

## Activity-promoting gaming systems in exercise and rehabilitation

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**Abstract**—Commercial activity-promoting gaming systems provide a potentially attractive means to facilitate exercise and rehabilitation. The Nintendo Wii, Sony EyeToy, Dance Dance Revolution, and Xbox Kinect are examples of gaming systems that use the movement of the player to control gameplay. Activity-promoting gaming systems can be used as a tool to increase activity levels in otherwise sedentary gamers and also be an effective tool to aid rehabilitation in clinical settings. Therefore, the aim of this current work is to review the growing area of activity-promoting gaming in the context of exercise, injury, and rehabilitation.

**Key words:** activity-promoting, Dance Dance Revolution, exercise, falls, games, gaming systems, injury, Nintendo Wii, rehabilitation, Sony EyeToy, Xbox Kinect.

### INTRODUCTION

Commercial activity-promoting gaming systems such as the Nintendo Wii (Nintendo; Redmond, Washington), Dance Dance Revolution (DDR [Konami Digital Entertainment; El Segundo, California], which can be used on a number of game consoles), Sony EyeToy (Sony Computer Entertainment; Tokyo, Japan), and Xbox Kinect (Microsoft; Redmond, Washington) require player motion and, in some cases, weight bearing to control gameplay. The active nature of these gaming systems may offer therapists and patients a number of potential benefits to complement traditional therapies.

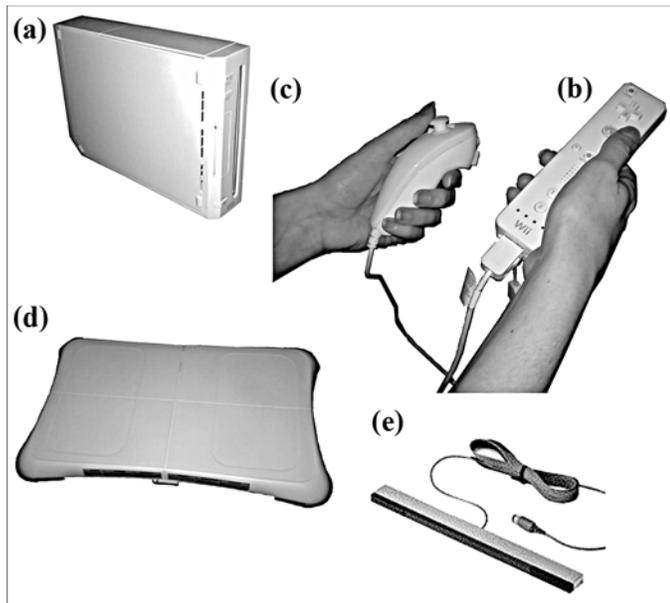
The Wii (**Figure 1(a)**), which has sold over 75 million units worldwide [1]) uses player movement to control gameplay (via an avatar called a Mii [pronounced “me”], which is an icon or figure representing the player in the game). Movement is controlled by the Wii remote, nunchuk, or balance board (or in combination). The Wii remote (**Figure 1(b)**, 200 g, 160 mm × 40 mm × 30 mm, and similar in size to a television remote control) uses a three-axis accelerometer to translate body movement into onscreen movement. Up to four controllers can be connected wirelessly to the console, allowing group play and social interaction. The Wii remote also provides basic audio and vibration feedback. An expansion device (Wii MotionPlus), which attaches to the Wii remote, allows for more accurate motion capture and complex gameplay. The Wii MotionPlus does this with a single- and dual-axis gyroscope. A secondary controller, the nunchuk

**Abbreviations:** ACSM = American College of Sports Medicine, CP = cerebral palsy, DDR = Dance Dance Revolution, EE = energy expenditure, HR = heart rate, MET = metabolic equivalent, NHS = National Health Service, RPE = rating of perceived exertion, TUG = Timed “Up and Go” test, VA = Department of Veterans Affairs, VO<sub>2</sub> = oxygen consumption.

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**Figure 1.**

(a) Nintendo Wii console (Nintendo; Redmond, Washington) and its peripherals. (b) Wii remote in right hand and (c) nunchuk in left hand, (d) balance board, and (e) sensor bar. Note: Wii MotionPlus is not shown.

(**Figure 1(c)**), also incorporates motion-sensing technology and provides additional controls. The balance board (**Figure 1(d)**, 3,500 g, 511.0 mm × 316.0 mm × 53.2 mm), incorporates pressure sensors to translate the movement of the player's center of pressure. The signal from the controllers are received by a sensor bar (**Figure 1(e)**). The console comes with *Wii Sports* (Nintendo), a game package for the Wii remote and nunchuk with Tennis, Baseball, Boxing, Bowling, and Golf (latter two games are self-paced). Another game, *Wii Fit* (Nintendo), uses the balance board to incorporate games that test balance, fitness, and strength.

DDR was initially released as an arcade game but is now commercially available on a number of game consoles. The controller is a floor mat that the player stands on. The player moves his or her feet in a set pattern, responding to arrows that scroll onscreen in time to the general beat of a piece of music. Game difficulty increases with the increase in tempo and number of arrows. The game calculates the accuracy of the player's performance through onscreen feedback.

The EyeToy, played on the PlayStation2 (Sony Computer Entertainment), differs from the Wii by using a color video camera (similar to a Webcam) capable of ges-

ture recognition that allows motion-controlled gameplay. PlayStation Move (Sony Computer Entertainment), a competitor to the Wii, also uses motion controllers (wands) during gameplay. It uses the camera technology of the EyeToy to track the wand's position, which detects motion using inertial sensors with a three-axis linear accelerometer and a three-axis angular rate sensor.

The Kinect competes with the EyeToy by also using video technology and gesture recognition. This device was recently released and also has controller-free gameplay with the player using his or her body. It was released during the month before the cutoff date for our review, so there is a paucity of relevant literature.

