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A Scoping Review of Exergaming for Adults with Systemic Disabling Conditions

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Abstract

Background: Exergaming, or playing a game on a television, computer or projector screen with a motion-monitoring system to enable control of on-screen action by bodily movements that result in a substantially greater expenditure of energy compared to resting levels, may be particularly relevant for adults with systemic disabling conditions because of its potential to increase health and function and improve adherence to rehabilitation/exercise programs. Thus, we conducted a scoping review of the literature on examining the usability and utility of low-cost exergaming technology in adults with systemic disabling conditions.

Methods: Comprehensive strategies were used to search for studies published or in-press between 1980 and July, 2011. Main inclusion-exclusion criteria were studies that examined the usability or utility of affordable exergaming technology (e.g., excluding fully immersive virtual reality platforms) in adults with systemic disabling conditions. We used the User-Orientation Evaluation Framework, GameFlow model, and Dobkin's framework on the progressive staging of pilot studies to determine the scope and quality of the existing literature.

Results: We identified 25 studies, which reported on 346 adults with disabling conditions. Most participants were male and stroke survivors. Only four studies employed a randomized controlled trial design and most studies were classified in the consideration-of-concept stage, according to Dobkin's framework. Few studies were comprehensive in their usability assessment. Common exergaming technology platforms examined were Sony PlayStation EyeToy, Nintendo Wii, and technology developed by the researchers of the study. Eight adverse events were reported across the 25 studies.

Conclusions: Research on exergaming using affordable exergaming technology platforms is still in its infancy. We recommend that randomized controlled trials be conducted with a long-term follow-up that employs a mixed-methods approach to collecting data. Multidisciplinary collaborations among exercise physiologist, behavioral scientist, rehabilitation scientist and neuromotor control experts are needed to advance the field and identify possible mechanisms of action.

Introduction

Although not a new concept, exergaming, or playing a game on a television, computer or projector screen with a motion-monitoring system to enable control of on-screen action by bodily movements that result in a substantially greater expenditure of energy compared to resting levels, has received a great deal of media attention over the last few years. This attention largely is the result of recent advances in video game technology that have made exergames more realistic and readily-available to the general public [1,2]. Common platforms on which to utilize exergames are virtual reality systems, computers mounted on exercise equipment and commercially available home video game consoles. The motion-monitoring system to enable control of on-screen action can range from handheld accelerometers and gyroscopes to haptic and video-capture technology [3]. Exergaming is advocated as an enjoyable way to meet physical activity guidelines to improve and maintain health in a variety of population segments [4-6], including adults with chronic systemic disabling conditions (i.e., a long-term condition that affects multiple organ systems or the whole body and limits participation in life roles) [7-10].

Since the 1980s, there have been a growing number of research studies in the rehabilitation literature on developing and evaluating virtual reality systems among adults with systemic disabling conditions [11,12]. Many rehabilitation studies have focused on examining the benefits of virtual reality systems that use video-capture technology and create fully immersive environments with large screen projections, head-mounted displays or concave projection screens [13]. These studies involve research subjects (e.g., stroke survivors) engaging in therapeutic exercises, sport and leisure activities and/or functional tasks within a virtual environment. Although this line of research has shown potential in improving health and function, cost and the expertise required to operate virtual reality systems have impeded its widespread distribution in clinical rehabilitation practices [14]. Thus, using commercially available home video game consoles is an appealing alternative to expensive virtual reality systems [15]. Occupational and physical therapists have suggested that incorporating exergaming

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utilized on home video game consoles into the rehabilitative care of patients with disabling conditions could lead to improved health outcomes by improving quality of care and exercise adherence [9,10].

Several studies have documented that adults with systemic disabling conditions do not receive quality rehabilitation care. Reasons for inadequate care include issues related to accessibility, affordability and continuity in services [16-20]. One way to increase accessibility and affordability of rehabilitation services is through web-based telehealth communication [21]. Exergames could be discussed in telehealth communications between a physical or occupational therapist and patient. For example, exergames can enable individuals to keep track of their personalized exercise program online and monitor progress towards meeting fitness goals, which could be sent to the therapist for review and feedback. Exergames could also be used within a clinical setting to reduce costs. For example, exergames can be used to help patients achieve the required practice to learn a new motor skill. With proper safety precautions in place, the therapist's time from supervising this low-skilled service could be reduced to focus on higher-skilled services, such as gait training and improving quality of movement [22]. Exergames used on home video game counsels could facilitate continuity in rehabilitation services by providing a common therapeutic modality to use across rehabilitation settings (i.e., acute, post-acute and home setting).

Exergaming may also improve patient compliance with both therapeutic and preventive/maintenance exercise programs [23]. Exergaming has the potential to be engaging and fun to play, which is important for people with disabling conditions that may experience many disincentives for engaging in physical activity and exercise. It is now generally accepted that routine engagement in physical activity can improve physical function, decrease utilization of healthcare services and improve quality of life in adults with disabling conditions [24-27]. However, adults with disabling conditions experience many health-related barriers to physical activity and can subsequently become extremely inactive [28,29]. Inactivity can lead to de-conditioning, secondary conditions (e.g., obesity, diabetes and cardiovascular disease) and ultimately further disability and increased utilization of healthcare services [30,31]. Exergaming may be able to break this disabling cycle by increasing motivation and influencing psychosocial constructs (e.g., self-efficacy) related to increased physical activity levels [23]. Exergaming in the home could remove common barriers that adults with disability often experience in going to a gym [32,33], while allowing for the possibility of social interactions in the home.

