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Original Article

An In-School-Based Program of Combined Fine Motor Exercise and Educational Activities for Children with Neurodevelopmental Disorders

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Abstract

This article introduces a game-based rehabilitation platform designed to integrate training of fine motor skills and cognitive functions. A novel computer interface device was developed that can effectively replace a standard computer mouse when doing exercises to rehabilitate hand function. This smart device converts signals from miniature motion sensors to signals equivalent to that of a computer mouse. In this way, nearly any object or utensil can be changed to function exactly as a computer mouse, simply by attaching the motion sensor. Multiple objects with varied sizes, shapes, weights, and functional demands for precision can be used for exercise and to practice a variety of gross or fine motor skills, and, importantly, while playing fun computer games. The platform was designed to work with modern and common computer games, which have a broad range of movement speeds and accuracy levels, cognitive activities (puzzles, choices, distractors), and educational content. The platform includes a designed assessment game with advanced data logging for electronic monitoring. Data analysis methods have been developed to quantify performance metrics that provide insights into the quality, efficiency, and skill of a child and thus mean to conduct trend analyses that indicate how the child is performing over time.

Introduction

Several central nervous system disorders affecting children (e.g., cerebral palsy, traumatic brain injuries, fetal alcohol spectrum disorders) result in co-occurring deficits, which may encompass physical and cognitive disabilities.[1–5] These difficulties have a considerable impact on development and on the acquisition of the practical, conceptual, and social skills that underlie many adaptive behaviors contributing to overall competence.[6] There are many factors to consider when developing rehabilitation and educational programs designed to improve physical skills, executive functions, and academic outcomes. As one example, constraint-induced movement therapy is a promising rehabilitation program for restoration of hand–arm function.[7] This treatment approach stresses that both functional demands and repetitive intensive training are important considerations in the rehabilitation of fine motor skills of the upper extremity; you need to handle objects and actively engage in the behavior in order to restore the functional skills. Indeed, there is growing evidence to support the idea of activity-dependent central nervous system plasticity and the notion that neural reorganization reflects learning achieved through generating real experiences, applying focused attention, simulating close-to-normal movements, and repetition.[8] However, it is often difficult to engage children in long-term and tedious rehabilitation regimens.

To this end, we have been exploring how to use the motivational power of computer games to maximize rehabilitation and learning.[9,10] Many exercise and cognitive games exist that include various movement speeds and accuracy levels, choices, distractors, puzzles, response time constraints, and strategy options, as well as visual–spatial and cognitive challenges that require multitasking. Several studies have provided preliminary descriptions of the benefits of videogames in education and rehabilitation training and show that well-designed interactive games can improve players' motor skills, executive functions, and academic outcomes.[11–15]

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FIG. 1. Components and set-up of the interactive exercise gaming system and adapted game controller objects: The miniature motion sensor is attached **(left panel)** to a four-wheeled Lego car and **(right panel)** to a sport ball.

Computer Game-Based Rehabilitation Platform

A novel game-based rehabilitation platform that combines fine motor exercises and learning activities for children with neurological impairments was developed. The premise is that the use of fine motor, cognitive, and educational games can assist in structuring engaging learning activities in the classroom for children with neurological impairments.

For this purpose a novel computer interface device (ID) was developed that can effectively replace a standard computer mouse when doing exercises to rehabilitate hand function. This smart device converts signals from miniature motion sensors to signals equivalent to that of a computer mouse. In this way, nearly any object or utensil can be changed to function exactly as a computer mouse simply by attaching the motion sensor. Multiple objects with varied sizes, shapes, weights, and functional demands for precision can be used for exercise and to practice a variety of gross or fine motor skills and, importantly, while playing fun computer games. For a detailed description of the ID, see Szturm et al.,[9] Andersen Hammond et al.,[16] Lockery et al.,[17] and Srikesavan et al.[10] We targeted finger–hand function and not just reaching movements; thus the control problems we have addressed are orders of magnitude more difficult because of the fineness of scale and diversity of geometric properties (e.g., size, shape, weight) and surface/material properties (e.g., slippery, compliant, sticky) of objects/utensils/tools used in activities of daily living.

