Development of a new scoring system for bilateral upper limb function and performance in children with cerebral palsy using the MIRA interactive video games and the Kinect sensor

I M Moldovan[1], A D Călin[2], A C Cantea[2], L A Dascălu[2], C A Mihaiu[2], O Ghircău[1], S Onac[1], O Rîză[1], R A Moldovan[3], L V Pop[4]

[1]Socio-medical services complex "Maria Beatrice", Alba-Iulia, ROMANIA

[2]MIRA REHAB LIMITED, London, UK

[3]Alba-Iulia Emergency County Hospital, ROMANIA

[4]"Iuliu Hațieganu" University of Medicine and Pharmacy, Cluj-Napoca, ROMANIA

[1]*ongmariabeatrice@yahoo.com*, [2]*contact@mirarehab.com*

[1]*www.mariabeatrice.ro,* [2]*www.mirarehab.com*

ABSTRACT

The aim of the study is to develop a reliable and valid occupational therapy scoring system for the assessment of bilateral upper limb function and performance in children with cerebral palsy (CP) using adapted MIRA (Medical Interactive Rehabilitation Assistant) interactive video games and the Kinect 360 Xbox sensor. MIRA is a software platform that uses the Kinect 360 motion sensor to interact with several video games adapted for children with cerebral palsy. 16 healthy children and 11 children diagnosed with cerebral palsy played four MIRA games that generate three performance quantifiers: distance (m), average acceleration (m/s^2) and score (points). The reliability and the validity tests performed suggest that the scoring of the MIRA testing schedule is a reliable and valid occupational therapy tool for the assessment of bilateral upper limb function and performance in children with cerebral palsy.

1. INTRODUCTION

Cerebral palsy (CP) is a neurologic impairment that starts at birth and leads to variable degrees of disability throughout the entire lifespan. It is the most common cause of physical disability in children (Rosenbaum, 2003) with a rate of 2 to 2.5 per 1,000 live births (Stanley et al, 2000).

Assessing motor function in children with cerebral palsy is a difficult task since many forms are encountered in clinical practice (hemiplegia, tetraplegia, diplegia, ataxia, and dyskinesia). The Gross motor function classification system (GMFCS) is a widely internationally-adopted scale that describes the self-initiated movements with particular emphasis on the control of the trunk and lower limbs (Palisano et al, 1997). The five-level scale is based on the concepts of disability (World Health Organization 1980) and of functional limitation (National Institutes of Health 1993). The Manual Ability Classification System (MACS) was designed to evaluate how children with CP use their hands when manipulating objects in daily activities (Eliasson et al, 2006). It is a five-level scale focused on manual ability, as defined in the International Classification of Functioning, Disability and Health (ICF; World Health Organization 2001). There is a lack of correlation between the upper limb and lower limb abilities in children with cerebral palsy. An exact agreement between MACS and GMFCS levels was found only in half of the children, suggesting that rehabilitation programs for the upper and lower limbs should be judged separately (Eliasson et al, 2006).

There is a growing interest in recent studies for developing new therapeutic interventions in order to increase the movements of the arms and hands of the children with CP (Mayston, 2001). However, MACS has a low sensitivity in identifying small changes in the arms and hands function. Thus, several occupational therapy assessments were developed. In order to demonstrate that a new therapeutic method is efficient, it should generate a significantly statistic improvement on a valid and a reliable scale. Without valid and reliable scales it is impossible to test the efficacy of a new therapeutic method. For children with bilateral upper limb neurologic impairments aged 5 to 15 years, the Melbourne Assessment of Unilateral Upper Limb Function (MUUL) is the most appropriate test (Wagner et al, 2012). It consists of videotaped occupational therapy sessions followed by an interpretation session in which the therapist quantifies the performance. The average time for evaluation of one upper limb is one hour, so for the bilateral evaluation of both upper limbs it reaches up to two hours.

Movement-based interactive video games (IVG) using Nintendo's Wii® and Microsoft's Kinect® motion sensors is a promising new therapy for children with cerebral palsy. The method is very well accepted by children, and seems to be effective in improving arm motor control, functional status, activities of daily living (ADL) and balance (Winkels et al, 2013; Tarakci et al, 2013; Gordon et al, 2012).

Interactive video games using Kinect 360 Xbox sensor of motion provide much information regarding parameters of movements (speed, acceleration, distance) that can be used in the evaluation of the upper limb function. Certain tasks can now be transferred from occupational therapy sessions into virtual occupational therapy sessions making the activity entertaining, motivational and fun. The instant scoring offered by the game can quantify the performance in achieving tasks thus reducing the time needed for the evaluation consisting in videotaped occupational therapy sessions.