Given these potential benefits, the research literature on exergaming in adults with systemic disabling conditions is rapidly growing. Furthermore, non-profit organizations and federal granting agencies have a renewed interest in funding healthy gaming research [2]. Thus, there is a critical need to examine how best to advance the research literature on exergaming. While there have been recent review articles on utilizing healthy gaming technology, to the best of our knowledge, these reviews have primarily focused on expensive virtual reality systems or only reviewed research studies in narrowly-defined population segments (e.g., healthy adults or individuals with a particular condition/disease) [13,34-37]. Furthermore, many of these reviews have not used a conceptual framework to guide search methodology and make research recommendations. Using a conceptual framework can help ensure a thorough review of the literature and can provide a classification system to organize studies and identify knowledge gaps [38].

In summary, exergaming may be particularly relevant for adults with systemic disabling conditions because of its potential to increase health and function, improve rehabilitation services and decrease rates of inactivity. However, exergaming technology and studies that evaluate such technology are growing rapidly across different scientific disciplines. To help avoid superfluous and redundant studies that fail to substantially advance the field towards evidence-based rehabilitation practice, we conducted a scoping review of the literature on examining the usability, benefits and risks of exergaming in adults with chronic systemic disabling conditions. The objective of the review was to identify gaps within the existing literature and make future research recommendations. We focused our review to exergames played on a television or computer screen with exercise equipment (e.g., bike or treadmill) or commercially available home video game consoles (i.e., Nintendo Wii or Sony PlayStation Eye Toy). See the following cited review articles for details on the potential benefits of virtual reality systems that use more expensive technologies (e.g., large screen projections, cave systems, head-mounted displays, robotics or electromyography) [7,8,11,12].

We used the following three conceptual frameworks to operationalize definitions, identify gaps in the literature and make future research recommendations: (a) User-Orientation Evaluation Framework [39], (b) GameFlow model for evaluating enjoyment in video games [40] and (c) Dobkin's [41] progressive staging of pilot studies for motor interventions in rehabilitation. We used the User-Orientation Evaluation Framework and GameFlow model to help determine both the extent and quality of the existing research literature to examine the accessibility, usability and utility of exergaming. Both of these models identify and define a set of constructs (e.g., accessibility, usability, utility and playability) that should be considered when examining how an individual will respond and react to interactive computer technology (i.e., User-orientation) and whether they will have fun playing it (i.e., GameFlow). It will be important to examine such constructs when determining the feasibility of incorporating exergaming into clinical rehabilitation practice and whether exergaming can realistically be used to increase exercise adherence in adults with systemic disabling conditions. We used Dobkin's framework on the progressive staging of pilot studies for motor/rehabilitation interventions to guide methodological recommendations for future research.

Methods

A scoping review involves the synthesis and analysis of existing research literature with the aim of providing greater conceptual clarity about a specific phenomenon. Although a relatively new methodology in healthcare research, its use and recognized utility is growing across research disciplines. Davis [42] suggested that a scoping review "provides a comprehensive and panoramic overview that not only illuminates its extent and context but also has the potential to influence policy and practice developments." Unlike a systematic review of the literature, evaluating quality of evidence is not the primary focus of a scoping review. Instead, the main purpose is to map existing literature by time (history of literature), location (where are the studies being conducted) and origin (highlight disciplines/theoretical underpinnings) to identify research gaps and make recommendations for future research [42,43]. Arksey and O'Malley [44] outline five stages in a scoping review: (1) identifying the research question and operationalizing the definitions; (2) identifying relevant studies through electronic databases, reference lists and hand-searching of key journals; (3) establishing inclusion-exclusion criteria for the selection of studies; (4) charting the data through a narrative review; (5) collating, summarizing and reporting the results.

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Step 1: Identify Research Question and Operationalize Definitions

The questions we aimed to answer from the existing literature in adults with systemic disabling conditions: (1) What are the benefits and risks of exergaming? (2) What strategies are being implemented to evaluate and promote the use of exergaming? (3) What are the usability barriers to exergaming? The User-Orientation Evaluation Framework [39], GameFlow model [40], and Dobkin's [41] progressive staging of pilot studies were used to operationalize definitions and classify studies included in the review. Tables 1 and 2 outline important constructs and definitions in each framework/model.

The User-Orientation Evaluation Framework is based on the principle of universal access (i.e., the accessibility, usability and acceptance of technology irrespective of social status and functional level) and draws upon theories from sociology, social psychology and information systems/computer science (e.g., Innovation Diffusion Theory, Theory of Reasoned Action and Technology Acceptance Model). The framework summarizes six universal access constructs/measures (i.e., visibility, perceived usefulness and ease of use, availability/approachability, quality of interaction, relationship maintainability and competitiveness) that should be considered within the context of the user's goals and characteristics. The GameFlow model outlines eight constructs (i.e., concentration, challenge, player skills, control, clear goals, feedback, immersion and social interaction) that seek to guide the evaluation of player enjoyment in video games. We used both the User-Orientation Evaluation Framework and GameFlow model to identify research gaps in the evaluation of exergaming technology and to provide guidance on making substantive research recommendations. Dobkin's [41] progressive staging of pilot studies details a four-stage pathway (i.e., consideration-of-concept, development-of-concept, demonstration-of-concept and proof-of-concept) in which research methodology should progress to generate evidence-based rehabilitation interventions. Thus, this framework provides guidance on making methodological research recommendations.