The ID uses as its input the signals from a miniature multiaxis motion sensor (miniBIRD®; Ascension Technologies, Milton, VT). The ID converts the linear or angular motion sensor signals to precisely emulate the signals of a standard optical computer mouse. Because the miniature motion sensor can be easily attached to nearly any object, this innovative approach allows a child to play any commercial videogame by movement of many diverse objects. This provides a highly flexible treatment tool applied to fine or gross manipulation skills, independent of function. Many object manipulations closely emulating daily functional tasks can be used to control and play any computer game, making practice a motivating and engaging experience. This approach to intervention allows not only focus on body functions and structures, but also emphasizes goals and outcomes related to activity and participation.

Figure 1 illustrates the set-up of the interactive gaming system. Each exercise object is instrumented with the motion sensor. Two adapted game controller objects are shown: (a) a sports soccer ball, which requires finger–hand control to precisely roll the ball, as well as coordinated wrist elbow and shoulder motions, and (b) a small four-wheeled Lego® (The Lego Group, Billund Municipality, Denmark) car that can be moved forward and backward using a pencil as an implement. When using the adapted game controllers, in addition to the motor accuracy and speed requirements, one can select computer games with different educational content and cognitive demands.

The adapted gaming system was designed to be used with any modern or common computer game. This is important for many reasons. First, commercial games offer a wide range of levels of precision and movements that vary in speed, amplitude, direction, and accuracy. Second, it is important to identify games that suit the individual preferences of a given child. The wide range of activities available in commercial educational and cognitive games makes this possible. Third, it is important to have a large variety of exercise, educational, and cognitive game activities in order to maintain high levels of motivation and interest among participating children. Knowledge of the therapeutic value (object and games choice) can allow the therapist to prescribe an integrated program to target specific goals, for example, speed, accuracy, strength, working memory, cognitive inhibition, maths, and language. It should be noted that there will also be the need to produce designed rehabilitation games with gameplay levels to match the limited, emerging skills of those more involved and severely disabled clients.

Assessment Game to Quantify Fine Motor Skills and Dual-Task Cognitive Function

An electronic game-based monitoring application was also developed for the present rehabilitation platform. This includes an automated monitoring subsystem with advanced data logging and analysis methods to record users' actions and choices while playing a therapeutic assessment game. Outcome measures (electronic records) are derived that allow healthcare providers and teachers the ability to monitor both physical and cognitive performance and to track change

