Virtual Reality
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ORIGINAL ARTICLE

Virtual reality software package for implementing motor learning and rehabilitation experiments

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Abstract Virtual reality games for rehabilitation are attracting increasing growth. In particular, there is a demand for games that allow therapists to identify an individual's difficulties and customize the control of variables, such as speed, size, distance, as well as visual and auditory feedback. This study presents and describes a virtual reality software package (*Bridge Games*) to promote rehabilitation of individuals living with disabilities and highlights preliminary researches of its use for implementing motor learning and rehabilitation. First, the study presents seven games in the software package that can be chosen by the rehabilitation team, considering the patient's needs. All game characteristics are described including name, function presentation, objective and valuable measurements for rehabilitation. Second, preliminary results illustrate some applications of two games, considering 343 people with various disabilities and health status. Based on the results, in the *Coincident Timing* game, there was a main effect of movement sensor type (in this instance the most functional device was the keyboard when compared with Kinect and touch screen) on average time reached by sample analyzed, $F(2, 225) = 4.42$, $p < 0.05$. Similarly, in the *Challenge!* game, a main effect was found for movement sensor type. However, in this case, touch screen provided better performance than Kinect and Leap Motion, $F(2, 709) = 5.90$, $p < 0.01$. Thus, *Bridge Games* is a possible software game to quantify motor learning. Moreover, the findings suggest that motor skills might be practiced differently depending on the environmental interface in which the game may be used.

Keywords Rehabilitation games · Virtual reality rehabilitation · Man–machine interface

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1 Introduction

Games based on virtual reality (VR) are accessible, motivate full-body movement practice and provide potentially challenging options for a variety of rehabilitation clients (Levac et al. 2015). The use of virtual and augmented reality systems for motor rehabilitation is increasing, mainly because of new interactive tools that enable body movement interaction, motivate the patient and promote entertainment, thereby making repetitive motor control practice more satisfying, as well as diverting attention from pain (Da Gama et al. 2012). These interactive games, activated through body movements, encourage players to produce larger movements and abandon sedentary life (Crocetta et al. 2015). Furthermore, they can promote motor learning and improve movement in people living with disabilities (Monteiro et al. 2014, 2017).

Virtual reality can be considered a computer technology that provides three-dimensional artificial sensory feedback, whereby the user engages in experiences similar to real-life activities and events. Also, it provides motor learning in the three dimensions of space and can be similar to movements that occur in the real world (Silva et al. 2015).

Among the commercial games available, Microsoft Kinect sensor is a low-cost tracking alternative that has been used in some studies (Hondori and Khademi 2014; Bieryla 2016). Other devices, like Leap Motion (San Francisco, CA, USA), and Nintendo WiiMote are also providing new opportunities, by creating natural user interfaces and conducting research in the field of health science (Juanes et al. 2016). System calibration of these games typically requires a body, arm or hand person analysis, which provides a new interface with movement calibration and possibilities to analyze disabilities for movement and performance (Pastor et al. 2012).

Evidence suggests that commercial gaming can be successfully used in patients' homes, as well as in clinical settings, indicating its potential for high-intensity practice of upper limb movements (Thomson et al. 2014). Despite these advantages, commercial games have some limitations. For example, the calibration of a game's difficulty is conducted with healthy players and does not consider individuals with disabilities. Also, full-body movement games are limited in their recognition of users in seated positions, which is necessary for enabling wheelchair users (Anderson et al. 2015; Levac et al. 2015). Another limitation is that the game scores or progress measurements are too generic, making them insufficient for tracking the progress of a person with a disability (Anderson et al. 2010).

Monitoring and optimizing physical behavior are vital in the field of rehabilitation. This approach requires valid and reproducible outcomes, to assess and monitor changes in individuals with a disability, even those who are wheelchair dependent (Nooijen et al. 2015). Moreover, providing rehabilitation teams with opportunities to determine and control the computing task performance of people with disabilities can help develop critical strategies to maintain or improve patient functionality (Malheiros et al. 2016).

However, in studies of the commercial games currently available, the rehabilitation team often rely on adapted solutions to use the game and provide motor learning. Most games use difficulty adaptation strategies, which depend on the game characteristics and lack reusability (Hocine et al. 2015) or benefits of use for individuals with a disability. Thus, there is a need for user-friendly commercial games for people with disabilities that allow therapists to identify an individual's difficulties and provide control over various variables. In this context, the current study proposed and applied a software package comprising a variety of games focused on rehabilitation, with consideration of motor learning outcomes that also allow the therapist to control speed, size, distance, as well as visual and auditory feedback.

Some of the games presented in this study have already been used by researchers in individuals with Down syndrome (Monteiro et al. 2017) and cerebral palsy (Monteiro et al. 2014), showing improved coincidence timing task performance with virtual objects. In another study, the software was applied to propose a protocol evaluating the effects of practicing VR games during computer classes, on the level of loneliness among students of a reference center for the elderly (Antunes et al. 2017). Hence, it is constructive to present and test further research and clinical practice opportunities that can be provided by this software package.