Step 2: Identify Relevant Studies

Multiple search strategies were used to identify studies on exergaming in adults with systemic disabling conditions. Four databases were searched – Pubmed, CINHAL, Web of Science and Scopus. The following MeSH and/or subject terms were used: virtual reality, video games, Wii, Kinect and EyeToy in combination with rehabilitation, physical activity, exergaming or exercise. In addition, the reference list of relevant review articles was searched to identify additional studies, and Google Scholar was scanned using relevant search phrases. The following journals were also hand-searched between 1980 and July, 2011 (including in-press articles that were available for review): Clinical Rehabilitation, Disability and Rehabilitation, Archives of Physical Medicine and Rehabilitation, American Journal of Occupational Therapy, Physical Therapy and Cyberpsychology, Behavior, & Social Networking.

Step 3: Inclusion-Exclusion Criteria

Inclusion-exclusion criteria were implemented to help ensure that we only reviewed exergames that are or could potentially be commercially available to the general public and be readily used in the home or clinical setting. Inclusion criteria were English language articles that examined the usability or utility of exergames in adults with chronic systemic disabling conditions (e.g., cardiopulmonary diseases, neurological conditions, developmental disability, poly-arthritis and other ailments of old age, such as mobility and balance problems) and were published or in-press between 1980 and July, 2011. Exclusion criteria were (1) conference proceedings and abstracts, (2) review articles that described ongoing research, (3) studies on children, healthy adults, adults in long-term care facilities and individuals with orthopedic injuries, single joint inflammation, amputations, burns, mental health disorders (not excluded if co-morbid condition) or non-disabling risk factors for cardiovascular disease (e.g., high blood pressure or cholesterol), (4) examination of technology (i.e., goggles and ear piece) that provide visual or audio cues during gait training, (5) validation studies for assessing motor function or ability to engage in activities of daily living, (6) studies focusing on cognitive rehabilitation, re-learning daily skills in a "real-life" virtual environment (i.e., grocery store, train platform, ATM machine) or mimicking movements of a therapist from a remote location. We also excluded articles that described using fully immersive virtual reality technology or playing exergames using large screen projections, cave systems, head-mounted displays, advanced haptic or force-plate technology (i.e., beyond commercially available joysticks with vibration and Wii Board), electroencephalography, electromyography and robotics. If it was not clear whether the technology used in the study met inclusion-exclusion criteria (e.g., whether advanced robotic or haptic technology was used), there needed to be an explicit discussion about the cost of the technology or about the potential of it being commercially available to the general public.

Search procedure

We first scanned titles to determine whether the study potentially examined exergaming in adults with systemic disabling conditions. In this initial search, we felt that it was important to include any article that could potentially describe a study examining the use of virtual reality/video game technology in adults with systemic disabling

Stage of Pilot study	Definition	Example
Consideration-of-concept	Exploring why and how an intervention might work	**Develop protocol to prescribe exergaming program (duration and intensity of session) **Explore usability and accessibility of platform to utilize the exergame **Identify appropriate safety precautions to take during exergaming
Development-of-concept	Standardizing the new intervention using a randomized control group and masked outcomes	**Standardizing the prescription of the exergaming protocol **Testing different exergaming protocols **Evaluate appropriateness of health outcomes **Identify potential mechanisms of action **Feasibility of research protocol (e.g., exploring the appropriateness of inclusion-exclusion criteria)
Demonstration-of-concept	Larger randomized controlled trial to obtain stable effect sizes estimates	**A randomized controlled pilot trial (15 to 20 subject/group) comparing the efficacy of a standardized traditional exercise program to an exergaming program.
Proof-of-concept	Fully powered randomized controlled trial to generate generalizable data	**A randomized controlled pilot trial (50 subject/group) comparing the effectiveness of a standardized traditional exercise program to an exergaming program.

Table 1: Dobkin's progressive staging of pilot studies for motor interventions.

User-Orientation Framework	
Construct:	Definition:
Visibility	Degree to which a non-user can become aware of the system.
Perceived usefulness & ease	Degree to which the user views the system as useful and being user-friendly to achieve a goal
Availability/Approachability	Degree to which potential users can reach/assess the system.
Quality of Interaction	Degree to which the system achieves satisfaction and meaningful outcomes
Relationship Maintainability	Degree to which the system develops and maintains relationship while not using it
Competitiveness	Degree to which the user views the system as more favorable compared to alternative systems
GameFlow Model	
Concentration	Degree to which the game can capture the users attention
Challenge	Degree to which the game sufficiently challenges and matches the users skill level
Player skills	Degree to which the game fosters learning and skill mastery
Control	Degree to which the user feels a sense of control over the game
Clear Goals	Degree to which the game presents understandable goals at appropriate times
Feedback	Degree to which the game provides appropriate feedback towards meeting goal
Immersion	Degree of engagement, absorption, and effortless involvement into the game
Social Interaction	Degree to which the game facilitates social interactions

Table 2: Definition of constructs for the user-orientation framework and game flow model.