The aim of the study is to test the reliability and the validity of the MIRA testing schedule, a set of four different movement based MIRA games designed to evaluate the upper limb function and performance in children with neurological impairments.

2. METHODS

2.1 Participants

11 children (4 girls and 7 boys), aged 4 to 11 years, diagnosed with cerebral palsy, included in "Maria Beatrice" Rehabilitation Center, Alba-Iulia, Romania, played the MIRA interactive video games using the Microsoft Kinect 360 Xbox sensor. 16 healthy children (10 girls and 6 boys), aged 4 to 10 years, included in the control group, also played the same interactive video games.

2.2 Interactive video games

MIRA (Medical Interactive Rehabilitation Assistant) is a software platform that uses the Kinect sensor to interact with medical video games created specifically as an aid for physical rehabilitation therapies and diagnosis. MIRA's therapeutic efficacy in rehabilitation is currently under investigation. The platform provides a patient management application designed for physiotherapists to store patient data related to their condition and diagnosis, create personalised therapy sessions and visualize statistics about their improvement. Thus, a dedicated rehabilitation schedule can be created for each patient from the medical games contained by the platform and it can be designed to test, train and measure several types of movements, in order to improve and quantify the range of motion, the coordination and the patient engagement.

The sensor used by MIRA, Microsoft Kinect, comprises an RGB video camera and two monochrome Infra-Red (IR) sensors of which one is also an IR laser projector, based on which a 3D depth map is created. The Kinect sensor allows recognition of the 3D location of the body joints, thus permitting the MIRA platform to analyse the movement and offer important feedback containing statistics and measurements. The joints/limbs that can be tracked are: head, shoulder centre/right/left, elbow left/right, wrist left/right, hand left/right, spine, hip centre/left/right, knee left/right, ankle left/right, foot left/right.

This study is focused on the use of the upper-limb MIRA package, mainly on games created for the rehabilitation in neurologic conditions of children. It combines physical, occupational and recreational therapies that are commonly used for the rehabilitation of the children with cerebral palsy. The movement-based interactive video games are created to target goals pursued in the traditional rehabilitation therapies: to develop coordination, maintain and improve flexibility and function in every-day activities, overcame physical limitation, increase self-confidence and induce positive emotions to encourage cooperation and perseverance. The games used in this study are Catch, Follow, Move and Grab, each having three difficulty levels (easy, medium and hard) and a series of levels that progress gradually. The data obtained from the Kinect sensor are processed and scaled according to the dimensions of the user's arm, such that, after calibration, the shoulders are mapped to the center of the screen and the user is able to reach with his or her hand a position mapped on the margins of the game's margins only when he or she stretches their arm completely, without moving their body.

2.2.1 Catch. Catch is a game that requires the user to move the arm in order to catch several objects appearing on the screen, in which case they receive points. If objects were not caught in a specific amount of time, they disappear and others will replace them in several locations of the screen. As the difficulty increases, the objects remain on the screen for a shorter time. In the hard level, the objects are in movement. High velocity and high acceleration movements are required for the completion of this game.

2.2.2 Follow. In Follow the user has to keep the hand on a shape on the screen and follow it as it moves around the screen on random path. While the users keep their hand on the shape, they gather points and a song will be playing. When their hand is not on the shape, the volume of the song decreases until it stops. The sound reappears when the hand positioning is correct. As difficulty increases, the time allowed for the hand to be outside the shape shortens and the speed of the moving shape increases. High precision movements of the arm are required to complete this game.

2.2.3 Move. The game Move requires the user to move objects with their hand on a predefined path. Paths come out in the order of their difficulty: verticals, horizontals, diagonals, and then circles and waves. Some points are given when the item is picked up, but most of them are rewarded when the objects reached the final position of the path. Getting out of the path for a certain amount of time implies losing the object (and some points) and starting all over again from the beginning of the path. As difficulty increases, the buffer time when the user is allowed to be off paths is shorter. This game requires movements that resemble the coordination tests used in the cerebellum dysmetria tests.

2.2.4 Grab. Grab is the only game that requires the use of two hands to pick up an object from a shelf and place it with both hands on the upper shelf. Moving hands too far away from each other might result in dropping the object, which must be picked up again, and in losing some points. Some points are given when picking up objects and most of the points come when the object is placed on the specified location on the shelf (Figure 1). As the difficulty increases, the upper shelf is moved higher and higher, and the distance allowed between the hands without dropping the object is smaller. The movements required are well coordinated, similar to those used in activities of daily living.