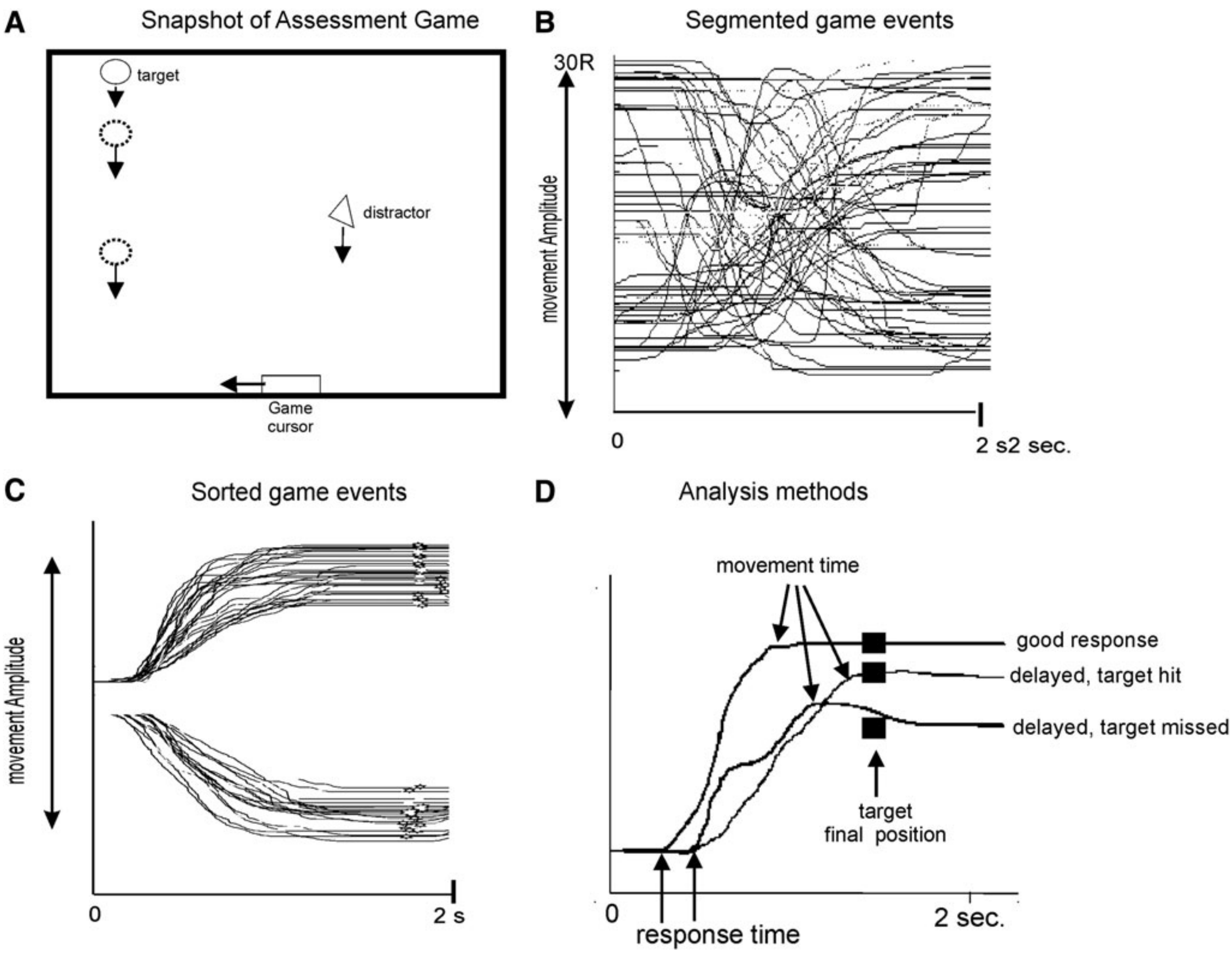

FIG. 2. **(A)** A snapshot of the assessment game. **(B)** Overlay plots of individual segmented game movements obtained from one game session. Time zero is the onset of target appearance (event onset), and end of event window is the time when the target disappears plus 500 milliseconds. Traces are game movements for upward and downward directions and for medium and large amplitudes. **(C)** Game events shown in **(B)** are sorted by direction and amplitude, and similar game events are grouped into one plot. In this case medium-amplitude movements in upward and downward directions are shown. **(D)** Traces of individual game event movements and illustration of analysis procedures. Arrows indicate movement initiation and end of game movement.

within each treatment session and over time. It could also provide timely feedback to the child. Having a flexible, computer-based platform that integrates both treatment and assessment is efficient and time saving. For general description of the assessment module and data analysis procedures, see Lockery et al.[17] and Srikesavan et al.[10]

Several recent studies have used computer-based pointing and visual search activities to probe and evaluate executive cognitive function.[5,18,19] One such test, Useful Field of View, is an objective, computer-based test of visual attention that is suitable for use with children.[20,21] A modified version of the Useful Field of View test was used in the present study in order to evaluate fine motor skills together with processing speed and cognitive inhibition. The goal of the assessment game is to move a paddle (single-axis game sprite) to catch moving objects. The objects appear at fixed duration (for example, 2 seconds) at random locations on the monitor and move horizontally from the left to right edge (or vertically from the top to bottom edge). Figure 2A presents a snapshot of the assessment game, which includes the game paddle and objects designated as targets or distracters. During gameplay, if the child moves the paddle and catches the target circle objects, then a point is scored. If the objects designated as distractors (i.e., triangles) touch the paddle, then the paddle blows up for 3 seconds (i.e., the child receives a penalty).