A software package offering a variety of games and interfaces enables rehabilitation teams to organize treatment protocols with practical possibilities for cognitive, motor and sensory disabilities, respecting the difficulties and limitations of each patient (Monteiro et al. 2014; Hondori et al. 2016). Thus, it is possible to hypothesize that patients with different disabilities would be able to use the software and would improve their performance by using the various games proposed. If this hypothesis is confirmed, the use of a software package could be a possible future approach for rehabilitation, offering diverse possibilities for the rehabilitation team to control variables during intervention under the lens of motor learning theories.

This article describes the characteristics of a new software game package, for examining upper limb rehabilitation under the lens of motor learning theories to be used among various groups of people.

2 Methods

This study describes the overall framework of a new software package (*Bridge Games*) designed to provide seven different games adapted to people with disabilities. Therefore, first, a description of the software is provided. Second, preliminary research outlining an application of some of the games for people with various disabilities is presented.

2.1 Bridge Games features (software package)

Bridge Games was built using Net C# and the MS SQL Server database. Figure 1 is a screenshot of the main screen, showing a menu with seven games. To select a game, the participant must click an icon using the mouse, touch screen or the tab key on the keyboard. Alternatively, a device

Fig. 1 *Bridge Games* main screen with seven games and options menu. The figure shows the use of Kinect or Leap Motion sensor for selecting an option. The selection can also be performed with the mouse, the tab key on the keyboard or the touch screen

without physical contact, such as Leap Motion and Kinect, can be used. In this instance, the participant must keep the virtual hand over the item to select it.

2.1.1 Basic concepts and general procedure

The first step to start a game session is to load a previously recorded participant (participants list) or insert a new one (new participant). After identifying the participant, a window with a list of the games available will open (main window—Fig. 1) and the system is ready to start a game session at the moment the user selects the game. Before start the game, there is an option with three available input options: acquisition, retention and transfer (motor learning phases). Every movement and every event in the session game is detected and the time of occurrence is stored in the database. The resulting data are stored in a local database, and when commanded by the researcher, synchronized with a central database in the cloud.

2.1.2 Data output

The resulting text file, Comma Separated Value (CSV) file format, contains the complete data of the transcription session: participant identification (name, date of birth, gender, type of pathology and researcher identification), session identification (date and time of start, date and time of end, total bubbles presented in the gamespace, number of reached bubbles, exercise type (acquisition, retention, transfer), sequence of events (bubble reached) and their duration, occurrence and movement type (body—Kinect or Leap Motion, touch screen, mouse, keyboard), duration, Y-axis, X-axis, movement region).

2.1.3 Different human–computer interfaces

Games can be played with five types of interface: mouse, keyboard, touch screen, Kinect or Leap Motion sensor. The therapist can repeat the same game using tactile feedback interaction (mouse, keyboard or touch screen), or without tactile feedback interaction (Kinect or Leap Motion sensors). Different human–computer interfaces sometimes require the same arm movement kinematics to control the game but differ in level of cognitive demand. For example, it may involve higher levels of indirect interaction (e.g., without tactile feedback) involving a different person's eye and hand movements and require them to perform a visuospatial transformation (Hondori et al. 2016).

2.1.4 Gamespace (game scene)

The gamespace is modeled using coordinates $x \times y$, where x represents the number of rows and y the number of columns. These coordinates are divided into nine movement regions (northwest, north, northeast, west, center, east, southwest, south and southeast). Each reached bubble holds information about the movement time performed by the patient in the corresponding coordinates x, y and region of the gamespace.

2.1.5 Timer

Bridge Games uses the classes named *Timer*, which avoids the problem, at the level of hundredths of a second, that is affected by other events occurring in the Windows environment. When creating a *Timer*, it is possible to specify an amount of time to wait before the first execution of the method (due time) and an amount of time to wait between subsequent executions (period). The *Timer* class has the same resolution as the system clock 3 (Microsoft 2015). This procedure was adopted to decrease the influence of computer hardware and software to perform tests involving time measurement (Crocetta and Andrade 2015).

2.2 Games comprising *Bridge Games*

Below, we briefly describe the seven games available in the package.

2.2.1 Follow the Master!

A series of four bubbles are presented on the screen, and the participant must select a sequence of bubbles (Fig. 2a): one bubble in Level 1, two bubbles in Level 2 and so on. A second player must complete the same sequence performed by the first player. After a correct sequence, the level of the game increases. When Level 4 is achieved, the number of

