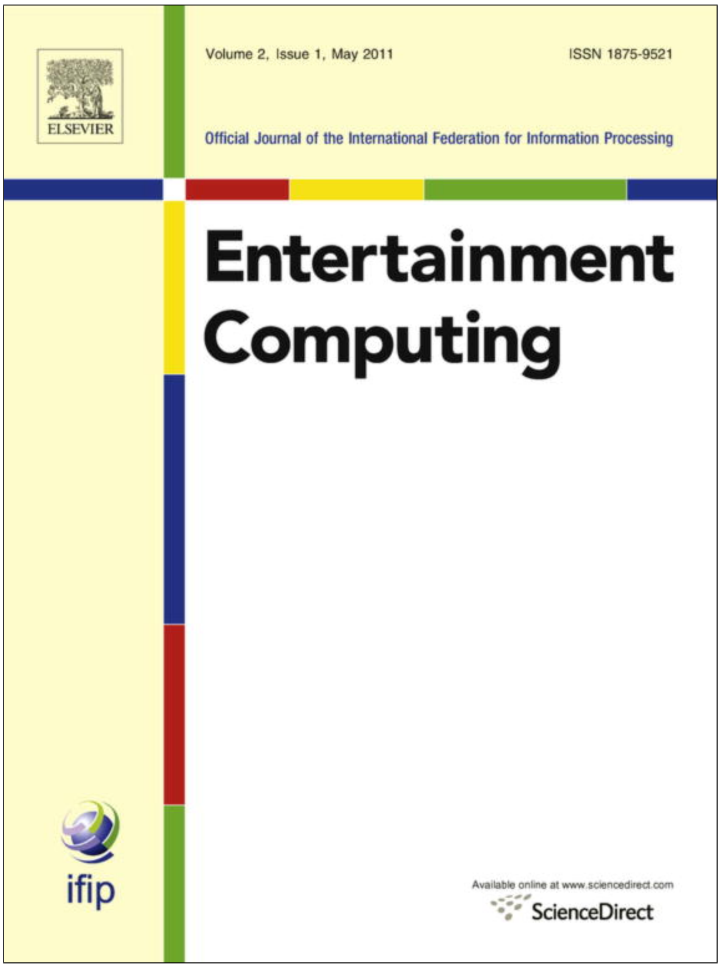
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The promise of exergames as tools to measure physical health

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ABSTRACT

Exergames are popular video games that combine physical activity with digital gaming. To measure effects of exergame play on physical outcomes and health behaviors, most studies use external measures including accelerometry, indirect calorimetry, heart rate monitors, and written surveys. These measures may reduce external validity by burdening participants during gameplay. Many exergames have the capability to measure activity levels unobtrusively through monitors built into game equipment, and preliminary analysis indicates that exergame measures are significantly correlated with external measures of caloric expenditure, duration of play, and balance. Exergames also have unique capabilities to measure additional data, such as the game challenges, player movement, and levels of performance that affect aerobic activity. Researchers could capitalize on the data collected by the exergame itself, providing an efficient, unobtrusive, comprehensive measure of physical activity during exergame play.

1. Introduction

Exergame is a term coined for the combination of exercise and digital gaming, involving the player in exertion to develop motor abilities during gameplay, focusing on large muscle groups rather than manual dexterity or fine motor skills [1]. Scholars have described exergames as exertion interfaces [2], next generation video games or screen-based activity [3], exercise video games [4], active video games [5,6], and everyday fitness applications [7]. Exergames are primarily designed to promote caloric expenditure and elevate heart rate for aerobic activity [8]. Internal devices built into exergames measure player input, including accelerometers, gyroscopes, cameras, exercise equipment, pads and mats, and pressure sensors [4].

Many popular exergames use a sport context in which player movement controls the movement of an on-screen avatar that can be an actual image or a graphic representation of the player. In other exergames, players control gameplay through footsteps on a dance pad such as in Dance Dance Revolution (DDR). Stach et al. [4] classified player input as six common forms: gesture (the player's bodily movement within a defined pattern), stance (the player's physical position), point (using a finger, hand, or hand-held device to aim towards the screen), power (the amount of energy expended), continuous control (the stability of performing a required action), and tap (the contact with a physical object). Player input is integrated into gameplay to determine the player's success and progress.

