Exergame Effectiveness: What the Numbers Can Tell Us

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Abstract

A sedentary lifestyle is linked to many diseases, including diabetes and heart disease, as well as ailments such as obesity, which is becoming the major root cause of early death in most industrialized countries. The advent of the television, computers and videogames has resulted in a more sedentary lifestyle, with more time spent in front of a screen more than ever before. Exergaming is a term used to describe video games that provide encouragement to exercise, particularly for an audience that may be reluctant to engage in the more traditional forms of exercise. Exergames are a commonly accepted method of encouraging more physical activity to promote better health for those with high levels of sedentary screen time. In this work, we survey a number of quantitative exergame studies to define a general set of elements that make exergames effective from a physical standpoint. We also examine the intended audience and the incentive elements necessary for an exergame to meet the needs of its audience. Finally, we examine our own exergame system and how well it performs against commercial systems.

CR Categories: H.5.1 [**Multimedia Information Systems**] Evaluation & methodology J.m [**Computer Applications**] Game Technologies.

Keywords: Exergames, Quantitative Analysis, SNAP, Sensor Networks.

1. Introduction

The effectiveness of exergames and fitness related game technologies have recently garnered a lot of attention by researchers. Exergames have two goals that are often quite difficult to achieve simultaneously, namely: *Incentive and Physical Benefit*.

These two goals are difficult to rationalize because a game often requires several attempts to perfect the required actions to complete the game objectives. Conversely, performance of the human machine degrades with fatigue, and repeated practice actually makes a physically demanding objective immediately more difficult.

Examinations of exergames have been mainly focused on the physical benefits of existing exergames. We can classify the existing literature into qualitative and quantitative evaluations. The qualitative body of work tends to focus more on descriptive results that are often exploratory and/or investigative. The findings in the qualitative research are not conclusive and cannot be used to make generalizations about exergames. They do, however, help us develop an initial understanding and sound base for further investigation. The quantitative research typically uses instrumentation to objectively measure the biophysical outcomes of participants. In this work, we examine the latter to draw out general conclusions and commonalities of several studies [Anders, 2008; Graf et al. 2009; Graves et al. 2008; Graves et al. 2007; Lanningham-Foster et al. 2009; Lillie et al. 2005; Maddison et al. 2007; McWha and Brown, 2009; Mellecker and McManus, 2008; Mellecker et al. 2009; Olmstead, 2006; Sell et al. 2005; Sell et al. 2008; Siegel et al. 2009; Walker et al. 2006]. We examine the physical aspects of exergame design in section 2.

Incentive is a very difficult aspect of the exergame to quantify, as different people will respond to different incentives. Whereas some players will enjoy an exergame based on yoga, other will find yoga as a disincentive. One of the issues in creating a whole game geared at losing weight, for example, is that if people don't see tangible results within a few weeks, they'll quit. Also, weight management comes not from exercise alone, but in conjunction with a sensible diet. In reality, most people on new workout programs won't see noticeable results for at least 1-2 months. Thus, an exergame needs to keep motivation for an extended period of time. If players have other reasons for playing an exergame such as a riveting hero's quest, social aspects, competition on leader boards, interesting content/storylines then maybe they will participate for the longer term. In other words, making the weight loss a secondary motivator rather than a primary motivator might be more successful in the long run.

In this work, we will show that the physical benefits of games has been effectively quantified and examined. Moreover, we will exhibit that the current game technologies still have a long way to go in improving effectiveness. We will examine the physical benefits of exergames in section 2, with a thorough review of studies that have quantified their physical effectiveness. We will examine incentive, which is often intangible, and a means of quantifying it using utility theory borrowed from economics, in section 3. In section 4, we will examine our system based on the use of sensor networks and the improved physical benefits provided. Finally, we will sum up our findings in section 5, and outline some base elements of considerations for anyone designing exergames.