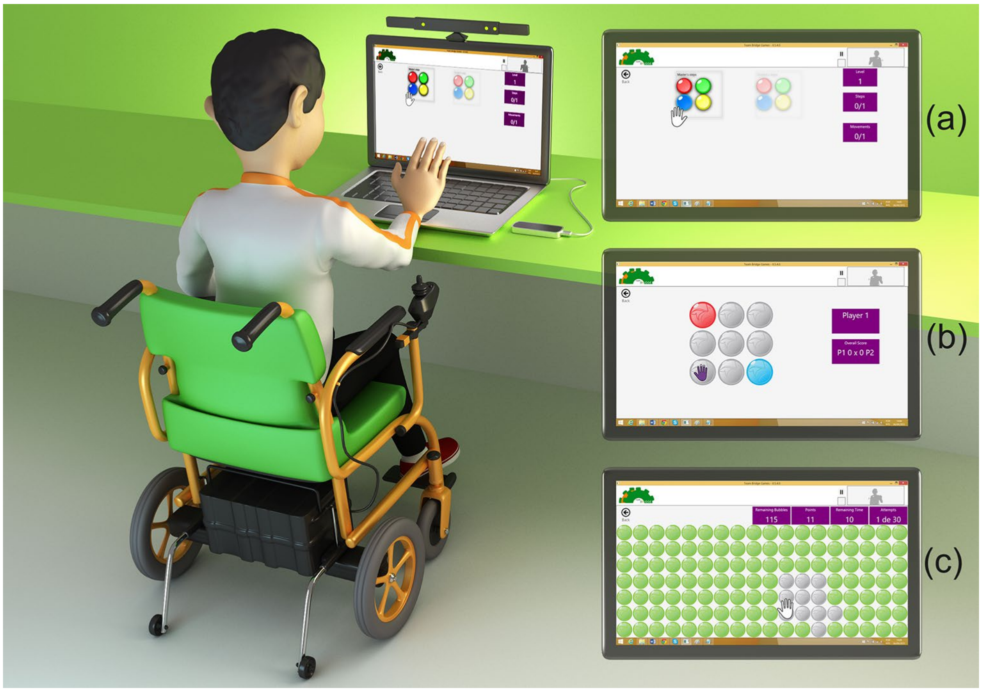

Fig. 2 Participant during performance in *Follow the Master!* game using the Kinect sensor. The highlighted screens correspond to the main screen of the games **a** *Follow the Master!*, **b** *Tic–Tac–Toe* and **c** *Check Limits*

bubbles presented increases to nine. In Level 6, 16 bubbles are presented. All bubbles are presented in different colors.

Objective: To stimulate memory and motor control, and the skill in different interfaces for acquisition of motion.

Measurements: Participant name; date of birth; gender; pathology type; researcher name; selected bubbles sequence; time between a bubble choice and other.

2.2.2 *Tic–Tac–Toe*

This game is identical to that of a standard tic–tac–toe game, in which a player competes against another person, taking turns to place pieces on a nine-square grid (Fig. 2-b). The first player to form a row, column or diagonal line wins the game.

Objective: To stimulate skills, as memory, strategy, motor control and the skill in different interfaces for acquisition of motion.

Measurements: Participant name; date of birth; gender; pathology type; researcher name; selected bubbles sequence; time between a bubble choice and other

2.2.3 *Check limits*

The gamespace consists of a series of bubbles, arranged in rows and columns, like a bubble wrap game. When the bubble is reached, it changes color (green–gray), and the participant hears the sound of a bubble exploding. The main goal is to touch as many bubbles as possible in 15 s. In the acquisition phase, the participant has 30 consecutive attempts of 15 s each (Fig. 2c). At the end of the time limit, a feedback message automatically prepares the player for the next trial. In the retention and transfer phases, the participant has five attempts of 15 s each.

Objective: Motor control, motor learning and speed performance. To evaluate the directions of movement, the time necessary to move between the bubbles reached, the response time, and the skill in different interfaces for acquisition of motion.

Measurements: Participant name; date of birth; gender; pathology type; researcher name; start game; end game; total bubbles presented in the screen; total points (bubbles reached); exercise type (acquisition, retention, transfer); occurrence (date and time); movement type (body, mouse or touch); duration; *Y*-axis; *X*-axis; movement region.

Feedback: At finale of each trial, there are feedback messages to improve motivation for playing the game, such as: “We started well! You had “xx” points. But I think you can improve”, or “You were better now. You had “xx” points. Can you improve?”.

2.2.4 *Random*

The aim of this game is to achieve a target bubble that changes color (gray–orange) at random positions in the gamespace (Fig. 3a). The gamespace is modeled using