The games available on these systems are "entertaining" and distracting and so the patient focuses on gameplay rather than his or her impairment, which in turn results in more enjoyable exercise and improved adherence to and completion of fitness and rehabilitation training [2]. The motion control of the Wii, EyeToy, and Kinect enable users to control and interact without the need to push multiple buttons on a game controller. This allows users with impaired dexterity to access, participate in, and benefit from gameplay. These commercial systems are relatively inexpensive and can be located in a person's home, making "training" more convenient. It may also be feasible to track rehabilitation at home (with specifically designed gaming programs) by the Internet so that a therapist can see if the patient is performing exercises correctly [3]. To reach these training goals, however, sustained gameplay that leads to unique gaming-related injuries may be required. Therefore, the aim of this review is to synthesize the current research in this growing area of activity-promoting gaming within the context of exercise, injury, and rehabilitation in the adult population.

## METHODS

We chose a scoping study to address the broad topic and different study designs in the literature [4]. This included published and nonpublished papers, abstracts, and review articles in English. We searched relevant review articles for information regarding additional studies. We used the search engine databases PubMed, Web of Knowledge, and Google Scholar. We also carried out Internet searches to observe the prevalence of anecdotal evidence. We searched for the following words and phrases:

“active computer games,” “exergaming,” “computer games and exercise,” “Nintendo,” “Wii,” “Playstation,” “Xbox,” “Kinect,” “Dance Dance Revolution,” “EyeToy,” “injuries,” “energy expenditure,” “Playstation Move,” “Wiihab,” “Wii-itis,” “Wiihabilitation,” “active video games,” “active gaming,” “exertainment,” and “new-generation computer games.” We reviewed only exercise and rehabilitation studies that used adult participants ( $\geq 18$  years old).

We did not include articles from the search results related to cognitive function, psychological rehabilitation, and education. We enforced no date of publication limitations on the search results. The final search date was December 2, 2010.

### ENERGY EXPENDITURE WHILE PLAYING ACTIVITY-PROMOTING GAMING SYSTEMS

Physical inactivity can lead to major health problems that can be alleviated by at least 30 minutes of moderate-intensity exercise 5 days a week [5]. The Wii, EyeToy, DDR, and Kinect are a new generation of gaming systems that use interactive physical activity—“exergaming” [6]—to increase energy expenditure (EE) by incorporating gameplay with exercise. In the literature, exergaming is targeted more towards children than adults. However, it is seen as a convenient activity that can be supervised in the home, and for those with low self confidence, the exercise may provide a means to practice physical activity in familiar surroundings [7]. In 2009, the Department of Health in the United Kingdom gave the Wii its seal of approval by allowing the “Change4Life” brand (a campaign to promote exercise and healthy eating) to be used by Nintendo on the Internet, in television advertising, and in stores [8].

The general trend these studies found in nonclinical populations was that EE while playing the Wii was not greater than brisk walking and that *Wii Sports* games were no substitute for the real sporting activity (**Table 1**). Only the change in EE in adults with cerebral palsy (CP) [9] and intellectual and developmental disabilities [10] while exergaming has so far been reported in the literature (**Table 1**).

#### Nintendo Wii Versus Walking

**Table 1** shows that EE was greater when playing the Wii compared with sedentary activities. The EE while playing the Wii for 4 hours per week would be equivalent

to walking at 2 mph on a treadmill [11], which is actually slower than an average comfortable walking speed (2.9–3.1 mph), suggesting a long walk at normal speed may be more beneficial. Willems and Bond compared self-paced brisk walking (speed of walking was not reported) with self-paced Wii gameplay (Tennis, Boxing, and Baseball) in a group of young adults ( $n = 10$ ,  $21 \pm 1$  years old [mean  $\pm$  standard deviation]) [11]. The group played the games for 10 minutes with 5 minutes of rest between games, totaling 30 minutes of gaming. The study applied the same protocol for the brisk walking. The metabolic equivalents (METs) for Wii Tennis, Baseball, and Boxing were  $2.1 \pm 1.2$ ,  $2.8 \pm 0.9$ , and  $4.7 \pm 1.4$ , respectively. These values were 2.6, 2.9, and 1.0 METs lower than self-paced brisk walking, respectively. For health gains, brisk walking for these adult subjects could be met with less than six 30-minute sessions per week. However, a combined session of playing the three games would not meet these guidelines. Wii Boxing appears to be the most beneficial game for EE because of the vigorous nature of the game and the need to use both arms for gameplay. However, only 60 percent of participants would have met the criteria when playing Wii Boxing for health gains with less than seven 30-minute sessions per week [11], and Lee and Pitchford reported that 10 minutes of playing Wii Boxing and Tennis resulted in METs that were classified as moderate physical activity [12]. Welch et al. noted that Wii Boxing “provided marginal physiological stimulus” for a group of nondisabled university students ( $n = 23$ ) compared with a fitness boxing video, with mean heart rate (HR) and rating of perceived exertion (RPE) greater for the latter (HR:  $134 \pm 21$  vs  $163 \pm 13$  bpm; RPE:  $11.5 \pm 2.7$  vs  $14.4 \pm 1.8$ ) [13]. For Wii Tennis, Sasser et al. reported that HR scores represented only 50 percent of the age-predicted HR maximum [14]; thus, this may not be a high enough intensity level to elicit health improvements based on American College of Sports Medicine (ACSM) guidelines.

#### Nintendo Wii Versus Actual Sports

At best, Wii games appear to result in moderate increases in EE, and at worst, Pray and Julie compared the EE of Wii Tennis with that of folding laundry or driving a car [15]. The EE of Wii gameplay is also markedly less than taking part in the actual sport. For example (in adolescents), EE per minute playing Wii Boxing was 12.1 kJ versus 26.8 kJ for actual spa boxing, and playing Wii Tennis versus actual doubles tennis was 12.5 and

**Table 1.**

Energy expenditure (EE) studies.