2 Survey of Exergames

Of fifteen quantitative exergame studies, six tested games for the Nintendo Wii [Anders, 2008; Graf et al. 2009; Graves et al. 2008; Graves, Stratton, Ridgers, and Cable, 2007; Lanningham-Foster et

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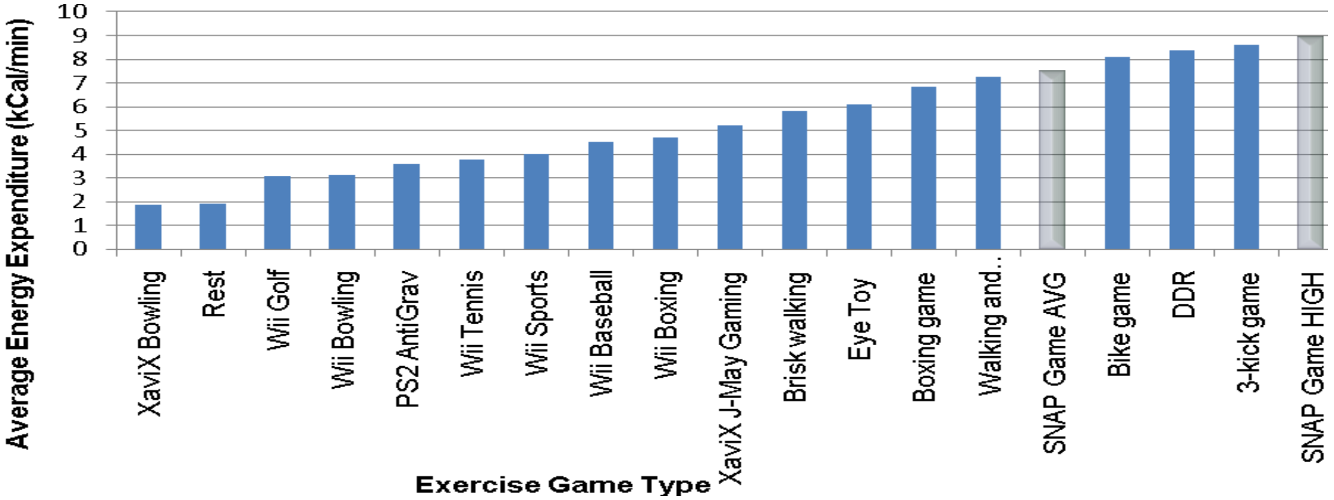

Figure 1: *Average energy expenditures from various commercial exergame systems [blue] and our proposed system [grey].*

al. 2009; McWha and Brown, 2009], three examined exertion with Sony's EyeToy games [Maddison et al. 2007; Sell et al. 2005; Walker et al. 2006] and six used Konami's Dance Dance Revolution [Graf et al. 2009; Lillie et al. 2005; Olmstead, 2006; Sell et al. 2008; Siegel et al. 2009; Walker et al. 2006]. One study compared exertion level of participants at different levels of game difficulty [Graf et al. 2009]. Another DDR study found that experienced players exerted more energy than inexperienced participants [Sell et al. 2008], which this work independently verifies. Some work has also been done to measure exertion of walking briskly or while watching TV or using a media system [Mellecker et al. 2009; Sell et al. 2005; Walker et al. 2006]. A summary of results is shown in Figure 1.

Children and adolescents are a popular target audience for quantitative exergame studies, leaving a gap in research addressing the needs of older populations. The majority of the quantitative studies involved participants with mean age under 20 [Graf et al. 2009; Graves et al. 2008; Graves, Stratton, Ridgers, and Cable, 2007; Lanningham-Foster et al. 2009; Maddison et al. 2007; Mellecker and McManus, 2008; Mellecker et al. 2009; Olmstead, 2006; Sell et al. 2008; Siegel et al. 2009; Walker et al. 2006]. Several studies measured exertion in people with mean age above 20 [Anders, 2008; Lillie et al. 2005; McWha and Brown, 2009; Sell et al. 2005; Sell et al. 2008; Siegel et al. 2009]. While Siegel et al. [2009] grouped participants into two groups: under 19 and 20 or over, only one study explicitly mentioned participants with a mean age above 30 [Lanningham-Foster et al. 2009]. No quantitative studies could be found measuring energy expenditure among middle-aged or older adult populations.