The assessment game application generates a logged game file to record time and position coordinates of (a) each game object and (b) the game paddle (slaved to movements of the adapted game controller), which represent the player's actions and choices. The sampling rate was 100 Hz. For example, when the duration of game events is set to 2 seconds (user defined), then a game session of 2 minutes would contain 60 game events. The duration of object motion from the top to bottom edge of the display was set to 1.5 seconds, and there was a 0.5-second delay between successive game events. Figure 2C presents overlay plots of movement trajectories for the individual, segmented game events (contextual) obtained in one logged game data file. Time zero is the onset of target appearance of each individual game event, and the end of event window (2 seconds) is the time when the target reaches the other edge of the display plus the 500-millisecond delay period. The starting location of the target object is presented randomly relative to the paddle, and the distance is randomly varied from medium (one-third to two-thirds of the monitor distance) to large (two-thirds to full screen). In Figure 2C the individual segmented game event plots are sorted into ''functional bins,'' which represent each direction and amplitude (i.e., medium and large). Only the group of medium-sized game movements is displayed for both upward trajectories and downward trajectories. Thus, in one game session of 2 minutes one can obtain for analysis 10–15 repeated trials of similar game events for each direction and different movement amplitude.

For each grouping of movement direction and amplitude, the following features of the segmented game movement trajectories are determined to quantify task performance:

1. Average motor response time was defined as the time from the appearance of the target to start of the player's (paddle) movement (see Fig. 2D).
2. Average movement time was quantified as 90 percent rise time between movement onset and end of the game movement. The end of the movement trajectory was established as a plateau (exceeding 100 milliseconds in duration) when the game paddle has either reached the target location or missed and has stopped in between game events (see Fig. 2D).
3. Movement efficiency was defined as the average residual error (difference) (error) between the user's trajectory and the ideal trajectory from initial paddle position to final paddle position.
4. Average end-point movement error was defined between the paddle location and final target location.
5. Variation was measured among the game movement trajectories within each direction and amplitude grouping.
6. Success rate was calculated as the percentage of targets caught.

The difference in performance measures between a simple task (for example, using a standard computer mouse) and a more complex task (for example, moving a wheeled car with implement or rotation of a glass or key) would reflect the added physical demands of the object-manipulation task in question. In addition, game speed and precision level (target and paddle size) could also be adjusted, and their effect could be evaluated. The difference in performance measures between simple task (target only) and more challenging tasks (target plus distractors) would reflect the effect of the added cognitive load.

Table 1 presents the various characteristics of the assessment game.

Pilot Testing in Class

Six children with fetal alcohol spectrum disorder participated in a pilot study: four boys and two girls (two 8-year-olds, three 9-year-olds, and one 10-year-old). The children were enrolled in a special needs educational program and were in the same classroom at a Grade 2 level. Fetal alcohol spectrum

Table 1. Characteristics of the Assessment Game

Health topic(s)	*Neuromuscular rehabilitation hand-arm function*
Targeted age group(s)	Toddlers, children, adults
Other targeted group characteristics	Hand injuries, amputations, arthritis
Short description of game data	Motion data of player's actions (game sprite coordinates) and game target coordinates
Target player(s)	Individual
Guiding knowledge or behavior change theory, models, or conceptual framework(s)	International Classification of Functioning, Disability and Health: Body structure/function and activity/participation
Intended health behavior changes	Sensory–motor and psychomotor
Therapeutic procedure(s) used	Assessment of fine/gross motor skills and specific executive cognitive functions
Clinical or parental support needed?	Initially, yes; after training period, none
Data shared with parent or clinician	Yes
Type of game	Active action based on Archinoid
Story (if any)	None
Synopsis (including story arc)	Not applicable
How the story relates to targeted behavior change	Not applicable
Game components	Mouse-controlled, game sprite, target objects, and distractor objects
Players game goal/objective(s)	To catch moving objects and avoid distractor objects when using a variety of therapeutic objects as game controllers
Game platform(s) needed to play the game	Computer with Windows OS (XP or greater)
Sensors used	Six degrees of freedom magnetic motion sensor and USB interface that emulates a human interface device–compliant mouse. The miniature sensor can be attached to one of many objects chosen for specific therapeutic outcomes (i.e., varied size, shape, weight, surface properties, or ergonomic properties and for two-finger, three-finger, whole hand, and bilateral hand functions).
Estimated play time	30 seconds to 3 minutes

disorder was based on a history of prenatal alcohol exposure, the presence of at least one dysmorphic facial feature, evidence of cognitive dysfunction, global clinical assessment of a multidisciplinary team, and confirmation by a physician specialist. Inclusion criteria included moderate learning disability and mild-to-moderate impairment of upper extremity fine motor skills (e.g., writing skills) or tremor. Ethics approval was obtained from the Human Research Ethics Board, Faculty of Medicine, University of Manitoba, and the local school division.