Author	Design	Sample	Method	Measure	Result
Lanningham-Foster et al. [1]	Single-group comparative study	34 ± 11 yr; n = 20 (10 M, 10 F)	EE and PA measured resting, standing, watching television seated, playing SVG (PS2 <sup>*</sup> ) and AVG (Wii <sup>†</sup> )	Accelerometer, inclinometer, data logger, and indirect calorimeter	Mean EE over resting (148 ± 71 kCal/h) and movement increased significantly (p < 0.001) above all activities when playing Wii.
Willems and Bond [2]	Comparative study, convenience sample	21 yr; n = 10 (7 M, 3 F)	Compared EE during three 10-min sessions (5-min rest periods) of brisk treadmill walking or Wii (Tennis, Baseball, and Boxing <sup>‡</sup> )	EE (measured with portable metabolic system) and MET	METs significantly higher for brisk walking compared with Wii (p < 0.05). METs significantly higher for Wii Boxing vs Wii Tennis and Bowling. Gameplay in young adults may not be sufficient to meet ACSM guidelines for physical activity of moderate intensity that provides health benefits.
Lee and Pitchford [3]	Convenience sample, counterbalanced design	29.1 ± 7.4 yr; n = 8 (3 M, 5 F)	Compared quiet sitting with Wii (Tennis, Bowling, and Boxing) for 10 min each	EE, VO <sub>2</sub> , and HR	METs score (p < 0.001) and HR (p < 0.01) of all activities statistically different from quiet sitting. METs score (p = 0.013) and HR (p = 0.001) significantly different among activities.
Welch et al. [4]	Comparative study, convenience sample, random control	21 yr; n = 23	Compared 30 min sessions of Wii Boxing, brisk walking, and fitness boxing video	HR and RPE	Significant difference between HR for all modes of activity (p < 0.05). RPE significantly less than Wii Boxing and fitness boxing video. Wii Boxing may provide marginal physiological stimulus.
Sasser et al. [5]	Comparative study	College students (18 yr; n = 29)	Five 5 min game conditions ( <i>Super Mario Bros. 3</i> , <sup>†</sup> <i>Super Mario Bros. 3</i> while standing, <i>Guitar Hero</i> <sup>§</sup> while standing, Wii Tennis, DDR <sup>¶</sup> ) and control	Mean and peak HR	DDR yielded highest mean and peak HR (p < 0.05). HR for DDR represented 60% of age-predicted HR <sub>max</sub> . Wii represented 50%, which may not be sufficient intensity for ACSM guidelines.
Hennig et al. [6]	Comparative study, convenience sample	College students (18 yr; n = 29)	Five 5 min game conditions ( <i>Super Mario 3</i> , <i>Super Mario 3</i> while standing, <i>Guitar Hero</i> while standing, Wii Tennis, DDR) and control	Mean and peak VO <sub>2</sub>	DDR yielded highest mean and peak VO <sub>2</sub> compared with all other modes (p < 0.05), corresponding with 3.4 and 4.2 METs. DDR would meet ACSM guidelines. Wii would require almost double time per week to elicit benefit.

Table 1. (cont)

Energy expenditure (EE) studies.

Author	Design	Sample	Method	Measure	Result
Hurkmans et al. [7]	Cross-sectional study	Bilateral spastic CP and ambulatory ability ( $36 \pm 7$ yr; $n = 8$ [5 M, 3 F])	EE by $\text{VO}_2$ while sitting and during Wii (Tennis and Boxing, each played for 15 min in random order)	EE and MET	Wii (Tennis and Boxing) determined moderate intensity physical activity.
Lotan et al. [8]	Comparative study	Exercise group: Moderate IDD level ( $52.3 \pm 5.8$ yr; $n = 28$ [16 M, F 12]) Control group: Age, IDD level, and functional abilities matched ( $54.3 \pm 5.4$ yr, $n = 31$ [15 M, 16 F])	Fitness program (5–6 wk); three 30 min Eye-Toy* sessions per week (self-selected games)	EE, modified Cooper test, and THBI	Exercise group: significant improvements in modified Cooper test and THBI ( $p < 0.05$ ), but not EE. Exergaming intervention suitable for adults with IDD and can result in significant improvements in physical fitness levels.
Sell et al. [9]	Comparative study	DDR players ( $21.8 \pm 3.5$ yr) Experienced: $n = 12$ M; inexperienced: $n = 7$ M	Maximal $\text{VO}_2$ assessments and 30 min DDR session	HR, RPE, RER, and $\text{VO}_2$	Significantly higher ( $p < 0.05$ ) exercise HR, RPE, RER, $\text{VO}_2$ , total and relative EE, and exercise intensity and less time and steps to expend 150 kCal.

\*Sony Computer Entertainment; Tokyo, Japan.

†Nintendo; Redmond, Washington.

‡Wii Sports (Nintendo).

§Harmonix; Cambridge, Massachusetts.

¶Konami Digital Entertainment; El Segundo, California.

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- Hennig L, Olsen C, Feleman K, Ulbright J, Rees S, Harshman J, Silvers MW. Oxygen consumption with various modes of video game interaction. *Med Sci Sports Exerc*. 2009;41(5 Suppl 1):551–52. <http://dx.doi.org/10.1249/01.MSS.0000356229.90186.08>
- Hurkmans HL, Van den Berg-Emons RJ, Stam HJ. Energy expenditure in adults with cerebral palsy playing Wii Sports. *Arch Phys Med Rehabil*. 2010;91(10):1577–81. [PMID: 20875517]
- Lotan M, Yalon-Chamovitz S, Weiss PL. Improving physical fitness of individuals with intellectual and developmental disability through a virtual reality intervention program. *Res Dev Disabil*. 2009;30(2):229–39. [PMID: 18479889]
- Sell K, Lillie T, Taylor J. Energy expenditure during physically interactive video game playing in male college students with different playing experience. *J Am Coll Health*. 2008;56(5):505–11. [PMID: 18400662] <http://dx.doi.org/10.3200/JACH.56.5.505-512>

ACMS = American College of Sports Medicine, AVG = active video game, CP = cerebral palsy, DDR = Dance Dance Revolution, EE = energy expenditure, F = female, HR = heart rate,  $\text{HR}_{\max}$  = maximum heart rate, IDD = individuals with intellectual and developmental disabilities, M = male, MET = metabolic equivalent, PA = physical activity, PS2 = PlayStation2, RER = respiratory exchange ratio, RPE = rating of perceived exertion, SVG = static video game, THBI = total heart beat index,  $\text{VO}_2$  = oxygen consumption.