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A relatively untapped potential of exergames, which is explored here, is as unobtrusive data gathering tools. More specifically, the player input that exergames integrate into gameplay is recorded by the exergame device, allowing researchers to access the data after gameplay or in real-time if data are wirelessly uploaded to an online portal. The logging and interaction framework (LAIF) proposes a framework to log and triangulate physiological, behavioral, and eye tracking data in games (specifically vision-based games) [9]. A similar methodology could be adapted to log activity and physical health data from exergame devices using sensor technology. Yet research often relies on external measures to capture physical effects of gameplay rather than taking advantage of exergames' data tracking capabilities.

In this paper, we first review current measurement of physical health in exergame studies, and we then discuss how built-in exergame measures may address limitations of external devices. Studies that incorporate exergame measures are reviewed, with an examination of measurement reliability and validity from our own exergame intervention and from an assessment of balance. Next we describe the use of exergame measures in intervention studies. We conclude with a call for extensive research on exergame data collection tools to establish the validity and reliability of these measures, thereby potentially expanding the ways that researchers collect data on players' physical health.

2. Limitations of external device measures

Effects of exergame play on physiological outcomes and health behaviors are quickly being documented [10], yet outcome variables are typically assessed using traditional external measures.

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To measure caloric expenditure, most studies use external accelerometry and indirect calorimetry, involving metabolic carts and facemasks to measure oxygen uptake [11–13]. To measure heart rate elevation and weight change, external monitors and scales are typically used [12,14,15]. Written surveys are often used to measure health behaviors including perceived exertion [12], total physical activity, and typical diet. These measures may become tiresome for participants over time, reducing the external validity of their reports about gameplay. Moreover, accelerometers and indirect calorimetry are typically restricted to laboratory settings [3,16] because they are expensive, obtrusive, and may need to be monitored for correct use. For instance, exergame studies that use the Intelligent Device for Energy Expenditure and Activity (IDEEA) often use multiple sensors for each participant to capture caloric expenditure, thereby considerably increasing equipment cost.

Caloric expenditure is a key measure of exergame effectiveness. Caloric expenditure is often approximated through accelerometry, which measures movement in multiple dimensions in order to approximate caloric expenditure. Exergame studies typically use external accelerometers. For example, the Actical is a hip- or waist-mounted tri-axial accelerometer; a similar device, the Actiwatch, is worn on the wrist. These physical activity monitors are lightweight and waterproof, and they can be worn for multiple days, which is advantageous for physical activity interventions. For instance, Actical accelerometers were used in a 20-week in-school intervention with seventy-four 12- to 18-year-old adolescents [17].

The IDEEA accelerometer is more taxing for participants than the Actical monitor. The IDEEA includes a waist-mounted recorder with sensors connected to the participant's body at the chest, the front of each thigh, and the underside of each foot. Sensors are attached with hypoallergenic medical tape. The IDEEA was used to measure caloric expenditure among a group of eleven 13- to 15-year-old athletic youth [11]. In this study, resting caloric expenditure was also measured with indirect calorimetry and a facemask [11]. Limitations noted by authors include that the IDEEA system may have underestimated energy expenditure because it does not detect arm movements well. Additionally, gaming took place in the laboratory, which may limit the external validity of findings.

Another traditional measure of caloric expenditure is indirect calorimetry, for which metabolic carts approximate energy expenditure via gas exchange, measuring oxygen uptake and carbon dioxide expulsion. A neoprene mask worn over the mouth and nose to measure gas exchange may be obtrusive to participants. The burden of the facemask may also necessitate short test sessions of only 5- to 30-min, as seen in many exergame studies [12,13,16,18]. A within-subjects counter-balanced design is important to ensure that measurement burdens do not differentially affect participants in each condition [19]. Even so, external equipment could impede effort or detract from the gaming experience, which could affect participant caloric expenditure.

Heart rate is often measured as an indicator of aerobic activity, and it is traditionally measured by an external device fitted on the wrist or chest, such as the Polar heart rate monitor [12,14,15]. However, studies are typically restricted to laboratory settings, and if heart rate monitors are used in field interventions, then participants must frequently report to the laboratory to download heart rate data [20]. This places additional measurement burden on participants and also introduces potential for internal validity problems if the monitors are not correctly used.