Each child was provided with a 45-minute session of interactive gaming activities and exercises. All sessions were conducted during class time and by a research assistant (physical therapist), under the supervision of the special needs teaching assistant. Each child received three sessions per week for five consecutive weeks. All sessions were conducted in the morning at the same time each day. For the treatment sessions, the following common objects were instrumented with the motion sensor and used to control motion of the game sprite: (a) Using the finger tips to roll a small 3-cm-diameter cylinder, small 6-cm-diameter ball, and a large soccer ball, (b) holding a small drinking glass with a tripod grasp and tilting forward and backward, and (c) rotating a small wooden knob held between the thumb and index finger. Each child played eight games per session. A pool of 30 educational and therapeutic games was used for this program. The chosen games were visually rich, fun, and engaging and incorporated the following: (a) Visuospatial tasks, (b) math and language skills, (c) choice and interference, (d) matching, and (e) graded movement accuracy and speed. The following are examples of games chosen for the 5-week, in-class treatment program:

1. ''Math Lines.'' Point and shoot a ball to moving objects. For example, if 10 is the outcome, and the ball you are shooting is numbered 3, aim and hit the moving object numbered 7. Single- and two-digit numbers were used with addition and subtraction (www.coolmath-games.com).
2. ''Darwin's ABC.'' This game involves building predefined words while scanning and searching for the correct letters in rising balloons (there are many balloons, and only one has the correct letter) (www.universalaccessgames.com).
3. ''Rocket Mania.'' Build exciting fireworks (that explode) by linking fuses (rotating line segments) to produce continuous geometric patterns to a burning match (www.popcap.com).
4. ''Bejeweled.'' This is a puzzle game where one arranges gems of different shapes and colors so they match in sequence with two or more of the same kind (www.download-free-games.com).
5. ''Aquaball and Action Ball.'' This is a horizontal, single-axis brick buster with slow to moderate speed and low to moderate movement precision. There are a small to moderate number of distractors and simple to complex two-dimensional backgrounds.
6. ''Butterfly Escape.'' This game requires horizontal, single-axis matching colors with low to moderate speed and low to moderate movement precision. There are a