22.2 kJ, respectively [16]. These games are primarily a form of entertainment that may help with motivation (which is important for rehabilitation). Some form of activity is perhaps better than none, and playing the more active games could counter the effects of a sedentary lifestyle.

We found no reports in the literature on the effect of playing the Wii as an intervention study to increase EE in an elderly sedentary population. Because these games may not elicit the same fatiguing response as the actual sport, it is likely, as seen in the next section, that Wii games may be played for longer to facilitate an increase in EE but that this may potentially result in Wii- or other gaming-specific injuries.

### **Nintendo Wii and Cerebral Palsy**

Hurkmans et al. compared EE while playing Wii Tennis and Boxing for 15 minutes each with inactive sitting and standing in eight adults with bilateral spastic CP (Table 1) [9]. Similar to nonclinical populations, Wii gameplay resulted in greater EE compared with either standing or sitting. The study found that EE for all participants was greater than 3 METs, suggesting that playing the Wii can meet ACSM guidelines to improve and maintain health in this population. Furthermore, the authors hypothesized that because fitness levels in CP are generally lower than nondisabled METs, persons with CP would actually achieve a higher percentage of their peak oxygen consumption ( $VO_2$ ) compared with nondisabled persons, thus resulting in greater health benefits for this population.

### **Other Activity-Promoting Gaming Systems**

Similar findings of increased EE using the Wii compared with sedentary activities and inactive computer games and EE comparative with walking have been reported for other gaming systems such as DDR [17–19], XaviX Bowling (SSD Company Limited; San Diego, California), the J-MAT (Jackie Chan Studio Fitness, SSD Company Limited) [20], and the EyeToy [21] in children. To date, few studies have compared other gaming systems in adults.

### **Energy Expenditure Associated with Dance Dance Revolution**

In college students, mean and maximum HR [14] and  $VO_2$  [22] were greater when playing DDR compared with Wii Tennis. These latter studies suggest that DDR

meets ACSM guidelines for physical activity, yet Wii gameplay does not [14,22]. However, Wii Tennis was played in these studies rather than the more active Wii Boxing. Sell et al. compared experienced with inexperienced DDR players [23]. Greater playing experience allowed these participants to work at higher intensities, thereby promoting greater EE. For example, an experienced player with a mass of 68 kg would expend, on average, an additional 102 kCal per 30-minute session compared with an inexperienced player of the same mass [23]. Norlin et al. reported an increase in HR maximum percent,  $VO_2$  maximum percent, and RPE with increasing difficulty in gameplay mode [24]. The intensity of the “difficult” gameplay mode meets ACSM guidelines for improving cardiorespiratory endurance.

The attitudes of 40 postmenopausal women (1 year since last menstrual period, 45–75 years old, and not currently engaged in regular exercise) toward DDR to encourage exercise were generally positive [25]. The most frequently cited advantages were the fun nature of the exercise and its perceived potential to improve coordination, whereas a concern cited was the potentially long and frustrating learning process [25]. This concern may be applicable to all commercial gaming systems that are not specifically designed for clinical populations.

### **Energy Expenditure Associated with Sony EyeToy**

There appears to be a paucity of research investigating the EE of gameplay using the EyeToy in adults. Rand et al. reported that *Kung-Fu Live* (Sony Computer Entertainment) for the EyeToy was sensitive enough to elicit differences in RPE between elderly (59–80 years old) and young (21–37 years old) players [26]. The EyeToy has been cited as a possible tool to help improve physical fitness in adults with intellectual and developmental disability [10]. After three 30-minute sessions per week for 5 to 6 weeks, significant improvements in the modified Cooper test (12 min walk/run) were seen in the EyeToy group compared with the control group.

### **Energy Expenditure Associated with Xbox Kinect**

We found no references to the Kinect in the literature regarding energy expenditure.

### **Play Opponents: Computer or Human**

Wii, Kinect, and EyeToy games can be played against human or computer competitors. When playing interactive computer games, arousal ratings and physiological

responses to gaming were greater when competing against a human than against a computer [27]. The magnitude of EE increase when playing the Wii does not seem to differ when playing against the computer or a human [28], but the social interaction may benefit in enjoyment or adherence to play when competing against a human. Such social interaction may be beneficial for the older population in setting up gaming-derived bowling or golf leagues.

### “Real World” Gameplay

Perhaps a limitation to these gaming studies is the ecological validity of them, i.e., how they are played in the “real world.” The studies presented have gameplay lasting no longer than 15 minutes. However, no research has evaluated the free-living patterns of Wii gameplay such as duration and frequency. The playing habits of DDR players have been reported, with most playing 2 to 3 times per week with 22.6 percent playing 4 to 6 times per week [29]. The average gameplay session lasted between 30 and 120 minutes. These survey respondents were both arcade and home users of DDR; therefore, it is possible that home users may play for longer.

## INJURIES ASSOCIATED WITH ACTIVITY-PROMOTING GAMING SYSTEMS

Injuries specific to games, such as PlayStation thumb [30–31], Nintendonitis [32], and Nintendinitis [33–34] have been reported in the literature. When playing the Wii, bodily movements direct gameplay for the majority of the games. These vigorous movements, along with the repetitive nature of the games, has led to reports of Wii-specific injuries. “Wiiitis” was first coined by Bonis in describing acute pain of the right infraspinatus as a result of playing Wii Tennis for several hours [35]. Since this first report, a number of other “Wiiitis” conditions have been cited in the literature.

### Commonly Reported Nintendo Wii Injuries

A review of self-reported, Wii-related injuries shows that hand laceration was the most common injury (**Table 2**) [36]. Interestingly, playing Wii Tennis resulted in nearly half (46%) of all injuries reported. This may be because of the dynamic nature and multiplayer options of this game, which can create collisions with other players, furniture, or walls, resulting in the report of a ruptured

**Table 2.**

Self-reported Nintendo Wii-related (Nintendo; Redmond, Washington) injuries between November 2006 and 2008. Adapted from: Sparks D, Chase D, Coughlin L. Wii have a problem: A review of self-reported Wii related injuries. *Inform Prim Care.* 2009;17(1):55–57. [[PMID: 19490774](https://pubmed.ncbi.nlm.nih.gov/19490774/)].