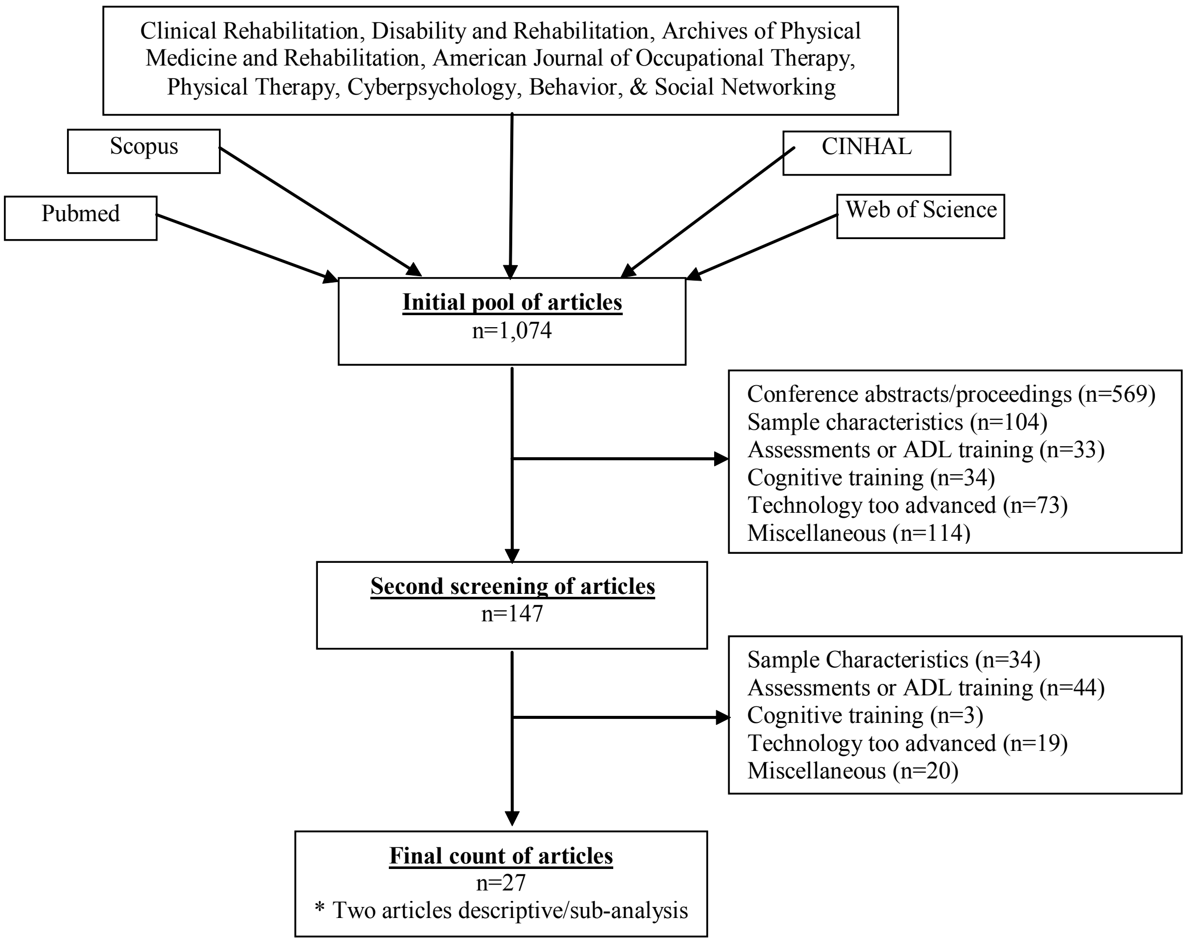

Figure 1: Flow of articles through the study.

conditions. After this preliminary search, we scanned the abstracts of articles to exclude reviews, conference proceedings and studies on children, healthy adults and other non-systemic conditions. We also excluded abstracts that described using fully immersive virtual reality technology. If there was any doubt as to whether the description of technology met study criteria, the study was moved to the final phase of review. In the final phase of review, we scanned the entire article to confirm inclusion-exclusion criteria. Thus, the final set of studies examined the usability and/or benefits of low-cost exergaming technology in adults with systemic disabling conditions.

Step 4: Charting Data

Coding of data: For the remaining pool of articles, sample characteristics (e.g., gender, age, type of disabling condition and mobility level), description of research design and outcomes (i.e., type of design, number of subjects and Dobkin 's [41] methodological classification framework) and characteristics of the exergaming interactions (i.e., location and frequency of exergaming, type of exergaming and description of the video game platform) were extracted from the articles. Articles were also coded as to whether they considered or examined the constructs specified in the User-Orientation Evaluation Framework or GameFlow model. Articles were coded as considering or examining the construct regardless of whether the construct was described from the perspective of the researcher (e.g., administering health outcomes) or the patient (e.g., asking the patient whether they had fun playing the exergame). The first and second authors independently coded each article. Disagreements were discussed until consensus was reached.

Results

Step 5: Collating, Summarizing and Reporting Results

We had an initial pool of 1,074 articles that had the potential to describe the examination of exergaming technology in adults with systemic disabling conditions. Of these articles, we excluded 1,047 articles (see Figure 1). We first identified and excluded 569 conference abstracts/proceedings and review articles (including review articles that described ongoing research). We then categorized and excluded 104 articles for not meeting criteria on sample characteristics, 33 articles for focusing on validating an assessment or activities of daily living (ADL) training and 34 for articles for focusing on cognitive training. We also excluded 73 articles for describing the use of fully immersive virtual reality technology or advanced robotics, and 114 articles for focusing on miscellaneous topics that were not about exergaming. For the remaining pool of 147 articles (i.e., third and final round of review), we excluded an additional 34 articles for not meeting criteria on sample characteristics, 44 articles for focusing on validating an assessment or ADL training, three articles for focusing on cognitive training, 20 articles for focusing on miscellaneous topics that were not about examining the utility or usability of exergaming and 19 articles for describing using advanced technology and not discussing the affordability of the technology. The remaining 27 articles were described as using six different technology platforms for playing a variety of different exergames. Two of the articles outlined the methodology of the study or described a subset analysis of a larger study [45,46]. Thus, 25 different studies were coded from the 27 articles.

