Entertainment Computing 2 (2011) 17–21

Contents lists available at ScienceDirect

Entertainment Computing

journal homepage: ees.elsevier.com/entcom

The promise of exergames as tools to measure physical health

Amanda E. Staiano [a,*], Sandra L. Calvert [b]

[a] Pennington Biomedical Research Center, Baton Rouge, Louisiana, USA
[b] The Children's Digital Media Center, Georgetown University, Washington, DC, USA

ARTICLE INFO

Article history:
Received 7 October 2010
Revised 4 March 2011
Accepted 12 March 2011
Available online 21 March 2011

Keywords:
Exergame
Physical activity
Physical health

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.

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.

* Corresponding author. Address: 6400 Perkins Road, Population Science, Pennington Biomedical Research Center, USA. Tel.: +1 225 763 2729, fax: +1 225 763 3009.

E-mail address: amandastaiano@gmail.com (A.E. Staiano).

1875-9521/$ - see front matter © 2011 International Federation for Information Processing Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.entcom.2011.03.008

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