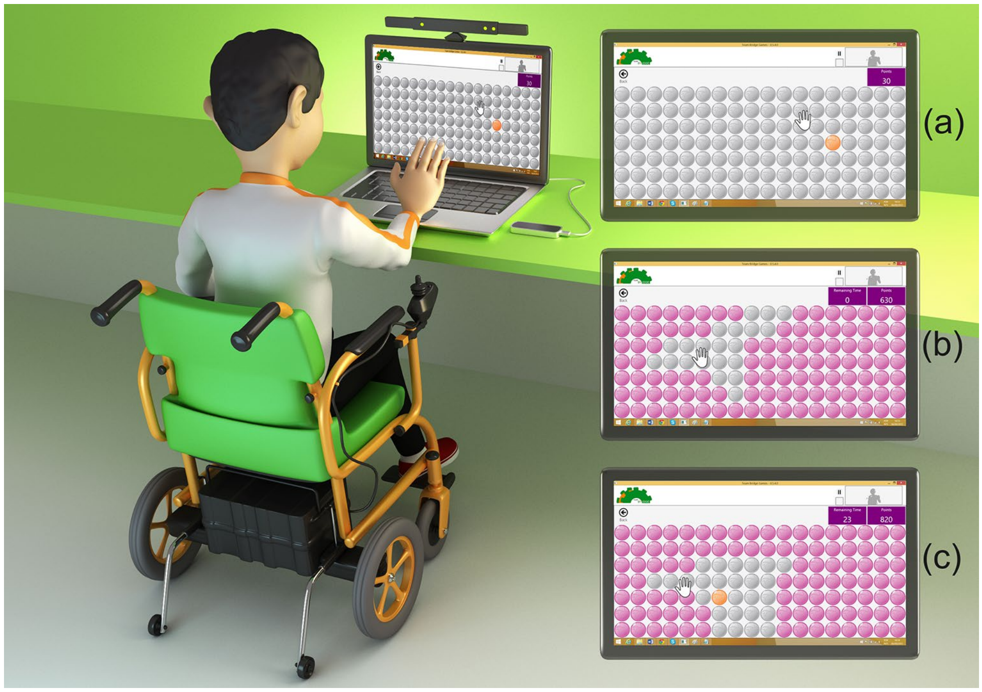

Fig. 3 Participant during performance in *Random* game using the Kinect sensor. The highlighted screens correspond to the main screen of the games **a** *Random* and *Breaking Wall* in **b** *dexterity zone* and **c** *random persecution* phases

coordinates $x \times y$, as described above, and the bubbles are gray. From a motor control and motor learning perspective, the game's pointing tasks require that players reach targets (i.e., orange bubbles) that appear in different areas of the game scene. A pointing task is performed successfully when the target bubble is reached.

Objective: Motor control, motor learning and speed performance. To evaluate the time needed to reach the bubble presented randomly, the response time and the skill in different interfaces for acquisition of motion.

Measurements: Participant name; date of birth; gender; pathology type; researcher name; occurrence (date and time); exercise type (acquisition, retention, transfer); movement type (body, mouse or touch); duration; *Y*-axis; *X*-axis; movement region.

2.2.5 Breaking Walls

This game is conducted in two phases: (1) *dexterity zone* (Fig. 3b) and (2) *random persecution* of bubbles (Fig. 3c). In a *dexterity zone* (Phase 1), the participant reaches bubbles as many bubbles as possible in 10 s. These reached bubbles define the participation's reach zone: The *dexterity zone* ranges according to the difficulty of the participant's motor abilities. In *random persecution* (Phase 2), the participant must pursue, as quickly as possible, a bubble that changes color (gray–orange) at random positions (Fig. 3c) for 30 s, within the range area defined in the *dexterity zone*. The gamespace is modeled using coordinates $x \times y$, the same as described above, and the bubbles are pink. From a motor control and motor learning perspective, the game's pointing tasks require that players defined his or her scope zone and reach targets (i.e., orange bubbles) which appear in different positions in the scope definition and a pointing task is performed successfully when the target bubble is reached.

Objective: Motor control, motor learning and speed performance. The *dexterity zone* represents the area where the participant can effectively make movements and reach the targets farthest from the starting point position or targets on a particular side of the zone. To evaluate the sequence and range of bubbles reached and time needed to reach the bubble presented randomly, the response time and the skill in different interfaces for acquisition of motion.

Measurements: Participant name; date of birth; gender; pathology type; researcher name; start game; end game; total bubbles presented in the screen; total points (bubbles reached in Phase 1); exercise type (acquisition, retention, transfer); occurrence (date and time); movement type (body, mouse or touch); duration; *Y*-axis; *X*-axis; movement region.

2.2.6 Challenge!

This game is conducted in two phases: (1) *dexterity zone* (Fig. 4a) and (2) *random persecution* of bubbles (Fig. 4b). In a *dexterity zone* (Phase 1), the participant reached as many bubbles as possible in 10 s. These reached bubbles define the