No.	Type
17	Hand laceration/bruise
5	Periorbital haematoma
3	Forehead bruise/laceration
2	Metacarpal fracture
2	Patellar dislocation
2	Ankle sprain/fracture
1	Chin laceration
1	Tooth avulsion
1	Quadriceps sprain
1	Lip laceration
1	Clavicular fracture
1	Epistaxis
1	Metatarsal fracture
1	Wrist strap injury

extensor pollicis tendon [37]. Furthermore, the majority of Wii injuries reported in the literature were sustained when playing *Wii Sports*, possibly because this is the introductory game included with the Wii console, and therefore the first game played, and is one of the more dynamic titles.

**Table 3** presents injuries from playing the Wii reported in the literature. The majority of these injuries were sustained from excessive gameplay, up to 10 hours in some cases, or resulting from a fall. These injuries are, in part, a consequence of the repetitive nature of the games; the rapid decelerations associated with aggressive gameplay with little resistance from the Wii remote that can result in significant eccentric loading leading to ultrastructural damage [38]; and the engrossment of the player, where unlike with real sports, physical strength and endurance are not likely to be limiting factors. The lack of deceleration, for example, and exaggerated arm swing (to mimic the tennis stroke and provide greater virtual ball velocity) may result in higher cervicothoracic torsion, thus leading to an increased risk of cervical carotid dissection as seen by Faivre et al. [39].

**Table 3** describes injuries mainly caused by excessive gameplay; thus, Nintendo’s recommendations for gameplay should be adhered to. If the Wii is to be used in rehabilitation and recommended for use as a tool to increase physical activity of otherwise sedentary individuals, then

**Table 3.**

Nintendo Wii-related (Nintendo; Redmond, Washington) injuries.

Author	Condition	Game	Patient
Bonis [1]	Acute tendonitis of right infraspinatus	“Several hours” playing Wii Tennis	29 yr, M
Bhangu et al. [2]	Acute Witiitis of left shoulder	“Aggressive play” of <i>Brunswick Pro Bowling</i> *	22 yr, M
Hipara and Abouazza [3]	Dislocation of left patella (Wii knee)	Fall while playing Wii Tennis	18 yr, F
Faivre et al. [4]	Internal carotid artery dissection	3 h consecutive Wii Tennis play	47 yr, F
Almedghio et al. [5]	Medial meniscal tear	Wii Bowling	23 yr, F
Meeke and Gonzalez [6]	Retroperitoneal hemorrhage from ruptured renal angiomyolipoma	“Aggressive” Wii gameplay	Age not reported, “young female”
Low [7]	Right-side primary spontaneous pneumothorax	Extended gameplay of <i>Wii Sports</i> (game not specified)	46 yr, M
Peek et al. [8]	Traumatic hemothorax following fall	Wii Tennis	55 yr, F
Boehm and Pugh [9]	Acute onset of carpal tunnel syndrome secondary to gaming	6–8 h Wii Bowling for 10 d	19 yr, F

\*Crave Entertainment, Inc; Santa Ana, California.

1. Bonis J. Acute Witiitis. *N Engl J Med*. 2007;356(23):2431–32. [PMID: 17554133]<http://dx.doi.org/10.1056/NEJMc070670>2. Bhangu A, Lwin M, Dias R. Wimbledon or bust: Nintendo Wii related rupture of the extensor pollicis longus tendon. *J Hand Surg Eur Vol*. 2009;34(3):399–400.

[PMID: 19457909]

<http://dx.doi.org/10.1177/1753193408098906>3. Hipara KM, Abouazza OA. The “Wii knee”: A case of patella dislocation secondary to computer video games. *Injury Extra*. 2008;39:86–87.<http://dx.doi.org/10.1016/j.injury.2007.07.034>4. Faivre A, Chapon F, Combaz X, Nicoli F. Internal carotid artery dissection occurring during intensive practice with Wii video sports games. *Neurology*.

2009;73(15):1242–43. [PMID: 19822875]

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[PMID: 21686424]

6. Meeke JJ, Gonzalez CM. Retroperitoneal haemorrhage from ruptured angiomyolipoma while playing Wii video games. *BMJ*. 2008;336.7. Low AC. Wii-related pneumothorax. *BMJ*. 2008;336.8. Peek AC, Ibrahim T, Abunasra H, Waller D, Natarajan R. White-out from a Wii: Traumatic haemothorax sustained playing Nintendo Wii. *Ann R Coll Surg Engl*.

2008;90(6):W9–10. [PMID: 18765020]

<http://dx.doi.org/10.1308/147870808X303100>9. Boehm KM, Pugh A. A new variant of Witiitis. *J Emerg Med*. 2009;36(1):80. [PMID: 18554849]<http://dx.doi.org/10.1016/j.jemermed.2007.11.104>

F = female, M = male.

these potential injuries should be considered when designing activities for rehabilitation and exercise. The number of injuries reported for the Wii (compared with other gaming systems) may be in part because of the number of units sold; therefore, an injury is more likely to manifest itself in a larger population of users.

### Injuries Associated with Dance Dance Revolution

DDR injuries have been reported in the literature from an Internet survey with 556 respondents from 22 countries [29]. Similar to the Wii, the injuries reported

for DDR were also a consequence of excessive play and poor technique. Also similar to the Wii, a number of accidents while playing DDR (the majority caused by playing for too long) resulted in injuries ranging from cuts and bruises to sprains and broken bones.

### Injuries Associated with Sony EyeToy

It is likely that some of the injuries reported for the Wii caused by excessive gameplay would be applicable to other gaming systems such as the EyeToy. However,

we found no reports of injuries from using this game platform in the literature.