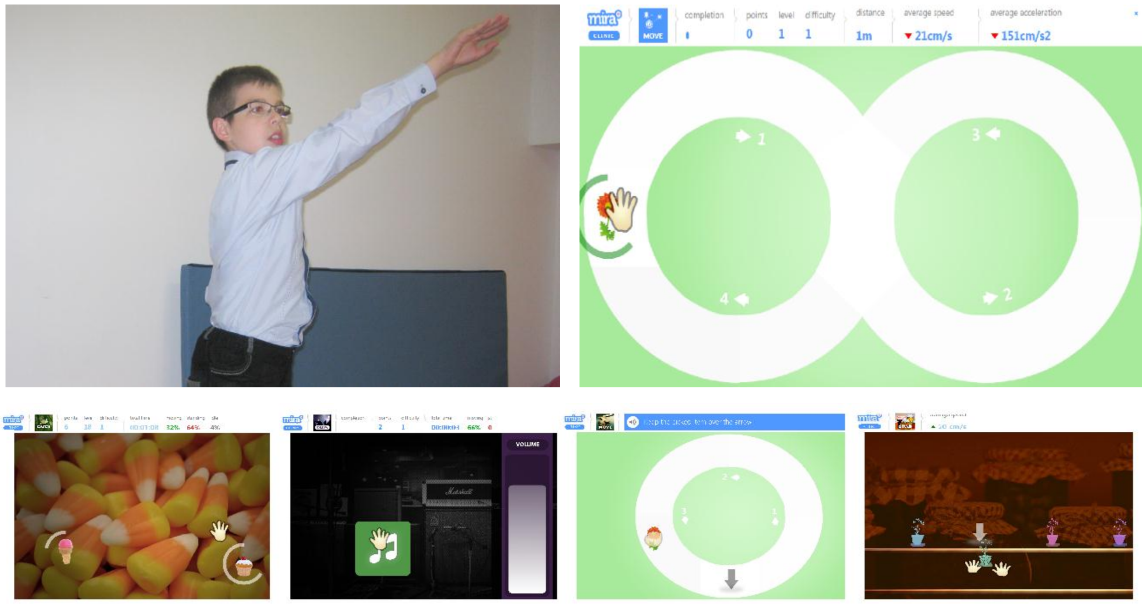

Figure 1. *Snapshots of the MIRA video-games; in order: a child with cerebral palsy while playing, Move - infinite path, Catch, Follow, Move - circle path and Grab. A short movie of MIRA testing schedule is available at http://www.mariabeatrice.ro/mira/mira-testing-schedule.*

During gameplay, the platform gathers movement statistics for each hand used in the games: time played, moving (active) time, game points, average speed, distance on 3D space and average acceleration. A testing schedule has been created, composed by Catch for the right hand and for the left hand, Follow for the right hand and for the left hand, Move for the right hand and for the left hand and Grab using both hands, each for two-minutes time with a 15-second pause time in between the games. At the beginning of each schedule, a calibration is made, consisting of positioning the camera angle and the user in the optimal position for playing the above games. At the end of the session, all games statistics and evolution charts can be visualized in the patient profile. The parameters that are quantified by the MIRA testing games are: distance, average acceleration and points (score).

2.3 Reliability

To assess test-retest stability, two sessions of MIRA testing schedule were done for each child from the CP and control group on two occasions at a minimum of 3 days and a maximum of one week apart. The paired t test and Wilcoxon's signed rank test were used as appropriate (paired t-test for parametric variables and Wilcoxon's signed rank test for non-parametric variables) to determine if any significant changes occurred between the test and the retest results. The statistical significance threshold was chosen at a $p < 0.05$. Intraclass correlation coefficients were calculated for the entire study group (CP and control group taken together). The difference between the two assessments was plotted against the average of the two assessments for each participant using the Bland-Altman plots, and 95% of the differences were expected to be less than 2 standard deviations from the mean difference between the two testing sessions.

Internal consistency (homogeneity of the items) was assessed using the Cronbach alpha statistic (alpha coefficient).

2.4 Validity

Construct validity was assessed by comparing the MACS stage with the MIRA assessment using Pearson's and Spearman's correlation coefficients. Logistic regression with the presence of illness was performed in order to assess the ability of the MIRA testing to predict the presence of cerebral palsy.