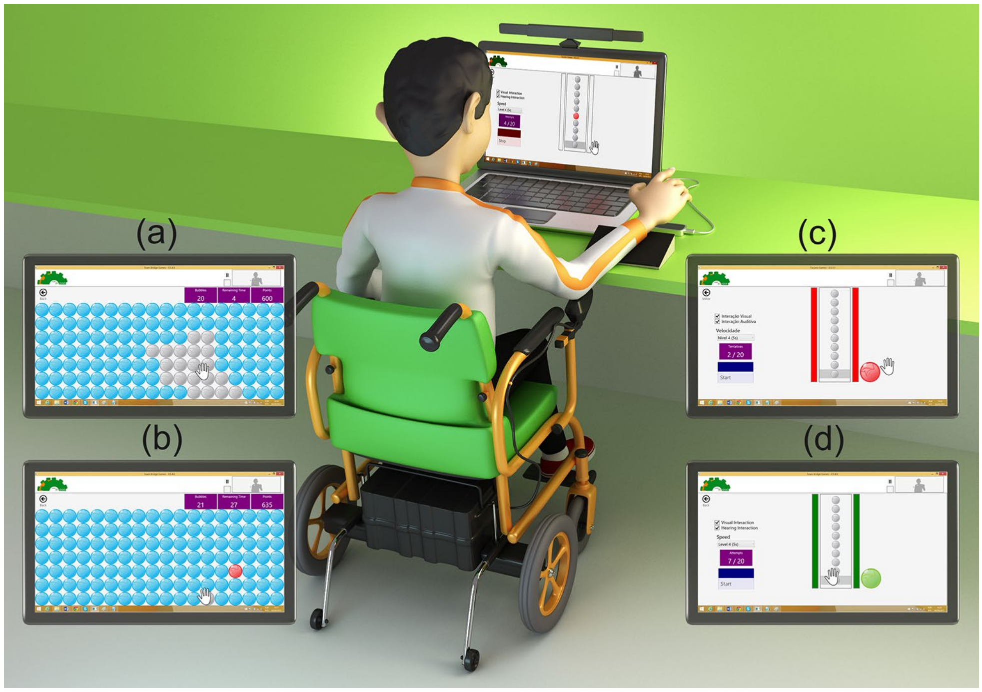

Fig. 4 Participant during performance in *Coincident Timing* game using Leap Motion sensor with a wedge to support the handle, leaving a required distance for capturing the movement of the fingers. Highlighted to the left is the main screen of *Challenge!* game in **a** *dexterity zone* and **b** *random persecution* phases. Highlighted to the right is the main screen of *Coincident Timing* game with a feedback of **c** fail and **d** success to reach the target

participation's reach: The *dexterity zone* ranges according to the difficulty of the participant's motor abilities. Before the next phase, the game waits for a definition of the fixed target bubble within the *dexterity zone*. Then, in *random persecution* (Phase 2), the participant must pursue, as quickly as possible, a bubble that changes color (blue–red) at random positions (Fig. 4b) for 30 s. This fixed bubble will always be merged with another bubble target, alternating between fixed and target. Upon reaching the first target bubble, the next target bubble is illuminated. The task involves moving leftward and rightward (reciprocating) as quickly as possible between two target bubbles. Target bubbles can appear out of the *dexterity zone* and are marked as "*challenge*" for further analysis. The gamespace is modeled using coordinates $x \times y$, the same as described above, and the bubbles are blue. From a motor control and motor learning perspective, the game's pointing tasks require that players defined his or her scope zone and reach targets (i.e., red bubbles) which appear in different positions in the gamespace and a pointing task is performed successfully when the target bubble is reached.

Objective: Motor control, motor learning and speed performance. The *dexterity zone* represents the area where the participant can effectively make movements and reach the targets farthest from the starting point position or targets on a particular side of the zone. Challenge the participant with targets beyond the zone of reach. To evaluate the sequence and range of bubble reached and time needed to reach the bubble presented randomly, the response time and the skill in different interfaces for acquisition of motion.

Measurements: Participant name; date of birth; sex; pathology type; researcher name; start game; end game; total bubbles presented in the screen; total points (bubbles reached in Phase 1); exercise type (acquisition, retention, transfer); middle point row; middle point column; occurrence (date and time); movement type (body, mouse or touch); duration; *Y*-axis; *X*-axis; movement region; is challenge.

2.2.7 Coincident Timing

Coincidence-anticipation timing refers to the ability to time a movement so that its arrival at a target coincides with a moving object's arrival at the same target (Kim et al. 2013). This game consists of the participant attempting to slide the hand avatar to coincide with the lighting of the final bubble on the runway (Fig. 4 in computer monitor, 4c and 4d). For each trial, the researcher operated the control button (start/stop) from the left side of the screen. A single trial consisted of the experimenter first cueing the participant by saying "Ready" and turning the first bubble red at the top of the runway. The *movement* of the bubbles down the runway followed this in seconds (the time was held constant throughout, defined by velocity parameter), according to the selection previously specified by the researcher. The magnitude and direction of each participant's error in anticipating the light's *arrival* at the end of the runway, in milliseconds, was recorded by the game. Upon completion of each trial, participants could see the extent to which their response was successful (green bubble; Fig. 4c) or fail (early or late, red bubble; Fig. 4d).

This game offers information for measuring the three common error scores used in measuring the accuracy of movement, according to Crabtree and Antrim (1988). These include constant error (CE, i.e., the directional *bias,* mathematically defined as the mean of a *signed* data set of error scores), absolute error (i.e., the *magnitude*, mathematically defined as the mean of an *unsigned* data set of error scores) and variable error (i.e., the *consistency*, mathematically defined as the standard deviation of the CE scores).

Objective: To evaluate the difference in time between the participant's execution of the response and the arrival of the object at the target location, overall temporal accuracy and hence coincidence-anticipation timing skill.

Measurements: Participant name; date of birth; sex; pathology type; researcher name; start game; end game; result (in advance, punctual, late); bubble (position of bubble reached); is visual enabled; is hearing enabled; interval; exercise type (acquisition, retention, transfer); movement type (body, mouse or touch); differential reached.

Parameters: (a) speed: set between five speeds for the bubble down-movement (Level 1 [20 s] to Level 5 [2.5 s]); (b) visual interaction: when checked, this is indicative of knowledge of results. A green bubble appears when movement is correct and red when it is early or late; (c) hearing interaction: when checked, this is indicative of knowledge of results. Four beeps are heard when the movement is incorrect, or one beep when the movement is correct.