Characteristics of the research samples: Table 3 (Data included as supplementary) provides an overall summary of the characteristics of the 25 research samples. The 25 research samples had 346 adults with disabling conditions. Most research subjects were male. Research subjects' ages ranged from 19 to 91 years old, with eleven studies having a mean age 55 years or below. Thirteen studies were conducted on people with stroke who had mild to moderate upper- or lower-extremity mobility impairments. The remaining studies included people with spinal cord injury, traumatic brain injury, older adults with balance problems, multiple sclerosis, developmental disabilities and across different disabling conditions (e.g., multiple sclerosis, arthritis, and fibromyalgia). Four studies were conducted in individuals who were ambulatory or used a mobility aid. Eight studies involved individuals who used a wheelchair, one study involved both wheelchair users and mobility aid users, and two studies involved adults with balance problems. Ten studies focused on people with mild to moderate upper-extremity impairments.

Research design & outcomes: Only four studies employed a randomized controlled trial design. According to Dobkin [41] classification framework, 24 studies were classified as being in the consideration-of-concept stage and one study was classified as being in the demonstration-of-concept stage. However, it did not report effect sizes. The most common types of outcomes were on upper-extremity function, followed by objective evaluation of physical function, self-reported physical function and mobility, and balance. Eight studies conducted open-ended or semi-structured interviews. All studies reported positive findings: either improvements in health and function outcomes or positive reports about accessibility and usability. The most commonly reported positive findings were improvements in upper-extremity function. Eight adverse events were reported across the 25 studies. However, six studies noted limitations/problems in the usability of the technology platform to engage in exergaming. The most commonly reported limitation was being unable to adjust the intensity of the game to the functional level of the patient and/or having difficulty using/controlling the technology.

Characteristics of the exergaming interaction: The most common technology platforms to play exergames were on the commercially available Sony PlayStation EyeToy and Nintendo Wii. Eleven studies where on technology that was developed by the researchers of the study; three studies were on the development of exergames, six were on the development of technology platforms to play exergames, and two developed both the platform and exergame. Eight studies examined Wii Sports (i.e., boxing, tennis, baseball and bowling), while fourteen studies examined games requiring users to reach and manipulate floating objects, such as popping a balloon. Exergaming training protocols were usually short in duration (i.e., 2 to 8 weeks), but consisted of several sessions per week (i.e., 4 times a week ranging from 15 to 180 minute sessions). Five studies examined patients using exergaming in their home environment.

User-orientation & GameFlow Constructs: All studies considered or examined at least one User-Orientation construct. Thirteen articles examined three or more constructs from the model. The most common construct examined was quality of interaction followed by perceived usefulness and ease, relationship maintainability and availability/approachability. No studies examined visibility and few studies examined competitiveness. The quality of interaction construct was primarily evaluated by administering health outcomes pre- and post-test, while relationship maintainability was primarily evaluated by adherence measures. Alternatively, fourteen studies did not evaluate GameFlow constructs. The few studies that did evaluate GameFlow constructs were primarily focused on developing a videogame specific to people with disabling conditions. The most common construct examined was feedback followed by immersion, player skills, and clear goals. Social interactions, concentration, challenge and control were rarely examined.

Discussion

In spite of the promising potential of exergaming technology to increase health and function, improve rehabilitation services and decrease rates of inactivity in adults with systemic disabling conditions, we found that research on exergaming using affordable technology platforms is still in its infancy. The lack of pervasiveness of exergaming in the rehabilitation literature is probably in part because affordable technology platforms have only become readily available over the last couple of years. However, the absence of randomized controlled trials and rigorous research methodology to enlist the perceptions and attitudes of adults with disabilities has impeded the advancement towards evidence-based rehabilitation practice for exergaming. Furthermore, few studies in this review were comprehensive in the examination of constructs from the User-Orientation Framework or GameFlow model. As a result, many fundamental questions remain about the usability and utility of exergaming technology among adults with systemic disabling conditions. For example, questions remain about perceptions and attitudes that influence the use of exergaming in adults with systemic disabling conditions (i.e., mediators), who is likely