Several studies conducted separate data analysis of male and female participants [Graf et al. 2009; McWha and Brown, 2009; Siegel et al. 2009] and one study examined male-only players [Sell et al. 2008]. Quantitative studies made health and fitness comparisons on a number of different variables, including differences in energy expenditure with human and computer opponents [McWha and Brown, 2009] and lean versus overweight players [Walker et al. 2006]. The quantitative studies examined ranged from between 7 and 33 participants [Olmstead, 2006; Sell et al. 2008].

All of the systems examined elicited average heart rates and energy expenditures above rest within their own studies. All of the systems, except XaviX Bowling, resulted in energy expenditures above an average rest value, calculated using rest data from multiple studies [Graf et al. 2009; Graves et al. 2008; Graves, Stratton, Ridgers, and Cable, 2007; Lanningham-Foster et al. 2009; Maddison et al. 2007; McWha and Brown, 2009; Mellecker and McManus, 2008; Mellecker et al. 2009; Walker et al. 2006]. The results show that exergames requiring any type of body movement result in increased energy expenditure over sedentary activities that do not require movement. While many of the games surveyed may not be sufficient to provide users with all of their recommended daily exercise, exergames still provide some health benefit over other forms of screen-based entertainment.

Systems towards the more energy intensive end of the spectrum typically involve predominantly leg movements [Graf et al. 2009; Lillie et al. 2005; Olmstead, 2006; Whitehead et al.; 2007; Sell et al. 2005; Siegel et al. 2009; Walker et al. 2006] for example, DDR, 3-kick, bicycling games, and our SNAP system. This finding is consistent with our hypothesis that games enforcing full-body movement will result in more rigorous exercise. Upper-body movement is limited in the majority of the games identified, which suggests that leg movement may be sufficient but fully body movement is preferred.

There are a number of factors that influence participants' level of exertion, including physical characteristics, motivation, and experience. There is a strong correlation between heart rate and energy expenditure, despite participant differences in age, height, weight, and other physical factors is shown in Figure 2. This finding is valuable for future testing of exergames and suggests that complex procedures for measuring energy expenditure are not necessarily required in order to estimate the physical effectiveness of an exergame. Digital heart rate monitors are a comparatively convenient and economical alternative to more sophisticated metabolic measures.

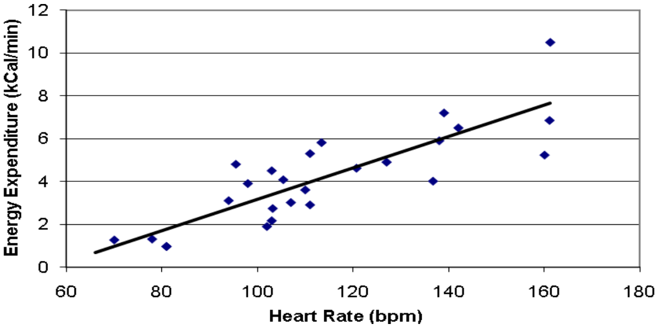

Figure 2: *Heart rate and corresponding energy expenditure across all studies.*

2. Incentive in Exergames

Attractiveness, motivation or incentive in exergames is most similar to the concept of utility value in the field of economics. A utility value is a theoretical concept that quantifies a person's satisfaction from consuming a good or service. Utility theory acknowledges that a consumer's utility value is hard to measure and changes from person to person. However, we can determine it indirectly from observations of consumer behavior under the assumption that consumers will strive to maximize their utility as they have, historically, in utility-based consumer analysis.