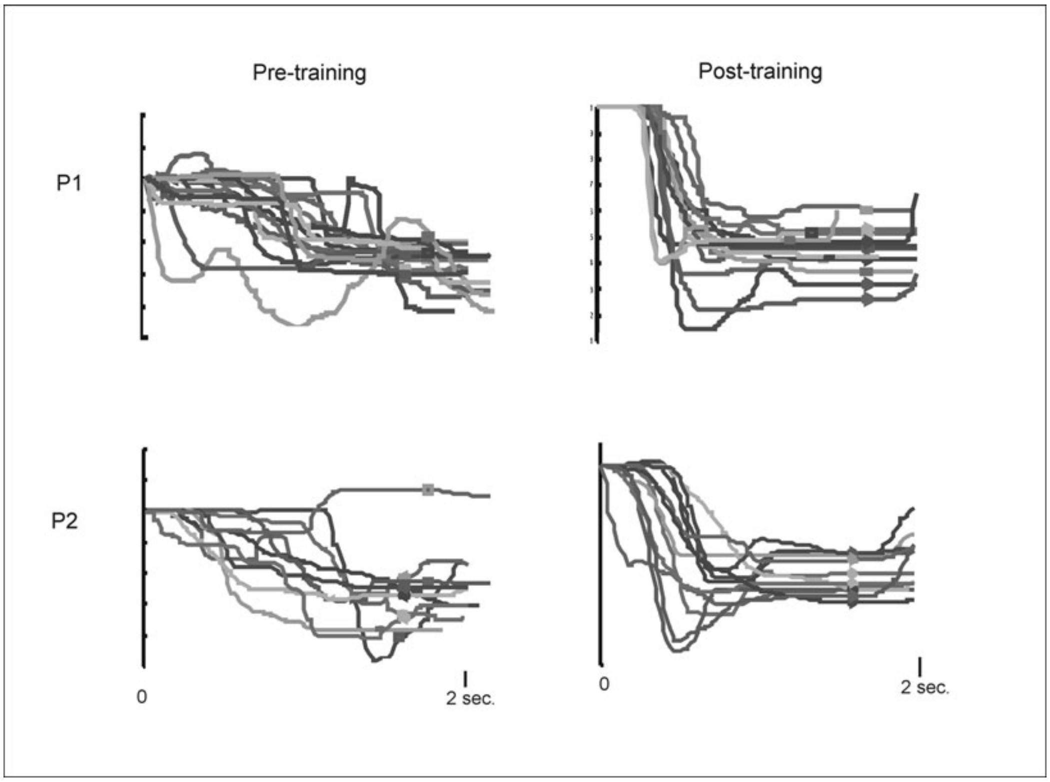

FIG. 3. Plots of segmented and sorted game trajectories (as in Fig. 2B) of two representative participants (P1 and P2) while playing the assessment game with the target plus one distractor and using the implement–Lego car as the game controller.

small to moderate number of distractors, as well as simple and moving backgrounds.

7. ''Feeding Frenzy.'' Two-axes games play with a slow motion element and low to moderate movement precision. There are a moderate to large number of distractors.

All training was treated as a classroom learning session, and a small area within the classroom was designated for the laptop and gaming equipment. The teacher and students did state that this did not distract or interfere with any classroom functions. The program received a high level of acceptance by all children and teachers. Typically, each morning, the children lined up waiting to begin their game-based learning activity session. In many cases, the children asked if the session could be longer, and this was true for the entire 5-week period. All children completed the study intervention as planned. Each of the six children completed the game-based assessments, which were delivered once a week.

In our assessment of child preferences for activity games, we discovered a wide variety of individual differences. Each child had his or her favorite games and ones he or she disliked. For some, it was word or math games; for others, it was puzzles or motor skill-type games. We found that it was important to have a variety of games to keep each child engaged in his or her fine motor skill training and learning activities. Knowledge of results through visual and auditory feedback of the games was available to each child during all training sessions, and this likely helped to reinforce the desired response. In addition, individualized feedback was also provided by the research assistant (i.e., amount and type of guidance and prompting provided to each child was adapted to the difficulty level of each game activity). Over the 5-week test period all children demonstrated modest improvements in performance in all treatment games in terms of correct choices, success rates, ability to ignore distractors, and the need for assistance from the researcher.

Each session began with the assessment game, target-only and target plus distractors using the implement–Lego car as the game controller. As illustrated in Figure 1, the Lego car is moved forward and backward using a pencil as an implement. Vertical directed force through the long axis of the pencil implement is required to push the car forward (move the game paddle upward), and a horizontal shearing force is needed to pull the car backward (move the game paddle downward).

Figure 3 presents plots of segmented game trajectories of two representative participants while playing the assessment game. As described in Figure 2, each plot contains overlays of 10–14 repeated movements of medium amplitude obtained from one logged game file. It can be seen in Figure 3 that following training, there is an improvement in the quality of