2.3 Participants

This preliminary research involved 343 people (males and females), aged from 9 to 100 years, with various pathology and health status (Table 1).

2.4 Testing procedures

A large-scale, multi-site intervention study was conducted to assess the "*Bridge Games"* measures on motor learning skills in different populations. The games were applied in special schools dedicated to working with children, regular schools, institutions with activities for older adults and healthy adults (considered as individuals without significant change in posture and movement) who agreed to participate in the research, across Southeast and Southern Brazil. At this stage, the interest was to identify how people might use two of the *Bridge Games* (*Coincident Timing* and *Challenge!*) and whether it would elicit any motor learning in different movement acquisition devices. The only inclusion criterion was age more than 7 years. The Ethical Committee of ABC Medical School (number 980629/2015), and the School of Public Health (numbers 105/15 and 248/15), University of São Paulo, approved the studies. Informed consent was obtained from all participants.

On one occasion, participants performed several consecutive activities, according to a standard protocol proposed by each researcher, either at their home, school or institution using the two games (*Coincident Timing* and *Challenge!*) selected from the *Bridge Game* software package. For those individuals with disabilities, the game was performed with the participants sitting in their wheelchair or on an adjusted chair (Fig. 2, 3, 4).

For persons with Duchenne muscular dystrophy, the use of Leap Motion sensor required the use of a wedge to support the handle, leaving a minimum distance for capturing the movement of the fingers of the dominant hand (Fig. 4). *Bridge Games* were applied in quiet, dedicated spaces, in

Table 1 Characteristics of all participants

Pathology	*n*	Mean age in years (SD)	Limits of age (min–max) in years	F:M
Alzheimer's	11	82 (11.2)	69–100	10:1
Amyotrophic lateral sclerosis	30	39 (16.3)	28–51	12:18
Asperger's	8	14 (2.7)	11–13	0:8
Autism	13	11 (1.8)	9–16	4:9
Cerebral palsy	4	13 (3.4)	9–20	0:4
Duchenne muscular dystrophy	60	21 (8.5)	15–27	0:60
Healthy	217	39 (22.0)	14–86	109:108
All participants	343	30 (27.0)	9–100	135:208

SD standard deviation; *min* minimum; *max* maximum; *F* female; *M* male which people could interact with the environment while their interaction was monitored and structured by a researcher.

Participants were instructed to move quickly and accurately to the target as soon as it was projected on the screen, to meet the criteria for success in each game described above.

2.5 Data analysis

The *Coincident Timing Game* data were analyzed using the difference, in milliseconds, in the time effectively reached by participant and the total amount of time to bubble target. Thus, the advance is considered as negative time and delay as positive. The average times obtained for each participant for the motion sensor used was calculated. We conducted a 3 (movement sensor type: Kinect vs. keyboard vs. touch screen) × 5 (pathology: cerebral palsy vs. autistic vs. Asperger vs. Alzheimer vs. health) univariate ANOVA.

The *Challenge* game data were analyzed using the number of bubbles reached in phase 1. The average bubbles reached for each game participant for the motion sensor used was calculated. We conducted a 3 (movement sensor type: Kinect vs. leap motion vs. touch screen) × 3 (pathology: Duchenne muscular dystrophy vs. amyotrophic lateral sclerosis vs. healthy) univariate ANOVA.

Post hoc comparisons were made using Bonferroni's test ($p < 0.05$). All statistical analyses were performed using SPSS version 20 with a significance level of $p < 0.05$.

3 Results

Preliminary results regarding the effectiveness of *Bridge Games* on the performance of healthy children, adults and elderly, as well as individuals with Duchenne muscular dystrophy, Alzheimer's disease, autism, amyotrophic lateral sclerosis, were extensively evaluated in the *Coincident Timing* and *Challenge!* games (Figs. 5, 6). The data showed encouraging tendencies for some individuals. The study included several tests and was based on a participatory design process that involved physicians, therapists and physiotherapists.

Participants took, on average, 15.7 min to perform the protocol using the *Coincident Timing* game and 14.0 min in the *Challenge!* game.

As expected, in the *Coincident Timing* game there was a main effect of movement sensor type (Kinect, keyboard or touch screen), on performance of sample analyzed, $F(2, 225) = 4.42$, $p < 0.05$). The same occurs with the different kinds of pathology studied, $F(4, 225) = 4.19$, $p < 0.01$. This results suggests Health group had better performance ($M = 309.8$), when compared to Asperger group ($M = 383.1$), Autistic group ($M = 425.7$), Alzheimer group