From classical economic theory to exergames, where the consumers are our players, designing exergames can be facilitated by acknowledging a few simple tenants:

- An exergame as a motivation tool is not designed for people who already engage in traditional physical activity. Thus, traditional motivation mechanisms are not likely to work well for the exergame target demographic.
- Utility values for different activities will vary from person to person; there will not be a one-size-fits-all model
- The effectiveness of an exergame is a combination of the motivation AND the physical benefit it provides.
- Utility values for different target demographics will reveal themselves over time through.

To our knowledge, there are no long term studies on the ability of exergames to maintain a player's interest and motivation, and provide the requisite physical benefits. The utility of different techniques thus remains uncharted and an open problem. It took economists decades of observing target demographics to develop utility value guidelines for consumer behaviors. However, we believe that a key factor to solving the incentive issue is through social facilitation. That is to say, a massively multi-person online system that allows like-minded individuals to socialize while engaging in the physical activities is a promising area for examination. This opens the incentive elements to a much more complex dynamic including peer pressure, duty, leadership and social engagement that single player offline games cannot necessarily provide.

3. Sensor Network Based Study

SNAP is a prototype exergame system that uses sensors attached to the player's limbs, requiring the individuals to move their entire body [Whitehead et al; 2007]. The SNAP system has various games that operate on its full body philosophy, including track and field events and a DDR inspired game that requires players to mimic eight dance positions to music. The participant must be in the correct pose by the time the depicted pose reaches the top of the screen. The attached sensor network then verifies whether or not the player has replicated the depicted pose properly. Each dance movement that a participant completes is evaluated by the sensor network attached to his or her wrists and thighs. If correctly performed, a score for that pose will appear on the screen. .

3.1 Study Setup

During SNAP sessions, participants were first given instructions on how to perform the eight dance poses, shown in Figure 3. Training was initiated at a speed of 20 Poses per Minute (PPM) and speed was then increased to 30 PPM. An additional 10 minutes of practice was completed at a speed of 60 PPM [the speed which they were tested]. In all, participants were given 30 minutes of experience with SNAP prior to the official tests. In testing sessions, participants played continuously for 15 minutes, then were given a 1 minute rest, followed by another 15 minutes of play.

	Age [years]	Height [cm]	Weight [kg]	Body Mass Index
Male	21.7 ± 1.8	178.4 ± 9.8	70.5 ± 8.6	21.8 ± 1.9
Female	21.9 ± 1.1	160.5 ± 2.8	64.0 ± 9.9	21.9 ± 1.1
Total	21.8 ± 1.5	170.6 ± 11.0	67.7 ± 9.4	23.3 ± 3.1

Table 1. *Participant Stats: Age, Height, Weight and BMI.*

Figure 3: 8 *Poses used in study*

We note that the SNAP system has been played perfectly at 80 PPM and is playable at speeds of 90 PPM. For this study, a moderate pace of 60 PPM was used, as players were beginners. The SNAP system was compared to Wii Fit Step Aerobics and a Sed-

Intervention	HR [bpm]	VO_2 [ml/kg/min]	MET	RER	RPE	Fun
SNAP	116.6 ± 7.4	12.0 ± 2.9	3.37 ± 0.7	0.83 ± 0.0	13 ± 0.0	3 ± 0.0
Wii	103.6 ± 8.6	10.8 ± 1.0	3.09 ± 0.3	0.82 ± 0.1	11.7 ± 1.5	3 ± 0.0
Sedentary	67.6 ± 7.2	3.1 ± 0.4	0.87 ± 0.1	0.86 ± 0.0	6.5 ± 0.8	2.8 ± 0.8

Table 2. *Mean HR, oxygen consumption, metabolic equivalent, respiratory exchange ratio [RER], RPE, and Fun ratings of the participants who completed the additional metabolic cart testing.*

entary Video Game [SVG]. The SNAP system compares well tocommercial systems as shown in Figure 1, and we expect that better results can be achieved with higher pose rates based on informal studies that have shown a linear relationship between pose rates (PPM) and relative perceived exertion.

