thus cheating was probably not very much in their minds. It is of intrinsic research interest, however, to monitor any innovative cheating or adaptive behaviors that may develop from different demographics (e.g., teenagers) in future experimental efforts.

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