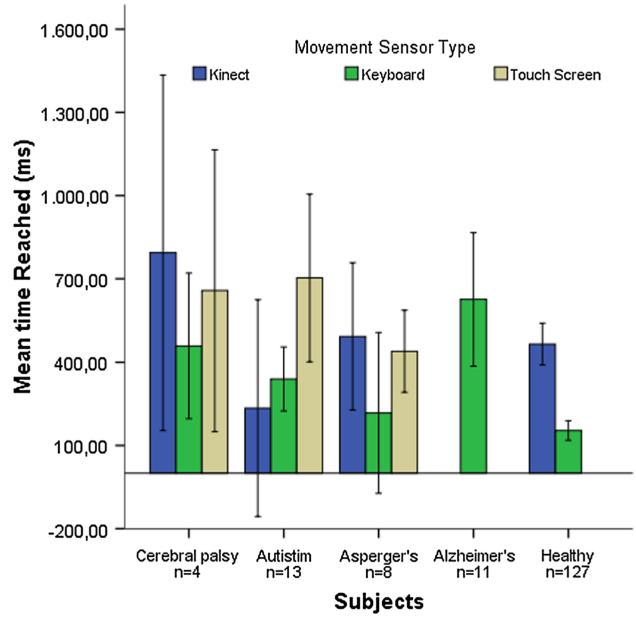

Fig. 5 The mean time reached (in milliseconds) and error bars of 95% confidence interval for the *Coincident Timing* game by individuals with cerebral palsy, autism, Asperger's, Alzheimer's disease and healthy individuals

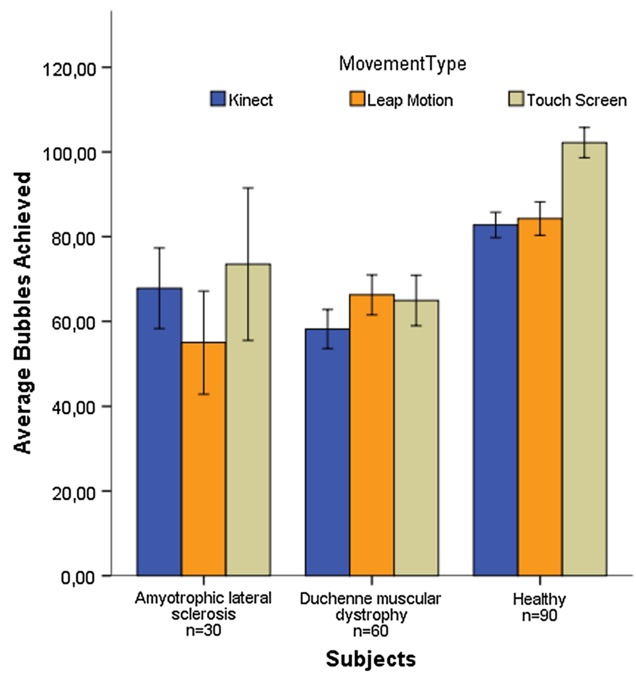

Fig. 6 Average number bubbles achieved and error bars of 95% confidence interval for the *Challenge!* game by individuals with amyotrophic lateral sclerosis, Duchenne muscular dystrophy and healthy individuals

($M = 626.0$) and cerebral palsy group ($M = 636.8$). The participants had better performance in keyboard ($M = 359.1$), when compared to Kinect ($M = 496.8$) and touch screen ($M = 599.9$). There was a marginal interaction between the type of movement sensor and the kind of sample pathology, on time performance in the game, $F(5, 225) = 2.20$, $p = 0.055$.

There was a main effect of movement sensor type (Kinect, Leap Motion or touch screen), in performance of sample analyzed in *Challenge!* game, $F(2, 709) = 5.90$, $p < 0.01$). The same occurs for the different kinds of pathology studied, $F(2, 709) = 115.69$, $p < 0.001$. This result suggests that persons from Health group had better performance ($M = 89.7$), when compared to amyotrophic lateral sclerosis group ($M = 65.4$) and Duchenne group ($M = 63.1$). And this results suggests that persons had better performance in touch screen ($M = 80.2$), when compared to Kinect ($M = 69.6$) and Leap Motion ($M = 68.5$). Finally, there was a significant interaction between the type of movement sensor and the kind of sample pathology, on the performance of bubbles reached in the game, $F(4, 709) = 5.72$, $p < 0.001$.

4 Discussion and conclusion

The present study showed a software package (*Bridge Games*), comprising a variety of games focused on rehabilitation that can offer a range of variables to be used for individuals with disabilities. According to Anderson et al. (2015), a limitation of commercial games like Nintendo Wii, PlayStation Move or Microsoft Xbox, is that therapists are unable to adjust the game settings, such as speed and difficulty of play. These limitations require therapists seek alternatives to adapt existing game consoles to control variables that may interfere with participants' performance and strategy (Lv et al. 2016; Bonnechere et al. 2017). Hocine et al. (2015) cited that adaptation parameters vary with the objective of the rehabilitation program, in addition to the space and time constraints of the therapy, and those variables should be controlled.

Therefore, using the proposed software package (*Bridge Games*), the therapists can adjust game parameters and obtain the sequence execution of movements performed by the participant including the times and positions reached. It also allows the therapist to choose between tasks that require directions of movement, response time execution, memory, strategy, overall temporal accuracy and, hence, coincidence-anticipation timing. For example, before starting the game, the therapist can choose five speed levels for the fall sequence of bubbles in the *Coincident Timing* game and choose whether visual, hearing interaction or both, are on or off. Monteiro et al. (2014, 2017) demonstrated the coincident timing task, with a variable speed and interface device, in a motor learning protocol and both studies found interesting results with improved performance in individuals with cerebral palsy and Down syndrome, respectively. As another example, in the *Challenge!* game, the therapist defines the fixed bubble position, while the game randomly sets another bubble target. The participant must repeatedly return to the same position because the bubble position is fixed. It allows the therapist to define a position that manages different movements of the participant, according to the research/intervention protocol.