First Author	Purpose	Design	Stage	# of patients	Age Mean	Gender %-male	Condition	Video game platform	Type of game	Length of intervention	# Use	# Game	Primary Conclusions
Bainbridge [75]	Examine benefits of exergaming program on balance	Pre-post	I	8	75	12.5%	Older adults with balance problems	Nintendo Wii	Soccer heading, ski jump, tightrope, etc.	30-min sessions 2x/week for 6 weeks in clinic	1	0	Potential to improve balance
Brosnan [76]	Examine benefits of exergaming on motor function	Pre-post	I	3	40	50% 1 NR	Stroke	Nintendo Wii	Tennis, bowling, golfing	45-min sessions, 4 times in clinic	1	0	Potential to improve function
Burke [77]	Development of exergamimg platform	Case studies	I	3	69	66.5% Stroke	low-cost video capture technology	Rabbit chase, bubble trouble, Arrow attack	1 time session in home	2	4	Positive feedback about usability	
Drexler [78]	Examine benefits of exergaming on fine motor and dexterity	Case study	I	1	59	100%	Stroke	Nintendo Wii	Bowling	30 to 60-min sessions 3x/week for 8 weeks in clinic	2	0	Nintendo Wii could be used as a treatment modality
Fitzgerald [51]	Compare GameCycle with standard ergometry	Cross-sect	I	13	41	92%	Spinal Cord Injury	GameCycle	Racing games	2 separate, 19 minute sessions in clinic	2	0	Motivate to exercise at higher intensities
Fitzgerald [52]	Development of exergaming platform	Focus groups	I	6	NR	NR	Designed for Wheelchair users	GameWheels	Racing games	1 time session in clinic	3	1	Motivate to engage in exercise
Flynn [79]	Examine feasabilty of exergame technology	Case study	I	1	76	0%	Stroke	Sony EyeToy	Goal attack, bubblepop, air guitar, pool, etc.	1-hr sessions, 20 times for 4.5 weeks in home	4	2	Feasible with potential to improve function
Guo [56]	Development of exergaming platform	Focus groups	I	10	Age range 22-58	NR	Wheelchair users	GameCycle	computer games/ Need for Speed II	1 time session in clinic	3	0	Motivate to engage in exercise
Gil-Gomez, Gonzalez-Fernadez [45, 58]	Compare exergaming to standard rehab	RCT	II	17	47.3	64.7%	Acquired brain-injury	Nintendo Wii	eBaViR,	1-hr sessions, 20 times in clinic	2	1	Potential to improve balance
Hurkmans [63]	Energy expenditure of exergame	Cross-sect	I	8	36	62.5%	Cerebral palsy	Nintendo Wii	Boxing and tennis	1 time, 15 min session in clinic	1	0	Wii Tennis and boxing are moderate-intense
Hurkmans [62]	Energy expenditure of exergame	Cross-sect	I	10	53.6	60%	Stroke	Nintendo Wii	Boxing and Tennis	1 time, 15 min session in clinic	1	0	Wii Tennis and boxing are moderate-intense
Joo [80]	Examine feasibility of exergaming with standard rehab	Pre-Post	I	20	64.5	65%	Stroke	Nintendo Wii	Boxing, bowling, tennis, golf, and baseball	30-min, 6 sessions for 2 week in clinic	4	0	Potential to enhance conventional stroke rehab program
King [81]	Examine benefits of exergaming on hand function	Focus group/ Pre-post	I	4	NR	NR	Stroke	low-cost video capture technology	Butterfly catching	9 sessions over 4 weeks in clinic	3	0	Potential to improve hand function and motivation
Lange [50]	Usability assessment of off-the-shelf exergames	Focus group	I	13	55.42	77%	Spinal Cord Injury/ cerebral vascular accident	Nintendo Wii & Sony EyeToy	Golf, bowling boxing; prototype game	1 time session in clinic	5	5	With supervision and feedback could be used in Rehab

Lange [57]	Usability assessment of new game	Interview	I	4	60	NR	Stroke	Nintendo Wii	Prototype game for rehabilitation	1 time session in clinic	4	6	Potential to use in balance rehab
Lotan [82]	Examine benefits of exergaming on fitness level	RCT	II/III	60	53	53%	Developmental disability	Sony EyeToy	Variety of games	30-min sessions 2x/week for 5 to 6 week in clinic	1	0	improved fitness level
Mouawad [83]	Examine benefits of exergaming on physical function	Pre-post with healthy controls	I	7	65.3	71%	Stroke	Nintendo Wii	Tennis, golf, boxing, bowling, baseball	1 hr sessions, 10 consecutive weekdays in clinic and 30 to 180-min/day in home	3	3	Improved physical function
O'Connor [54]	Development of exergaming platform	Cross-sect.	I	45	42	93%	Wheelchair users	GameWheels	Racing games	One time session in clinic	4	3	Potential to elicit exercise training response
O'Connor [53]	Examine benefits of manual wheelchair gaming	Cross-sect.	I	15	37	67%	Wheelchair users	GameWheels	Need for Speed-II	One time session in clinic	3	1	Potential to motivate engagement in more intense exercise
O'Connor [55]	Compare differences in propulsive forces with and without game play	Cross-sec	I	10	38.7	50%	Wheelchair users	Game-Wheels/ SmartWheel	Need for Speed-II	One time session in clinic	1	0	Increased physiological responses with game play
Plow [66]	Examine the benefits of exergaming on function and fitness	Pre-Post	I	30	43.2	23%	Multiple sclerosis	Nintendo Wii	Wii Fit	30 min sessions 3 to 5x/week for 14 weeks in home	4	0	Increased fitness levels
Rand [84]	Usability assessment of off-the-shelf exergames	Interview	I	12	68	42%	Stroke	Sony EyeToy	Wishy-Washy, Kung-Fu	1 time session in clinic or home	3	1	Feasible to use in high-functioning stroke survivors
Saposnik [46, 85]	Compare exergaming to recreational therapy	RCT	II	22	61.3	64%	Stroke	Nintendo Wii	Wii Sports and Cooking Mama	60-min, 8 sessions over a 14-day period in clinic	2	0	Feasible and safe with potential to improve health outcomes
Wood [86]	Examine benefits of exergaming on UE function	Pre-post	I	4	60	75%	Stroke	Palanca	Pong	30-min, 13 consecutive sessions in clinic	3	0	Potential to improve UE function
Yavuzer [87]	Examine benefits of exergaming with inpatient rehab on UE function	RCT	II	20	61.1	45%	Stroke	Sony EyeToy	Kung-Fu, Goal attack, MrChef, Dig, and Home-Run	30min sessions, 5-days a week for 4 weeks plus conventional rehab in clinic	2	0	Potential to enhance conventional stroke rehab program

RCT=Randomized Controlled Trial, UE= upper-extremity, Cross-sect=cross-sectional, # Use=Number of user-orientation constructs examined, #Game=number of Gamflow constructs examined.