Perceived exertion is an important indicator of player effort to reach levels of aerobic activity, and it is often measured through the Borg rating of perceived exertion (RPE) scale which is administered frequently throughout exercise [12]. Pre-adolescents playing Wii Sports and Dance Dance Revolution rated perceived exertion higher during exergame play than during treadmill or rest [12]. In addition to a neoprene facemask to measure oxygen consumption, an accelerometer to measure step count and approximate caloric expenditure, and a chest strap to monitor heart rate, participants also periodically rated their RPE in a survey external to gameplay [12]. Numerous measures may decrease external validity of the gameplay experience, particularly for children.

Demanding measures may be especially problematic in measuring perceived exertion for participants with physical disabilities. A GameCycle intervention evaluated levels of perceived exertion in eight adolescents with spina bifida that caused limited ambulation [20]. At baseline and 16-weeks, RPE was measured at every minute of gameplay, in addition to a heart rate monitor and a metabolic cart with a facemask [20]. The laboratory measures likely created a more arduous experience than participants had experienced during regular gameplay at home, where they wore a heart rate monitor only. Put another way, these extraneous measurements may have inflated perceived exertion.

3. Benefits of built-in exergame measures

Exergame equipment can measure physical health effects. If proven to be reliable and valid, using built-in exergame measures could be cost-effective, save time, and provide a more natural gaming experience compared to the use of external measures. Exergame manufacturers including Nintendo, Microsoft, Sony, and Intel, have built data collection and analysis functions into their equipment so that consumers can track their personal fitness progress. Software such as those found in Nintendo Wii exergames produce graphs of the player's caloric expenditure and body mass, based on both self-report and objective exergame measures (see Fig. 1).

Many exergames integrate accelerometers into the system. For example, the Nintendo WiiMote is an accelerometer that estimates caloric expenditure during gameplay based on an algorithm of player movement, sex, age, and weight. When the Wii balance board is used, an objective measure of player weight can be input into the caloric expenditure algorithm. Otherwise, the weight is contingent on player's self-report or on the researcher inputting the weight correctly. Caloric expenditure as reported by the exergame unit is rarely included in empirical studies of exergames, despite the fact that this is the caloric number that players will use to monitor their progress during gameplay.

In addition to accelerometers, new exergames such as Nintendo EA Sports Active 2 and EA Sport NFL Training Camp include a heart rate monitor in the game package so that players can track heart rate continuously throughout gameplay. Players then monitor change in average heart rate over a week or month of play. Exergame heart rate monitors may provide a more thorough assessment of the beneficial physiological changes derived from exergame play. For instance, an external monitor revealed that 12 min of Dance Dance Revolution play in twenty-two 11- to 17-year-old overweight and non-overweight children elevated heart rate to levels of cardio-respiratory fitness at all levels of gameplay but did not produce sufficient VO_2 max [18]. Recording heart rate through exergame monitors may be particularly useful for in-home or unsupervised physical activity interventions. Heart rate monitors in the Wii Active 2 and EA Sports NFL Training Camp exergames are placed on the left forearm rather than a chest strap, which might increase player use in unsupervised settings.

Exergame heart rate monitors may also allow for lengthier test sessions compared to external devices. A study of 6- to 12-year-old children playing XaviX and J-Mat exergames examined only 5-min bouts of play using external monitors [16]. Although heart rate was higher during exergaming than during sedentary gaming, whether