Another important characteristic of the software package (*Bridge Games*) is that it provides various types of interface possibilities for the rehabilitation team. Monteiro et al. (2014) illustrated that different devices for interaction with the same virtual task could provide different results. For instance, using a device such as webcam, Kinect or Leap Motion, provides abstract information (without physical contact) and can achieve different performance compared to the same task performed using a touch screen, mouse or computer keyboard that offer more concrete information (with physical contact). Probably, a task without physical contact elicits different spatiotemporal organization of the movement than more natural environments, resulting in participants presenting different performances (Monteiro et al. 2014).

Based on the preliminary researches using the *Bridge Games* to compare different interface interactions, our results using the *Challenge!* game by amyotrophic lateral sclerosis, Duchenne muscular dystrophy and healthy individuals showed that the touch screen provided better performance compared to Kinect and Leap Motion. This result is in agreement with the existing works (Monteiro et al. 2014, 2017). Moreover, the findings suggest that tactile stimuli are key to creating sensorial information and providing functional benefits when compared with the task performed without physical contact.

A similar phenomenon was found with the *Coincident Timing* game, used by individuals with cerebral palsy, autism, Asperger's, Alzheimer's disease and healthy individuals. The results were analyzed considering the constant error (CE) that takes into consideration the direction of the error and is negative when, on average, the participant underestimates the time of arrival of the incoming stimulus and positive when the participant overestimates its time of arrival (Rodrigues et al. 2009). Overall, participants showed a positive CE, represented by a positive average time to achieve the bubble in the *Coincident Timing* game. In this instance, the most functional device was the keyboard, when compared with Kinect and touch screen. Thus, for all participants, a concrete and commonly used device, such as a keyboard, seemed to be more functional. It was noted that regardless of the disease, task or device, healthy individuals always performed better, among the participants studied.

This result was expected, given the motor skill difficulties presented in Duchenne muscular dystrophy (Malheiros et al. 2016) and amyotrophic lateral sclerosis (Iwasaki et al. 1990), as well as the cognitive impairment that characterizes Alzheimer's disease (Stanmore et al. 2017) and autism, which influence and hinder any functional task (Herrero et al. 2015).

Developing a successful game, particularly one intended to benefit those suffering from a serious condition is not easy. One of the challenges in designing such a game for people with disabilities is to present a game that is appealing, fun to play, engaging and at the same time achieves its main goal (Patrizia et al. 2009). A key feature of a successful game is its ability to provide the player with an adequate level of challenge (Hocine et al. 2015). The results presented regarding improved performance and the observations made during data collection demonstrated that the games available on *Bridge Games* present challenging features that motivate participants to achieve their best capacity. Rehabilitation games should be considered a component of the overall rehabilitation protocol and not a self-sufficient activity (Bonnechere et al. 2017). Moreover, as rehabilitation is a long process, the challenge for game designers is to create games that can generate patient excitement and sustain their motivation throughout the entire duration (Hocine et al. 2015).

Based on the present findings, we can confirm our hypothesis that individuals with various disabilities were able to use the software and could improve their performance during the games proposed. Thus, the software package could be a possible future approach for rehabilitation, offering a range of possibilities for the rehabilitation team to control the variables during the intervention.

5 Limitations and future studies

The current study has several limitations that should be mentioned. First, we presented seven games and collected data using only two of the seven games in *Bridge Games.* The data were sufficient to achieve the goal of this study, which focused on presenting a software package. However, it is recommended that further researches consider the idea and possibilities for its practical applications and future protocols, with specific and in-depth needs of individuals with a particular disability. The second concern is that although we identified some motivation during the practice, future studies should evaluate this variable more precisely. Particularly, to address the issue of motivation in therapy, we recommend more clinical research integrating *Bridge Games* into rehabilitation via modified game control interfaces, as a supplement to traditional rehabilitation practice. The advent of motion controllers for home-based video games makes using rehabilitation-relevant motions to control games feasible and has the practical advantage of reducing cost compared to complex virtual reality/robotic interfaces (Lohse et al. 2013). The third concern is that we could not assess the cognitive or motor function, to distinguish the different deficiencies assessed. Such information could provide more explanations about the differences between the groups of participants. Moreover, the software package (*Bridge Games*) limited the outcome parameters to non-immersive virtual tasks, and we could not compare the results to a real task. As cited by Monteiro et al. (2017) replicating the data by applying the learned skills to a real task could have gained further insight into our findings. Therefore, it is recommended that future studies look at comparing the findings with a real environment situation because this could provide additional, valuable knowledge. However, we suggest that the software package (*Bridge Games)* may be a viable and beneficial option to be used for improving motor and cognitive disabilities.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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