### Injuries Associated with Xbox Kinect

We found no references to the Kinect in the literature regarding injuries.

## REHABILITATION WITH ACTIVITY-PROMOTING GAMING SYSTEMS

Computer-based rehabilitation is not a new phenomenon. For example, the EyeToy has shown the potential to promote exercise [40] and enhance upper-limb-related motor functioning in patients with stroke [41]. However, it appears that the Wii has captured the imagination of those in rehabilitation settings as a means to facilitate rehabilitation. One of the main reasons for employing video games in rehabilitation is their ability to increase motivation and produce a distraction from mundane and boring and/or painful treatments [42]. Kato proposed that video games are “play” for adults [42] and that gameplay has the following attributes: voluntary, intrinsically motivating, active (perhaps physical) involvement, and a make-believe quality [43], all of which may help improve psychosocial functioning.

### Rehabilitation Associated with Nintendo Wii

The attraction of activity-promoting gaming systems as a rehabilitation tool is perhaps their relative inexpensiveness, attractive graphics that make playing more enjoyable and potentially aids with adherence to rehabilitation programs, and the relative ease of gameplay that progresses as the player improves. This may not accurately present balance improvement because games can be manipulated, but an independent measure of balance (i.e., with a force plate) can show if balance has improved after training. Simple sophistication and a large user base make the Wii an attractive home- and clinical-based user interface for rehabilitation and exercise [44]. The potential for social interaction as a motivating tool to facilitate rehabilitation must also not be forgotten. Van den Hoogen et al. proposed that gaming systems can be part of an engaging and interactive multiplayer tool to help reconnect patients with their social environments, either with the rehabilitation itself or with partners and children and/or grandchildren. [45]

Using the controllers and balance board with *Wii Sports* and *Wii Fit* has been cited as a possible tool to enhance the process of rehabilitation. Anecdotally, the Wii is used in a number of settings within the National Health Service (NHS) in the United Kingdom (<http://www.wiihabilitation.co.uk/>), such as for the elderly and patients with pathologies (stroke, amputation, and Parkinson disease). The Wii has also been employed to facilitate rehabilitation at Department of Veterans Affairs (VA) centers in the United States (**Figure 2**). In 2007, seven



**Figure 2.**

Veterans using donated Nintendo Wii (Nintendo; Redmond, Washington) equipment at the Washington DC Department of Veterans Affairs Medical Center. Washington DC VA Medical Center. Aquilent donates Wii equipment to hospitalized vets [Internet]. Washington (DC): Department of Veterans Affairs; 2009 [updated 2009 Nov 10]. Available from: <http://www.washingtondc.va.gov/news/giftaquilent.asp>

VA facilities reported having a Wii, but by 2008, more than 80 facilities reported having at least one Wii [46]. For patients with amputation, Nintendo requested that Össur UK (Manchester, United Kingdom), a manufacturer of prostheses for people with lower-limb amputation, produce an advisory document on the suitability of *Wii Fit* exercises as a recreation or rehabilitation tool [47]. These guidelines have been adopted by the British Association of Chartered Physiotherapists in Amputee Rehabilitation, who produced a document aimed at guiding therapists using *Wii Fit* with patients with amputation in the NHS [48]. However, we found no research into the feasibility and/or effectiveness of the Wii in amputation rehabilitation.

Only recently has the use of activity-promoting gaming been reported in the scientific literature as a tool incorporated into rehabilitation (**Table 4**), and the majority of these studies have been case studies. In community-dwelling fallers (>70 years old), a 12-week training session (twice a week) reported significant improvement in the mean Berg Balance Scale score after 4 weeks compared with baseline. However, this improvement was not carried through to the end of the 12-week training program and possibly reflects the inadequate increase in exercise intensity. The authors found no improvement in the Tinetti Balance Test or Fall Efficacy Scale International scores compared with baseline [49]. Of the patients, 92 percent expressed a desire to exercise with the Wii in the future; however, negative recurring themes were pain and/or discomfort and difficulties attending sessions in the clinic [49]. A case study of an 89-year-old multiple faller who attended six 1-hour treatment sessions of Wii Bowling also showed improved balance (Berg Balance Scale, Timed "Up and Go" test [TUG], and Dynamic Gait Index scores) and possibly reduced the risk of falls [50]. Two studies used *Wii Fit* in patients with stroke. Sugarman et al. [51] carried out a feasibility case study of an 86-year-old female with a diagnosis of a vertebro-basilar cerebral vascular accident that took place 5 weeks before the intervention. This patient played four games (Table Tilt, Balance Bubble, Tightrope Walk, Lotus Focus) for 45 min on four consecutive training days. The patient also performed normal physical therapy. An advantage of using *Wii Fit* appears to be its novelty; the patient reportedly enjoyed the Wii sessions and felt that she received up-to-date treatment. The patient improved her TUG score by 10 seconds, she was able to play the games with no external support after the fourth

session, and her ambulation improved (qualitatively). Furthermore, she also reported that she felt more successful in "catching herself."

Duetsch et al. compared standard care with the *Wii Fit* for two patients poststroke [52]. The *Wii Fit* patient (48-year-old male, 10 years post ganglia cerebral infarction) and the standard care patient (34-year-old female, 7 years post subarachnoid hemorrhagic stroke) undertook three 1-hour sessions per week for 4 weeks. The *Wii Fit* patient trained on a number of games (Boxing, Bowling, Baseball, Ski Jump, Ski Slalom, Tightrope Walk, Lunge, and Park Stroll). Posttraining, gait speed improved by 19 percent for the *Wii Fit* patient and 12 percent for the standard care patient; the TUG score also improved by 23 percent for the *Wii Fit* patient and 15 percent for the standard care patient.

Even though these initial rehabilitation findings are promising, we found no randomized crossover design studies reported for the Wii against traditional rehabilitation. Only after such a study can a comparison between these two rehabilitation methods be made. Saposnik et al. reported a proposed clinical trial protocol for patients with stroke, but the results from this study have not yet been reported [53]. Furthermore, it may be difficult to deny a patient group a tried and tested training method for a novel, yet untested, training modality. It may be more likely that the Wii is used complementary to traditional methods rather than as a replacement, either in a clinical setting or in the home.