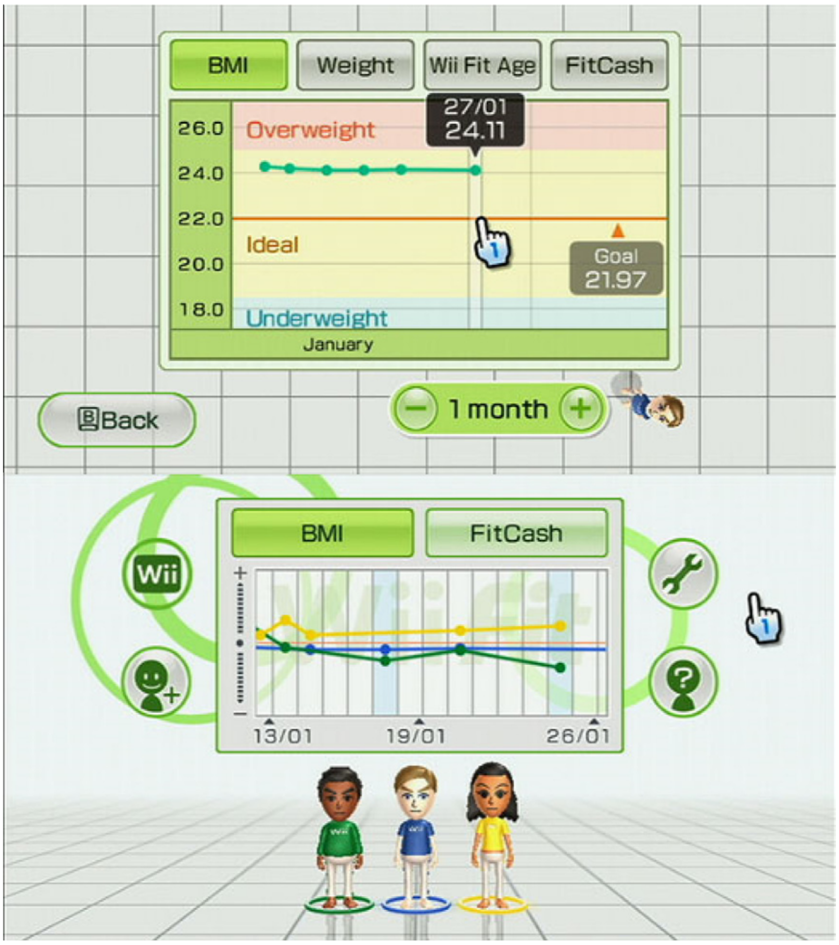

Fig. 1. Images of physical health tracking from Nintendo Wii Fit.

or not this heart rate elevation is sustained over repetitive play might be answered with exergame heart rate monitors. Using internal exergame devices to monitor heart rate can ensure comprehensive measurement. Reliability and validity studies are needed to determine the accuracy of exergame heart rate monitors compared to gold standard monitors, such as Polar heart rate monitors that are ubiquitous in rigorous scientific experiments.

Exergames can provide unique information about the gaming experience that an external device cannot, as they can be used unobtrusively to examine the particular factors that affect aerobic activity. In particular, exergame devices can reveal how varying challenges within the game produces fluctuations in aerobic activity. Sustained caloric expenditure and elevated heart rate are needed to reach levels of cardiorespiratory fitness [21], but gameplay does not necessarily produce consistent expenditure levels. For instance, thirty undergraduates playing the Sony EyeToy exergame produced short bursts of energy expenditure followed by long breaks [21]. Data from the EyeToy could reveal how in-game challenges impact caloric expenditure. Heart rate elevation may also differ based on the particular exergame played: twelve 20- to 27-year-olds playing Wii Sports boxing met standards for cardiovascular fitness as measured by a Polar monitor, whereas playing Wii tennis did not [22]. Because exergames like Wii Sports track the different games played within a gaming session, researchers could capture change in caloric expenditure and heart rate based on the particular game that is played.

Player movement is a significant predictor of caloric expenditure. Because exergames must read body movement via infrared communication and accelerometry, data on body movement may be derived from the exergame unit. Exergames could thus supplement or replace direct observation methods, such as an observation of 134 children's activity patterns at a video game center, where larger body movements produced higher energy expenditure [3]. New developments in exergame hardware, including the Microsoft Kinect and PlayStation Move, provide additional motion tracking capabilities that could contribute to a more precise measure of body movement. Specifically, the Sony Move uses the PlayStation Eye camera to wirelessly track player movement, and the Microsoft Kinect uses infrared detection to track motion, facial expression, and voice recognition. This information could contribute to the understanding of player movement and thus caloric output.