Table 3: Research design, outcomes, & description of exergaming technology.

to benefit from exergaming (i.e., moderators), the safety precautions that should be implemented to reduce risk of injury, the strategies needed to promote use of exergaming in the home and whether exergaming can achieve equivalent or even better health outcomes than traditional therapeutic exercise programs.

Several studies in this review used objective assessments or questionnaires to report on the positive health benefits of exergaming in a clinical setting over a short period of time (i.e., pre- and post-test) among adults with a moderate or high level of function or with a condition expected to get better or not progress. While these studies help provide some rationale for using exergaming in clinical rehabilitation practice, these positive findings are not surprising in light of existing research that indicates that physical activity improves health and function in adults with systemic disabling conditions [24,25]. Furthermore, supervised exercise sessions tend to result in better compliance and subsequently better outcomes [25,47]. Thus, studies that examine exergaming in supervised sessions without collecting data on perceptions or mechanisms of action are somewhat redundant with the existing exercise and rehabilitation literature in adults with systemic disabling conditions [25,48].

There is a need to conduct research that examines exergaming in an ecologically-valid approach in order to facilitate evidence-based rehabilitation practice guidelines. For example, examining exergaming in patients who transition from inpatient and outpatient to residential and community settings (i.e., exploring how exergaming can facilitate continuity in different rehabilitation settings), and conducting research on subjects who have more moderate impairments or who are expected to decline in function over time (i.e., multiple sclerosis and Parkinson's disease) will be important. Many of the studies in this review only included patients with a high level of function and/or a non-progressive condition. While inclusion of these types of patients makes for "cleaner science", individuals with more moderate impairments or who have conditions that are expected to progress may have unique barriers to exergaming that will need to be identified and addressed before exergaming can be readily used in clinical rehabilitation practices.

User-orientation and gameflow constructs

Most studies examined at least one construct from the User-Orientation Framework. However, few studies evaluated constructs from the GameFlow model. Few studies examined the visibility construct from the User-Orientation Framework as well as social interaction, concentration, challenge and control constructs from the GameFlow model. Nonetheless, examining these constructs will be important because adults with systemic disabling conditions may experience health-related barriers that make it difficult to access and control exergaming technology or make the games too challenging to play. Furthermore, social interactions may be an important construct to consider, as it may be a powerful incentive to promote exergaming adherence in adults with systemic disabling conditions [49].

Although several studies examined User-Orientation constructs, many of the studies did so informally or "in passing." Thus, while it is noteworthy to find that most studies indicated that research participants generally had favorable attitudes towards exergaming, data on attitudes and perceptions that are collected informally or in passing should be considered preliminary. Mixed-methods research (i.e., using both qualitative and quantitative research methodology) is needed to rigorously examine User-Orientation constructs. An example of such research was the study conducted by Lange [50]. This study explored the usability of the Sony PlayStation EyeToy and Nintendo Wii. Both focus groups and standardized questionnaires were used in the study. Participants in the study reported that exergaming would help keep them motivated to stay physically active and that the exergames offered a distraction from their disability. However, it was also observed that some participants had difficulty navigating through the menu and that game play was sometimes too fast. The authors noted that commercially developed exergaming technology is not entirely applicable to rehabilitation practice and individuals with disability.

Thus, some researchers have taken it upon themselves to develop and/or improve the usability of exergaming technology. We found that the studies in this review that described the development of new exergaming technology were more likely to consider constructs from the GameFlow model. Fitztgerald [51,52], O'Connor [53-55], Guo [56], Lange [57] and Gil-Gomez and Gonzalez-Fernandez [45,58] are all examples of such studies. Fitztgerald O'Connor and Guo developed a technology platform that enabled wheelchair users to control the on-screen action of several commercially developed video games with an upper-body ergometer or wheelchair. The series of studies conducted by this research group indicate that the Game^{wheel} and Game^{cycle} can increase motivation to exercise and subsequently improve fitness levels in adults who use wheelchairs. Gonzalez-Fernadez [45], Gil-Gomez [58] and Lange [57] all developed Nintendo Wii exergames designed specifically for use in people with disabilities and rehabilitation practice. These studies focused on evaluating health outcomes and GameFlow model constructs, and concluded that these developed exergames are fun to play, improve health outcomes and can be incorporated into rehabilitation practice. Because these researchers examined GameFlow model constructs, they were able to modify and adapt it to the needs of adults with disabilities.

We note that although exergaming technology developed by academic researchers may be able to address many of the problems with commercially developed exergaming technology, questions still remain as to whether it will be possible to widely disseminate this technology [59]. Researchers who have developed exergaming technology will need to demonstrate that their technology is more cost-effective than commercially developed technology and that the technology can be widely disseminated to rehabilitation clinicians and their patients. It seems that the best solution would consist of a partnership between academia and video game corporations with the goal of developing and distributing exergaming technology that meets the needs of rehabilitation clinics and adults with disabilities.