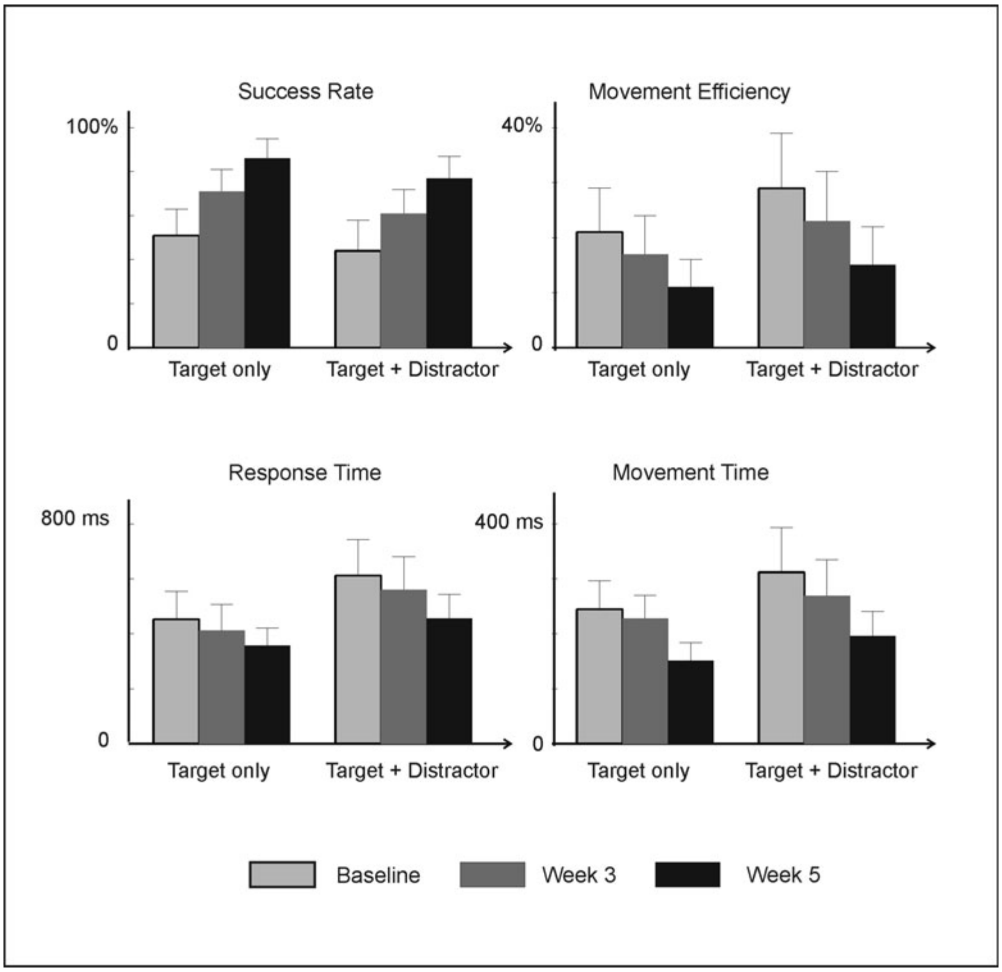

FIG. 4. Success rate, movement efficiency, response time, and movement time at baseline and at the end of Weeks 3 and 5 of the treatment program. Data are group mean ± standard error of mean (bars) values.

the movement trajectories and a substantial reduction in variation among the sample of repeated game movement.

Figure 4 gives the group means and standard errors, pre- and postintervention, of four performance measures obtained from the fine motor skill and dual-task cognitive assessment. Because of the small sample size, a *t* test was not performed. As is evident in Figure 4, the success rate was much lower when a distractor was added to the game task. Similarly, movement quality, response time, and execution time were also much greater when a distractor was added to the game task. Judging by the percentage change pre- to post-intervention, the results demonstrate a substantial, positive effect of the training program on several aspects of the children's performance. Over the 5-week training period success rate and movement efficiency improved by 30–50 percent for target-only and target plus distractor task condition. Response times improved pre- to postintervention by 75 percent, and movement time improved by 60 percent.

Conclusions

The present rehabilitation platform provides the basis for an innovative and motivating exercise and learning regimen, through the use of digital media and pervasive computer technologies. The approach and systems are designed to provide enhanced access to fine motor exercises. The targeted use of quality, engaging cognitive and educational games can assist in structuring effective adaptable learning activities and in improving children's engagement in the learning process.

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Author Disclosure Statement

No competing financial interests exist.

T.S., E.P., and J.M. were responsible for the study concept and design, data acquisition, analysis, and interpretation, and preparation of the manuscript. C.S.S. was responsible for data interpretation and preparation of the manuscript.

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