Exergame ratings and levels of performance, such as levels of challenge met in Dance Dance Revolution, can classify players as experienced or novice. This built-in capability is less expensive and time-consuming than using an external observer to measure player capability, and it may provide a more objective monitor than self-report. If validated with external behavioral observation, these internal device measures could provide an objective measure of player skill and performance. For instance, in-game ratings were used to classify 19 undergraduate males as experienced or novice players of Dance Dance Revolution. Experienced players produced higher cardiorespiratory output with less time and fewer steps than novice players did [23].

4. Use of built-in exergame measures as research tools

Built-in exergame measures could replace or supplement the external measures currently used by researchers. The General

Active Input Model (GAIM) developed by Brehmer and colleagues [6] proposed a programming model for how researchers can abstract exergame data for multiple categories of player input. However, the authors caution researchers that the toolkit must be adapted to encompass new data collection capabilities of recently released exergame interfaces such as Sony's PlayStation Move and Microsoft's Kinect.

Exergames also offer wireless upload capabilities to report performance online, potentially providing instant data access for researchers. Data are tracked both continuously and in periodic reports, depicting an extensive overview of player's activities. For example, in the Nintendo Wii Active 2 exergame, workout progress can be instantly uploaded online to profiles that include details of each workout completed, as well as gender, height, weight, and birth date.

One obstacle to data acquisition is that data and algorithms to calculate energy expenditure, heart rate, and other physiological measures are proprietary data of the gaming companies. Unless these data and the algorithms are released to researchers or to the general public, it is unclear how accurate these measures are. Researchers should validate exergame-derived data, such as caloric expenditure, with gold standard caloric monitors like Actical [17] and IDEEA [11] accelerometers. Moreover, researchers could call upon industry to release the proprietary data and algorithms used to calculate caloric expenditure and other physiological measures to examine their validity.

4.1. Reliability and validity of built-in exergame measures

Reliability and validity of exergame measures are important to determine the extent to which exergames can be used to capture physical changes within research studies. Researchers could establish reliability of exergame measures through within-device study designs, and validity could be established through between-device designs comparing exergames to gold standard measures such as Polar heart rate monitors, Actical and IDEEA accelerometers, and indirect calorimetry. If the internal game measures are reliable and valid, exergames could replace external devices, or at least provide additional measures of aerobic activity in field studies in which external accelerometers, indirect calorimetry, and heart rate monitors are not practical or affordable. Since accelerometers and heart rate monitors are built within the gaming device, it poses no additional burden to the participant, yet it can provide a wealth of data for researchers as well as for the participants who may be trying to achieve a goal, such as to lose weight.

To investigate the validity and reliability of caloric expenditure reported by the Wii Active exergame, our research team analyzed the concordance of energy expenditure reported by the exergame with an external device, the Actical accelerometer. Thirty-two 15- to 19-year-old overweight and obese adolescents played 30- to 60-min sessions of Wii Active exergame in a 20-week intervention. We examined forty-eight sessions of caloric expenditure, comparing reports of the Wii unit to reports of hip-mounted Actical accelerometers. Bivariate correlations revealed that caloric expenditure reported on the Wii was moderately related to Actical reports, $r = .408$, $p = .004$ (see Table 1). Although this correlation is highly significant, the gap between Actical-derived and Wii-derived caloric expenditure highlights the need to examine the accuracy of the exergame caloric monitor. A more accurate measure of gameplay was the duration of play recorded on the Wii unit, which highly significantly correlated with the duration of activity recorded on the Actical, $r = .966$, $p < .0001$. These results indicate that exergame devices may be accurate and reliable in estimating length of play, yet further research needs to be conducted to establish whether the caloric expenditure measures built in to exergames is sufficient for research purposes.

One exergame device that has been tested for validity and reliability is the Nintendo Wii balance board used in the Wii Fit exergame, which can have important applications for diagnosing and decreasing fall risk in a clinical setting. In a sample of 30 healthy and physically abled participants, the validity and reliability of the Wii balance board were tested against laboratory-grade force platform, which is the gold standard that physicians use to measure patients' center of pressure for balance [24]. Between-device comparisons were made at two separate occasions under a variety of balance activities. As displayed in Table 1, overall there was good to excellent test–retest reliability within-device (intraclass correlation coefficient or ICC = 0.66–0.94) and between-device (ICC = 0.77–0.89) for all balance exercises, providing evidence that the balance board is a valid tool to assess balance. In fact, the minimum detectable change was higher for the Wii balance board compared to the laboratory-grade force platform in three of four tests. Researchers note that the low cost and portability of the balance board make it particularly appealing for measuring balance. More research investigating the use of exergames for assessment of physical health indicators is needed.