Fourteen moderately inactive university aged participants (7 female, 7 male), completed the entire study. The additional inclusion criteria were: aged 18-25, not a current sports participant, and not currently exercising vigorously two or more hours per week. Anthropometric data of the participants is shown in Table 1. According to their BMI scores, 6 of the participants were classified as overweight and 8 had ideal weights.

3.2 Study Results

SNAP significantly outperformed both the Wii and the sedentary video game. The SNAP system was significantly more successful in placing more participants in their target heart rate range for weight management. It also placed participants in the target heart range for cardio-respiratory benefit. These results could be improved if SNAP were played at a higher speed.

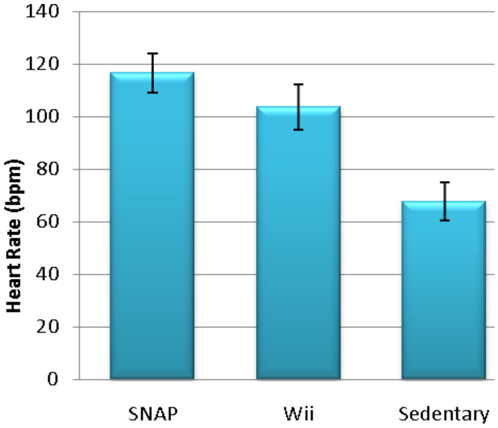

Figure4: *Mean heart rates of the participants while playing SNAP, Wii Step, and the SVG.*

3.2.1 Metabolic Cart Testing

The metabolic testing also shows the highest mean HR playing SNAP, followed by the Wii Step and SVG respectively. This trend was also observed with respect to VO_2 values obtained. The average values measured during testing are located in Table 2.

3.2.2 Heart Rate, Perceived Exertion and Fun

The SNAP intervention elicited significantly higher mean heart rates [HR] than both the Wii Step and SVG, as seen in Figure 4. Mean Relative Perceived Exertion (RPE) values were also significantly better (p =< 0.001) for SNAP over Wii Step and SVG, outlined in Figure 5. The fun ratings were not statistically different (p = 0.79) see Figure 6. Of interest is that the SNAP game was not more or less fun than a typical video game. The Fun rating was asked as part of an exit questionaire to determine the player's impression of the game. It is important to note here that the concept of fun, does not necessarily equate to incentive. In fact, there were no precise measures of incentive in this study as it was setup to study the physical effectiveness of the system. Much more work is required to examine if the SNAP device itself provides adequate incentive for players. We suspect that the device alone is not enough to encourage players to continue once the novelty elements have been exhausted. However we also believe that the device allows for a better range of possibilities when designing incentive elements into exergames.

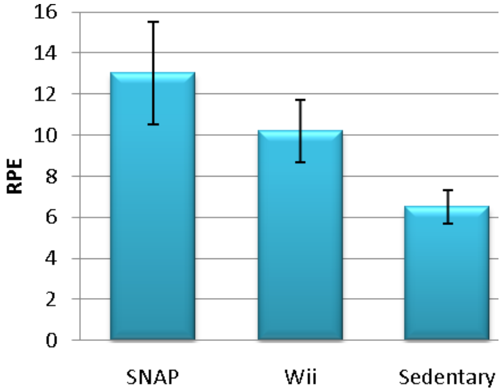

Figure 5: *Mean ratings of perceived exertion [RPE] rates of the participants while playing SNAP, Wii Step, and the SVG.*