### **Response to Using Nintendo *Wii Fit* in Nondisabled Adults**

Structured research investigating the effectiveness of the Wii in improving balance and its use in rehabilitation is a relatively new area. Nitz et al. showed that two 30-minute sessions over a 10-week period using *Wii Fit* did improve balance and lower-limb muscle strength in eight nondisabled females (aged  $46.6 \pm 9.9$  years) [54]. The games played by these subjects (at home) were not controlled, and they chose which games they played. The training regime needed to include *Wii Fit* activities from the yoga, strength, balance, and aerobic options. The authors also encouraged subjects to increase the level of difficulty as the training duration increased. This is the first reported study in the literature that has attempted to carry out a controlled trial demonstrating the effect of using the Wii on balance. These results are encouraging, but the subjects were nondisabled, active, and relatively

**Table 4.**

Use of Nintendo Wii (Nintendo; Redmond, Washington) in rehabilitation.

Author	Design	Sample	Method	Measure	Result
Williams et al. [1]	Community-dwelling fallers, intervention study	Wii exercise group (76.0 ± 5.2 yr, <i>n</i> = 15); standard care group (76.5 ± 4.8 yr, <i>n</i> = 6)	Wii exercise group: attended individual supervised exercise twice weekly for 12 weeks. Games included Table Tilt, Soccer Heading, Ski Slalom, Jogging, Hula Hoop, and Ski Jump.* Standard care group: attended 12-week exercise/education program supervised by NHS physiotherapists.	FES-I, Berg Balance Scale, Tinetti Balance Scale	Baseline vs week 4: mean Berg Balance Test significantly improved. ( <i>p</i> = 0.02). No improvement in either balance score in standard care group. Wii deemed acceptable form of exercise for elderly.
Clark and Kraemer [2]	Case study	Unspecified balance disorder, multiple faller (89 yr, F)	Six 1 h treatment sessions over 2 weeks. Wii Bowling <sup>†</sup> (minimum 2 games per session) competed against investigator. Actual minimum time per session was 40 min.	Berg Balance Scale, DGI, TUG, ABC	Decrease in falls risk shown by increase in Berg Balance Scale (48–53) and DGI (19–21) scores and decrease in TUG time (14.9–10.5 s).
Sugarman et al. [3]	Feasibility case study	Vertebra-basilar CVA (86 yr, F)	4 consecutive training days playing Wii (Table Tilt, Balance Bubble, Tightrope Walk, Lotus Focus*).	Berg Balance Scale, functional reach, TUG, posturography	10 s decrease in TUG time. Modest improvement in Berg Balance Scale, functional reach, and posturography. Observational improvement in gait. Wii deemed as having potential for use in clinical settings.
Deutsch et al. [4]	2 individual case studies	48 yr (M) and 34 yr (F)	Comparison between 2 stroke patients: standard care vs Wii-based care. Three 1 h sessions per week for 4 weeks.	Gait speed, distance walked, DGI, TUG	Both participants showed improvement in all measures. Wii resulted in larger gains posttraining, but gains not sustained at follow-up compared with standard care.
Boyle et al. [5]	Convenience sample, intervention study	22 yr, <i>n</i> = 10	Assessed patient acceptability and usefulness of Wii for exercise in adults with CF. Sports simulation games played against physiotherapist for average 20 min.	HR, SpO <sub>2</sub> , BBS, BMS, patient enjoyment (directly pre and post)	BBS ( <i>p</i> = 0.005) and BMS ( <i>p</i> = 0.009) scores significantly increased. No significant increase in HR and SpO <sub>2</sub> . Mean patient enjoyment 9/10. Wii has potential as alternative form of exercise.

**Table 4. (cont)**

Use of Nintendo Wii (Nintendo; Redmond, Washington) in rehabilitation.

\*Wii Fit (Nintendo).

†Wii Sports (Nintendo).

1. Williams MA, Soiza RL, Jenkinson AM, Stewart A. Exercising with computers in later life (EXCELL)—Pilot and feasibility study of the acceptability of the Nintendo Wii Fit in community-dwelling fallers. *BMC Res Notes*. 2010;3:238. [PMID: 20831836] <http://dx.doi.org/10.1186/1756-0500-3-238>
2. Clark R, Kraemer T. Clinical use of the Nintendo Wii Bowling simulation to decrease fall risk in an elderly resident of a nursing home: A case report. *J Geriatr Phys Ther*. 2009;32(4):174–80. [PMID: 20469567] <http://dx.doi.org/10.1519/00139143-200932040-00006>
3. Sugarman H, Weisel-Eichler A, Burstin A, Brown R. Use of Wii Fit system for the treatment of balance problems in the elderly: A feasibility study. Proceedings of the Virtual Rehabilitation International Conference; 2009 Jun 29–Jul 2; Haifa, Israel. Los Alamitos (CA): IEEE; 2009.
4. Deutsch JE, Robbins D, Morrison J, Guarrera-Bowly P. Wii-based compared to standard of care balance and mobility rehabilitation for two individuals post-stroke. Proceedings of the Virtual Rehabilitation International Conference; 2009 Jun 29–Jul 2; Haifa, Israel. Los Alamitos (CA): IEEE; 2009.
5. Boyle L, Lavery K, Elborn JS, Rendall JC. Use of Nintendo Wii for exercise in adult CF patients. *J Cyst Fibros*. 2009;8(S2):S71. [http://dx.doi.org/10.1016/S1569-1993\(09\)60283-6](http://dx.doi.org/10.1016/S1569-1993(09)60283-6)

ABC = Activities-Specific Balance Scale, BBS = Borg Breathlessness Scale, BMS = Borg Muscle Fatigue Scale, CF = cystic fibrosis, CVA = cerebral vascular accident, DGI = Dynamic Gait Index, F = female, FES-I = Falls Efficacy Scale International, HR = heart rate, M = male, NHS = National Health Service, SpO<sub>2</sub> = oxygen saturation, TUG = Timed “Up and Go” test.

young adults. Furthermore, the training regime was not controlled or supervised, with only three subjects completing all training sessions. It is possible that a greater effect would be seen in subjects who are relatively sedentary, are older, and have more structured training sessions.