Potential mechanisms of action

Few of the reviewed studies explored mechanisms of action (i.e., why exergaming may be effective), which will be essential for improving the usability and utility of exergaming technology. Mechanisms of action need to be explored by experts in the field of exercise physiology, behavioral science and neuromotor control. From an exercise physiology perspective, research indicates that playing commercially available exergames does not always meet recommended intensity guidelines for moderate physical activity [60]. However, even light-intensity physical activity can result in some health benefits; particularly, in adults who are highly inactive, which is the case with many adults with systemic disabling conditions [28,29,61]. Furthermore, Hurkmans [62,63] concluded that playing some Wii Sports games can reach moderately intense levels of physical activity in stroke survivors and adults with cerebral palsy. Further research should identify the characteristics of low, moderate and vigorous exergames so that a classification system can be developed to categorize newly developed exergames. This will help clinicians decide which exergames are most appropriate for their patients and negate the need to conduct research every time a new exergame is developed.

From a behavioral science perspective, it will be important to utilize behavior change theories (e.g., Theory of Planned Behavior [64] and Social Cognitive Theory [65]) and measure constructs from these theories (e.g., self-efficacy, outcome expectations, social norms, past experiences, etc.) to help determine why patients may or may not be adherent to an exergaming program and whether there are particular user characteristics that will make it more likely to be adherent to an exergaming program. The assumption that exergaming will lead to increased adherence because it is fun should be brought into question. We found in our study involving the evaluation of Nintendo Wii Fit in the home over a 14-week period that individuals with MS stopped playing once the novelty wore off and contacts had ceased with the patient. We concluded that the Nintendo Wii Fit does not appear to be the "magic pill" to promote long-term participation in physical activity, and that user characteristics (e.g., gender, race, disability level, past experiences and attitudes towards video games) might influence the types of exergames that patients like to play and the type of strategies that should be implemented to promote adherence [66]. A "one-size-fits-all" approach to delivering exergaming interventions may result in non-adherence. For example, not all research participants will find it appealing to utilize only sports-related exergames. The incorporation of behavioral change theories into exergaming research will help identify moderates and mediators that will help guide the implementation of strategies that take into account user-specific characteristics to promote exergaming adherence.

From a neuromotor control perspective, we have noticed that many rehabilitation professionals have speculated that exergaming will lead to improvements in physical function because the repetitive motions required to play the game will result in motor learning. However, this hypothesized mechanism of action (i.e., repetitive motions) does little to describe the full potential of exergaming to promote motor learning and neuroplasticity [67]. In a review article by Carey [68], it was argued that motor learning and neuroplasticity is best achieved through contextual interference (CI). CI can be defined as the degree to which practice situations promote cognitive engagement [69]. Cognitive engagement is increased through the incorporation of multiple and complex tasks that happen at random practice intervals [68] and may not be optimized simply by repeated execution of a movement without complex and adaptive motor planning [70,71]. Carey [68] suggest that higher CI during practice situations might lead to a greater release of neurotrophins that induce neuroplastic changes (e.g., synaptogenesis, synaptic efficacy, neurogenesis, and cortical re-mapping [70-73]. Exergaming may be an ideal method to promote CI and neuroplasticity. This is because exergaming may be able to achieve a high degree of CI (through incorporation of random, complex and continually adaptive training) while causing an up-regulation of neurotrophic factors (e.g., Brain-Derived Neurotrophic Factor) from being physically active [74]. Thus, measurement models need to be developed on how best to detect neuroplastic changes during exergaming (e.g., whether it be from Functional Magnetic Resonance Imaging, Transcranial Magnetic Stimulation, electroencephalography and/or blood draws for neurotrophic compounds). Such measurement models will help identify the most optimal exergaming experience to promote CI and neuroplasticity. It is likely that exergaming that only requires an individual to repetitively reach for an object will not achieve a high degree of CI and, therefore, not utilize the full potential of exergaming to promote motor learning and neuroplasticity.

In terms of limitations of this review, we acknowledge that our review, although very comprehensive, may not have included all exergaming studies that met our criteria. However, the purpose of a scoping review is to summarize the breadth of existing literature to identify overall gaps rather than identify all pertinent studies like in a systematic review of the literature. It would not have been meaningful to calculate effect sizes due to heterogeneity in intervention outcomes and the small number of participants in the clinical trials. Another limitation to this review is its reproducibility. Because both the User-Orientation Framework and GameFlow model are conceptual frameworks, and the exclusion criteria of advanced robotic technology, fully immersive virtual reality and affordable technology are relative terms, others may have operationalized definitions differently, which could have led to differences in the inclusion and coding of articles. Lastly, we acknowledge that the User-Orientation Framework and GameFlow model might not have been relevant to all studies included in this review. However, we contend that to advance exergaming research in adults with disabling conditions will require comprehensive assessments on the utility and usability of exergaming technology, which can be facilitated with the frameworks/models used in this review.

Conclusion

Advances in exergaming technology will unquestionably outpace academic research on examining the utility and usability of exergaming. Therefore, research that is generalizable across different exergaming technology and/or can account for advances in exergaming technology will have the greatest potential to advance existing knowledge and generate evidence-based practice guidelines. It is encouraging to note that only a few studies reported adverse events and that most studies reported that patients generally liked to engage in exergaming. However, these findings need to be confirmed with additional research. We recommend that randomized controlled trials be conducted with a long-term follow-up that employs a mixed-methods approach (i.e., collect both quantitative and qualitative data) to collecting data. To help ensure the ecological-validity of the study, the control group should receive a traditional exercise program and the study should follow patients from the clinical setting into the home setting. Furthermore, we recommend a multidisciplinary approach, which includes exercise physiology, behavioral science and neuromotor control, to identify possible mechanisms of action, who (i.e., user characteristics) will benefit the most from an exergaming rehabilitation program, and which types of exergames are most efficient in promoting motor learning and fitness.

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