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Original research

Physiological and psychophysiological responses to an exer-game training protocol

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ABSTRACT

Objectives: Exer-games and virtual reality offer alternative opportunities to provide neuro-rehabilitation and exercise that are fun. Our goal was to determine how effective they are in achieving motor learning goals and fitness benefits as players gain experience.
Design: We employed a repeated measures design to determine changes in physical exertion and engagement with training.
Methods: Fourteen healthy adults trained on the XBOX Kinect video game Dance Central using a skill-based protocol to examine changes in energy expenditure (EE), heart rate (HR), METs, limb movement, game proficiency, and player engagement in initial, post-training, and transfer-testing of a full-body dance exer-game. Data were analyzed using repeated measures analysis of variance, $p < 0.05$.
Results: Both EE, HR, and METs increased from initial (EE 4.89 ± 1.35, HR 103 ± 18, METs 4.25 ± 0.72) to post-training (EE 5.92 ± 1.25, HR 110 ± 15, METs 5.05 ± 0.75) and were greatest during transfer-testing (EE 6.34 ± 1.35, HR 115 ± 17, METs 5.42 ± 0.88, $p \leq 0.001$). Proficiency, measured by game scores, also increased from initial to post-training and transfer-testing ($p \leq 0.002$). Limb movement and player engagement remained unchanged.
Conclusions: It is important to understand whether player physiological and psychophysiological responses change with continued game-play. Although Dance Central involves whole-body movement, physical exertion remained at moderate levels after training. As exer-game and virtual reality systems move from their initial novelty, research about how players react to continued involvement with a game can guide game developers to maintain a freshness through game progression that preserves the participant's attentional focus, minimizes attrition and maintains a prescribed level of energy exertion.

1. Introduction

Exercise video games (exer-games) and virtual reality (VR) based systems are increasingly being used for physical activity and rehabilitation goals in the treatment of different neuropathologies such as traumatic brain injury,[1] stroke,[2] spinal cord injury,[3] and Parkinson's disease.[4] High intensity task-specific exercise promotes neural reorganization, neuroplasticity, and improvements in function,[5] as well as improvements in health-related physical fitness and cognitive function.[6] In fitness training or neurologic rehabilitation, exer-games and VR training offer the potential to deliver these gains in a cost effective manner, in socialized group activities, tele-rehabilitation, and on-line interactive exer-gaming.[7]

To achieve exercise and rehabilitation goals, improved performance requires intensive skilled practice, focused attention, progressive challenges, immediate feedback, and knowledge of results.[8] To reach these goals, exercise adherence is critical, requiring that the exer-game or VR is engaging and players are motivated to return. Additionally, exer-games and VR must record data on the level of play and performance in order to ascertain whether the participant attains specific goals. If the outcome is improved physical fitness, do the players perform at a high enough intensity with ongoing progressive challenges as they improve? If the goal is rehabilitation-related, is there accurate tracking and feedback of performance related to functional outcomes?

Research to date on exer-games or VR systems for physical fitness and neuro-rehabilitation has primarily focused on proof of

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concept in small samples. In the case of exer-games for the goal of physical fitness, the literature does not reflect energy expenditure (EE) of well-trained advanced players. Rather, participants are briefly 'familiarized' prior to determining EE during game-play. The majority of research reports that participants exert 3–5 metabolic equivalents (METs) (light to moderate activity) when they play exer-games such as Wii Fit, Wii Sports, Dance Dance Revolution, Kinect Dance Central, and Eye Toy activities.[9–11] Others have demonstrated moderate to vigorous exercise intensity (4.2–7.1 METs).[9,12,13] Therefore, exer-games have potential to stimulate adequate conditioning of the body, but changes with skill development are unstudied.

Games that use sensors that measure full body motion or require activities that use the large muscles of the lower extremities result in greater physical activity.[14] The incorporation of whole body movement may also result in greater player engagement while playing exer-games through immersion.[15] Player engagement is important because a positive experience makes it more likely that a player will return to play again. Engagement is also important for any training program (exercise or rehabilitation), as attrition rates tend to be high.[16]

We focused on two aspects of game-play, including both physiological and psychophysiological measures relevant to any type of exercise. To study the effect of exer-game training on these variables, we selected the interactive dance game, Dance Central for the Xbox 360, as it uses the Kinect sensor to process full body motion capture and determine performance scores. Dance Central offers a number of choreographed dance styles and music, potentially appealing to a range of players.

We hypothesized that compared to an initial baseline trial following a "familiarization" period, player training would result in the following: (1) increased physical exertion; (2) increased upper and lower extremity movement; (3) improved game proficiency; (4) demonstration of motor learning by transfer of proficiency; and (5) greater player engagement.