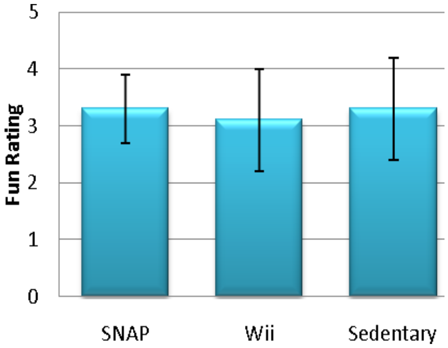

Figure 6: *Participants mean fun ratings for SNAP, Wii Step, and the SVG, including error bars.*

When the mean HRs for the three interventions were compared between gender it was observed that the females had higher heart rates as outlined in Table 3. SNAP elicited the greatest HR followed by Wii Step and the SVG. The mean HRs among and between interventions were also compared using BMI classification. The result of this analysis indicated that there were no significant differences among or between interventions due to BMI [p=0.112]. The mean HRs by BMI classification are located in Table 4.

	Males	Females
SNAP	108.7 ± 10.8	125.0 ± 13.6
Wii	92.6 ± 9.7	106.5 ± 10.8
Sedentary	73.0 ± 6.1	76.4 ± 4.6

Table 3. *Mean HR for each intervention by gender*

	Ideal Weight BMI	Overweight BMI
SNAP	110.6 ± 10.3	125.1 ± 15.9
Wii	94.8 ± 7.5	105.7 ±15.1
Sedentary	74.5 ± 5.5	74.8 ± 5.9

Table 4. *Mean HR for each intervention by BMI classification*

3.2.3 Cardio Respiratory and Weight Management Benefits

Using the ACSM's Target Heart Rate Ranges (THR-R) for weight management (55-69% HR_{max}) and cardio respiratory fitness (65-90% HR_{max}) [ACSM, 2006], the proportion of participants whose HRs fell within their respective THR-Rs were calculated and are shown in Table 5($HR_{MAX} = 220 - age$). Significantly more participants had a mean HR within the weight management range playing SNAP compared to the Wii ($p < 0.01$). Similar trends were observed for the cardio respiratory THR-R; more participants mean HRs fell within the range using SNAP compared to the Wii Step. As expected, none of the participants reached either THR-R while playing the SVG. We expect that better results could be achieved by the SNAP system at 80 PPM and with more experienced players.

	% Participants in WMR	% Participants in CRR
SNAP	73.0	13.3
Wii	26.0	0.0
Sedentary	0.0	0.0

Table 5. *Proportion of participants whose mean Heart Rate fell within their Weight Management (WMR) or Cardio respiratory (CRR) ranges for fitness*

3.2.4 Energy Expenditure

The mean energy expenditure (EE) was calculated for each intervention The mean EE was highest for the SNAP followed by the Wii Step and sedentary intervention. SNAP EE was significantly greater than both the Wii Step and sedentary interventions ($p < 0.001$). The Wii Step EE was also significantly higher than the SVG ($p < 0.001$). The EE of the SVG was effectively the resting rate, which is not unexpected. Results are outlined in Figure 7.

3.2.5 Skill Level and SNAP Physical Effectiveness

Skill scores were calculated for each participant for the SNAP intervention as a percent of total moves performed correctly. These scores were positively correlated with the HR of the participant ($r = 0.438$) as shown in Figure 8. This suggests [what we have confirmed informally] that with practice, SNAP players' skill levels increase, which results in a higher heart rate and better fitness outcomes.