4.2. Use of exergame measures in intervention studies

Despite the data tracking and analysis capabilities of these exergame devices, researchers rarely incorporate exergame measures into their methodologies. To address this deficit, we used built-in exergame measures in our 20-week Wii Active intervention for seventy-four 15- to 19-year-old overweight and obese adolescents [25]. For each 30- to 60-min gameplay session, we recorded data from the Wii console including the estimated caloric expenditure of play, the workout routine, the partner, and the duration of play [25]. Although this study was conducted in a public high school where research assistants recorded information, in-home interventions are also possible if the exergame is connected to an online portal to instantly upload data reports for researchers. One limitation is that player progress may depend on the partner or opponent. In the Wii Active intervention, player data were intrinsically linked to the performance of the partner for that day, which contributed toward total play time and percentage of workouts completed. However, the partner profile could also be tracked online, without the dependence on self-report. One potential issue, though, is if a participant selects a different avatar to play at each gaming session, thereby disrupting accurate tracking of individual performance.

Table 1
Correlation coefficients of exergame measures and gold standard measures.

Study	Variable	Exergame device	Gold standard device	Correlation coefficient
Staiano et al. [25]	Caloric expenditure	EA sports active for Nintendo Wii	Actical accelerometer	.408*
	Duration of play	EA Sports Active for Nintendo Wii	Observer report	.966**
Clark et al. [24]	Balance	Nintendo Wii balance board (test–retest = .66–.94)	Laboratory-grade force platform	.77–.89

Note. Correlation coefficients are Pearson's *r* for Staiano et al. [25] and inter-class correlation for Clark et al. [24].
* $p < .01$.
** $p < .001$.

Another exergame intervention used a video memory card to measure adherence and estimate energy expenditure in a 6-month Dance Dance Revolution intervention for 30 overweight 9- to 18-year-old youth [26]. A novel combination of exergame measures, a daily diary, and researcher-conducted phone interviews provided three measures for data collection. Participants were instructed to play DDR for 30-min per day, 5 days per week. In addition to recording daily minutes of DDR play in a diary, participants also periodically turned in video memory cards which also recorded gameplay duration and caloric expenditure. The semistructured phone interviews occurred biweekly for the first two months and monthly for subsequent months in order to capture number of days per week of DDR use, as well as enjoyment of DDR play. Body mass index (BMI) was measured at baseline, month 3, and month 6, by trained nurses.

Results indicated that 12 of the 21 children played DDR at least twice per week in the first 3 months, yet only 2 continued to play DDR twice per week between months 3 and 6. Exergame play was not associated with change in BMI, yet researchers noted this may be due to the self-report nature of exergame use which may have overestimated play. Unfortunately, technical problems with the video memory card excluded that data from analysis. Only 12 of the 30 participants submitted diary and memory card data at the 3-month follow-up. Of these, 5 memory cards contained no data and only an average of 54% of exergame sessions were recorded in dairies with a range of 1–89%. Had the memory cards reliably captured actual gameplay, association between exergame play and BMI may have been more accurate. This experience indicates a need to train participants in how to use memory cards to ensure that exergame data collection is successful as well as the need to send reminder prompts to participants, perhaps through text messages on their cell phones, for them to use those cards.

5. Conclusion

Exergames are promising research tools to supplement or replace external devices to measure caloric expenditure, heart rate, and health behaviors. Exergames can also capture important aspects of gameplay including factors that impact aerobic activity and adherence. In comparing exergame monitors to gold-standard external measures, exergames moderately correlate for caloric expenditure and are highly significantly correlated for duration of play and pressure of balance. Reliability and validity of exergame measures would have to be linked to external measures, including accuracy of caloric expenditure, heart rate, and adherence monitoring. Proprietary data including caloric expenditure and heart rate algorithms would have to be made available to researchers to establish the validity of exergame measures. Once reliability and validity are documented, exergames may prove to be efficient, unobtrusive, comprehensive research tools to measure participants' physical health.

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