2. Methods

Fourteen healthy participants (seven women, seven men, ages 26.6 ± 9.5 years, height 172 ± 11 cm, mass 69 ± 19 kg), recruited by flier at a local university, volunteered for this study. A prior power analysis determined for a repeated measures design, with one group, three measurements, a medium effect size ($f = 0.50$) and alpha = 0.05, a sample size of 12 was required. All individuals were free of recent musculoskeletal injury, visual or auditory impairment, color blindness, neurological disease, or heart condition, based on their answers to a questionnaire for participation inclusion or exclusion. Each participant had minimal or no experience playing Dance Central on the Kinect prior to participation. During training and recording sessions, participants wore workout clothing. Each participant gave informed written consent and the Institutional Review Board for human ethics granted ethical approval for this study.

Participants trained on Dance Central (Harmonix Music Systems, Inc., Cambridge, MA) for the Xbox 360 gaming console and Kinect motion sensor accessory (Microsoft Corp., Redmond, Washington, U.S.). The gaming console was attached to a 50-in video monitor. Participants played in a 1.8 m × 3.6 m square, approximately 2 m from the Kinect motion sensor and video monitor. During Dance Central game-play, players stand in front of the monitor and follow an avatar dancing on the screen. The gaming console includes a motion sensor, skeletal estimation sensor, with facial and voice recognition that captures the player's movement and compares it to those of the z-score underlying the avatar movements. Game scores are based on movement and timing accuracy of the individual compared to the z-scores.

To determine metabolic expenditure via indirect calorimetry, participants were outfitted with a portable gas analysis system ($K4b^2$ Cosmed Inc., Rome, Italy) comprised of a small metabolic analyzer, battery pack, and face-mask and a chest strap heart rate (HR) monitor (Nike, Beaverton, OR). The facemask was attached to a turbine flow-meter allowing for real-time collection of VO_2 values. The $K4b^2$ unit (~925 g) was strapped to the participant using the manufacturer's harness. Prior to each testing session, the $K4b^2$ was calibrated according to the manufacturer's instructions. The $K4b^2$ has been well validated for measurement of metabolic expenditure.[17] During testing, VO_2, VCO_2, and HR were monitored continuously and recorded using the $K4b^2$ breath-by-breath analysis. The beginning and end of each game-song were marked using the $K4b^2$ marker feature.

To determine limb movement, we collected kinematic data using a 10-camera motion capture system (Vicon, Oxford, UK), sampled at 120 Hz. Participants were outfitted with a full-body marker set using the Vicon Plug-In Gait model.

To determine changes in player proficiency, game scores were recorded during data collection. To determine whether player engagement altered with greater experience with the exer-game, all participants were asked to fill out a game-play questionnaire at initial and post training data collection. The questionnaire, based on the Game Engagement Questionnaire,[18] included 19 questions using a 7-point Likert scale. Elements included questions related to immersion, flow, fun, and exercise usefulness.

We used a skill-based protocol in which participants trained until they attained certain designated skill levels for testing. The game was initially played at the easiest level (familiarization period) and progressed to medium and then hard levels, each with increased complexity of choreographed movements. Dance Central uses a star scoring system; from 0 stars to a perfect score of 6 stars. Players were required to achieve a minimum of 3 stars to advance to the next level of difficulty. Participants trained twice per week for 30–40 min per training session. Total time spent training by each participant was approximately 4.5 h (261.79 ± 34.34 min, range of training time from 262 to 342 min over 7 to 9 sessions).

Prior to testing, participants were introduced to Dance Central with instruction in the operations of the gaming console and game menu. This included how to log in, select game-songs, unlock the game song's next level of difficulty, and interpret their scores. Players further familiarized themselves with Dance Central by playing several game-songs, with instructions to perform the choreography as accurately as possible to maximize their game score.

Metabolic and kinematic data collection occurred twice: (1) following the first session of training and (2) upon qualification for post-testing. At initial testing (Initial-E), metabolic data was collected on the easy level for three designated game-songs ('Poker Face', 120 beats min^{-1}; 'I Know You Want Me', 128 beats min^{-1}; and 'Move Ya Body' 124 beats min^{-1}). These songs were designated at a difficulty level of 1, 1, and 4, respectively, according to the games ranking system. Kinematic data were also collected on easy for the game-song 'Poker Face'. To qualify for post-training testing, each individual had to obtain 4 stars at the hard level on the designated game-songs. All participants met the skill-based criterion for final testing at all levels.

Post-training testing (Post-E and Post-H) consisted of playing the same game-songs on the easy and hard levels. Also during post-testing, to demonstrate generalizability of their learning, players were tested while playing three new game-songs on the hard level (New-H) ('Funkytown', 106 beats min^{-1}; 'Galang'05', 101 beats min^{-1}; and 'Crank that Soulja Boy', 140 beats min^{-1}). The new game-songs were designated at a difficulty level of 2, 2, and 3, respectively, which was sufficient to demonstrate a transfer of