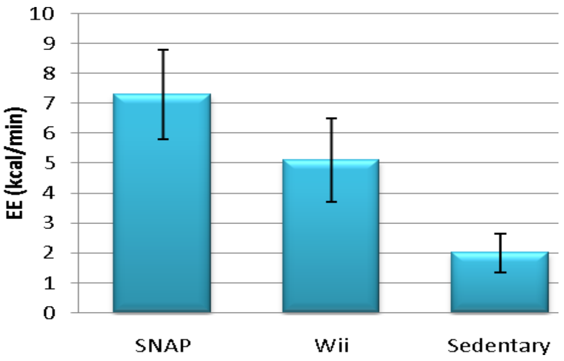

Figure 7. *Participants mean EE for SNAP, Wii Step and SVG.*

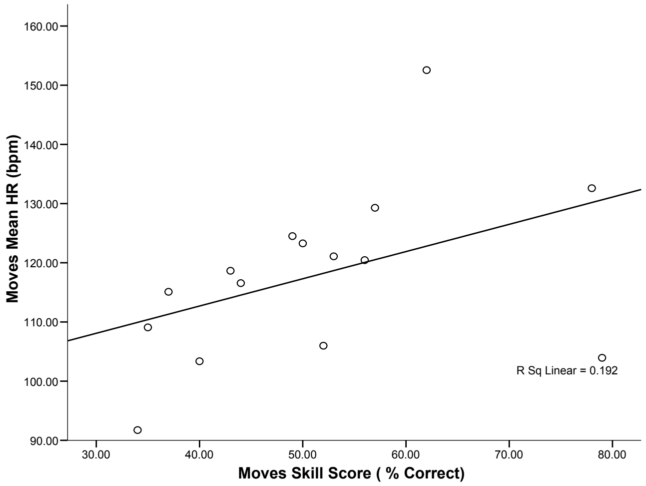

Figure 8: *Correlation between SNAP mean HR (bpm) and SNAP skill score (% correct) for participants who played.*

5 Conclusions

Exergames are being hailed as a possible solution to problems with childhood obesity and sedentary related diseases. However, most commercial systems on the market today are insufficient in providing high levels of health benefits. To ensure that exergames are effective, designers must consider two core issues: incentive and physical benefit. The results of this survey and our own study confirm the following recommendations in the design of exergames:

- Sensor systems must be able to tell what the entire body is doing to avoid cheating.
- Activities should be leg-based or more generally make use of the larger muscles in the body.
- Experience leads to better physical benefits, so incentive elements must lead to improved experience, while providing continual incentive to play.
- Long term benefits require a long term investment. The game's incentive elements must provide long term [months and years, not hours and days] motivation.
- Incentive elements must provide adequate recuperation time [for example, a good story element or self pacing].
- Incentive elements may not be fitness oriented at all.

Our SNAP system was originally created to be a fun game, not an exergame. We believe that its effectiveness as an exergame is due to the sensor network's enforcement of full body motions, making it difficult to cheat the system to get a high score. Players who are motivated by a high score are thus required to conduct the required motions and poses correctly to achieve a high score. This forces players to engage in the desired movements and achieve physical benefits while maximizing their utility value (the satisfaction of a high score). As well, the games created for the SNAP system were designed primarily with fun in mind, with the intention that they should be repeatedly playable. The end result has shown itself to be a significantly more effective exergame than existing exergame systems from a physical stand point.

The incentive issue remains an area that we believe is open ground for future research. Longer term studies are required to determine if incentive mechanisms actually work since the answer lies in how often a person returns to the game over a long period of time. i.e. How often does a person use the exergame as a means of exercise over the course of 1,2, or even 3 years. All of the previous research has focused on the physical benefits and systems are starting to show promise if they can keep players interested and participating in the long term. As well, we can begin modeling the utility value of an exergame by its genre. If a person likes to play first person shooters and dislikes Dance Dance Revolution, a game like Posemania [Whitehead et. al, 2007] will have very low utility value and thus make the SNAP-based game ineffective as an exergame. However for the DDR lovers, it offers a new experience and much higher utility value.

Finally, as the survey shows, evaluations of exergames can be done with inexpensive heart rate monitors as there is a direct relationship between heart rate and energy expenditure. This opens up a much more efficient means of analysis of different activities in the lab prior to completing a full set of metabolic cart tests, which are relatively invasive and discourage potential participation in studies in order to quantify utility in exergames.

4. ACKNOWLEDGMENTS

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