### Rehabilitation Associated with Using Dance Dance Revolution

Brumels et al. compared the efficacy of traditional and game-based (Wii and DDR) balance programs in a population of 18 to 24 year olds [55]. Training was undertaken 3 days per week for 4 weeks, and each session lasted between 12 to 15 minutes. Postural sway in the sagittal plane, measured by a force plate, significantly improved for the DDR and Wii only. The authors reported no statistical differences in postural sway between the Wii and DDR. Furthermore, game-based balance programs were perceived as less difficult, more engaging, and enjoyable compared with the traditional program. Brumels and Young have developed preventative and rehabilitative exercises using DDR [56]. Even though these exercises are designed to help bridge a gap between static and functional movement, the effectiveness of such exercises has yet to be reported.

### Rehabilitation Associated with Using Sony EyeToy

Rand et al. reported that elderly (70.0 ± 5.7 years old) nondisabled participants enjoyed using the EyeToy and found it easy to use [26]. Furthermore, they found the EyeToy, and in particular *Kung Fu Live*, sensitive enough to distinguish between younger and older participants, as

well as between patients with chronic and acute stroke. However, even though the patients with stroke reported enjoyment using the EyeToy, it did appear to be less suitable for patients with acute stroke who experienced severe unilateral weakness. These patients expressed frustration when not able to interact with the game using the weaker side. Such frustrations may be exacerbated when using handheld controllers such as the Wii remote. Rand et al. therefore suggest that the EyeToy has greater potential for patients with chronic stroke [26].

Flynn et al. reported a case study for a 76-year-old female who experienced a right hemorrhagic stroke 17 months before the start of the study [57]. She undertook 20 1-hour sessions over 4.5 weeks using the EyeToy. Training was carried out in the patient’s home, and the research team did not supervise the training sessions. She played 15 different games 108 times (in total) over the 4.5 weeks (~5.5 games per session). After training, the authors saw clinically relevant improvements in the Fugl-Meyer Assessment, Berg Balance Scale, Upper Extremity Functional Index, Motor Activity Log, and Beck Depression Inventory. Furthermore, no adverse effects, such as falls or increased pain, during the gaming sessions suggests that self-directed training in the home environment can be relatively safe. However, before retirement the patient was a physical therapist and professor of physical therapy; thus, whether such self-directed training using gaming systems can be applicable to a population that lacks this expertise has yet to be explored.

Hemiparetic inpatients ( $n = 20$ , 12 months post-stroke, mean age 61.1 years) took part in a 4-week training

program [41]. In addition to the conventional program, half the group received 30 minutes of treatment with the EyeToy (5 games that all trained the upper limb) while the remaining half received a placebo of watching the games for the same duration without any physical involvement. Upper-limb motor function benefited more from EyeToy games in addition to the conventional rehabilitation program than rehabilitation without the EyeToy. This effect carried over during the 3-month follow-up.

### Rehabilitation Associated with Using Xbox Kinect

We found no studies using the Xbox Kinect reported in the literature regarding rehabilitation.

### Applications—Hardware and Software

Commercial activity-promoting gaming systems are primarily entertainment systems, not specifically designed to be rehabilitation tools. However, a number of studies have adapted the hardware and developed software to turn the Wii into a more useful rehabilitation tool.

Matamoros et al. customized the Wii remote and nunchuk for patients with stroke so that it could transmit physiological data, such as grip strength and finger force, while performing therapy in a virtual environment [58]. Martin-Moreno et al. proposed a similar application for the Wii remote as a tool to aid physiotherapy exercise movements by providing intuitive and interactive software for the patient that allows progression, adherence, and technique to be monitored remotely by the Internet [3].

The rehabilitation studies mentioned earlier have used the Wii “off-the-shelf,” using the games that come with the Wii console. These games are perhaps not designed to facilitate rehabilitation goals; thus, specifically designed games may be needed. Games for health-care have been designed for patients with burns, diabetes, asthma, and bladder and bowel dysfunction. For example, the game *SnowWorld* (developed by Professors Hunter Hoffman and David Patterson, University of Washington Harborview Burn Center, Seattle, Washington), a game designed to reduce body motion with “cool” (temperature) imagery, i.e., ice and snow, showed a 20 percent reduction in subjective reports of pain compared with standard analgesia [59]. Games like *Packy and Marlon* (Raya Systems, Inc, now Health Hero Network; Mountain View, California) and *Bronkie and Bronchiasaurus* (Raya Systems, Inc), both on the Super Nintendo console (Nintendo), are designed to provide education in the management of diabetes and asthma, respectively [60–61].

Both games have been reported to improve self-efficacy, self-management, and self-care behaviors compared with nongaming controls. For the Wii, the development of health-specific games in the manner of those described appears to be in its infancy.

## CONCLUSIONS

Activity-promoting gaming systems may encourage activity (especially in sedentary individuals) and complement rehabilitation. Both the Wii and DDR have shown to increase EE compared with inactive video games and are comparable with walking (but not with actual sports). Improving physical activity in the sedentary elderly may be the next focus of research.

The literature also shows that gaming-related injuries are usually a consequence of excessive gameplay. It must be remembered that the injuries we present, though serious, are rare when considering that, for example, 75 million Wii consoles have been sold worldwide.

In rehabilitation settings, anecdotal evidence and a series of case studies have provided encouraging results supporting the use of gaming. However, there is a paucity of work investigating its use in larger-scale studies. A potential limitation of the available commercial games and gaming systems, even though they encourage improvements in balance, strength, and fitness, is that they are not necessarily designed for rehabilitation. Future work may wish to design more specific games to complement rehabilitation that are focused on the needs of the user. For example, González-Fernández et al. developed an easy Balance Virtual Rehabilitation System (the eBaViR System), which uses specific games designed for the rehabilitation of balance disorders [62].

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