3. RESULTS

3.1 Participants

The average age in the study group was 7.4±1.9. The average age in the CP subgroup was 7.8±2.4 while the average age in the control subgroup was 7.1±1.6 ($p=0.38$). The sex ratios were not significantly different between the two subgroups ($p=0.45$). Two of the children in the CP group had spastic paraparesis, six had spastic tetraparesis and three had a mixed form, spastic and dyskinetic tetraparesis. According to the GMFCS scale, four children in the CP group were stage 1, four children were stage 2 and three children were stage 3. According to the MACS scale, six children in the CP group were stage 1, three children were stage 2 and two children were stage 3. The absolute agreement between GMFCS and MACS was 0.56, with a 95% CI of -0.56 to 0.8. Equal scores for the two scales were found only in four children.

3.2 Reliability

All 27 participants included in the study completed the two MIRA testing evaluations. All intraclass correlation coefficients (ICC) for the points achieved in the seven games included in the MIRA testing were above 0.81, the ICC for the total points being 0.94. For two of the seven games (Catch wrist right and Grab both hands) the average points were significantly higher in the second examination compared to the first examination ($p<0.05$). All intraclass correlation coefficients (ICC) for the distance achieved in the seven games included in the MIRA testing were above 0.73, the ICC for the total distance being 0.9. For two of the seven games (Catch right wrist and Grab both hands), the average distance was significantly higher in the second examination compared with the first examination ($p<0.05$). All intraclass correlation coefficients (ICC) for the average acceleration achieved in the seven games of the MIRA testing were above 0.41, the ICC for the total distance being 0.83. For two of the seven games (Catch right wrist and Grab both hands), the average distance was statistically significantly higher in the second examination compared to the first examination ($p<0.05$).

The Cronbach alpha coefficient revealed a high internal consistency (overall alpha=0.97). Each of the variables taken into account contributed positively to the overall alpha value.

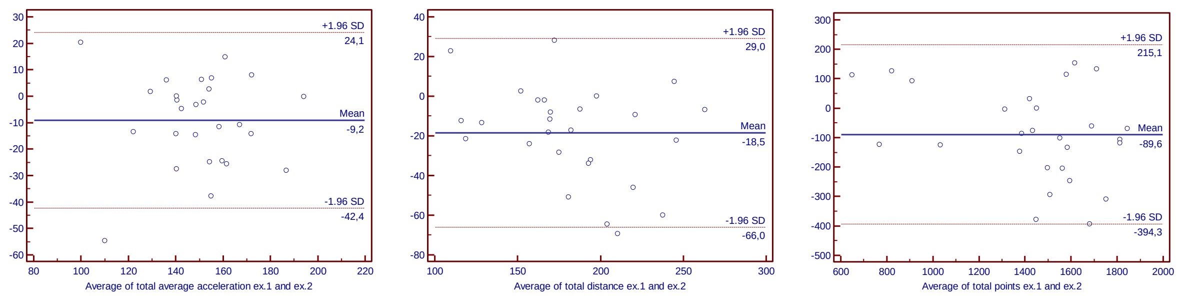

Figure 2. *Bland Altman plots for first and second test results for total average acceleration (left), total distance (centre) and total points (right), for the MIRA testing schedule.*

Bland Altman plots used to test the repeatability of the two examinations revealed that more than 95% of the data plots were placed within the ±2 standard deviations from the mean difference between the two testing sessions for the total average acceleration, total distance and total points (Figure 2). More than 95% of the data

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plots for average acceleration and points were placed within the ±2 standard deviations from the mean difference between the two testing sessions in each of the seven games.

3.3 Validity

The comparison between the MIRA testing results in the healthy versus the CP group is shown in Table 1. The healthy group achieved higher values of test parameters than the CP group for all the variables. Statistical significance was reached for all the parameters involved in the Catch right wrist, Catch left wrist, Follow right and left wrist points, Move right and left wrist points and for total points. For each of the latter variables, univariate logistic regression with the presence of illness was performed, in order to determine their ability to predict the presence of CP. Those found to be significant predictors of cerebral palsy in the study group are depicted in Table 2. Multivariate logistic regression could not be performed because of the relatively small number of participants (Peduzzi et al, 1987). Since the points obtained in almost every game were found to be predicted for the CP, the ROC curve analysis was performed for the points in order to determine the diagnostic value of the scoring of each game (Figure 3).

Table 1. *Comparison between the MIRA testing parameters in the healthy versus the Cerebral palsy group. The p value refers to the paired t test for the normally distributed variables and to the Mann Whitney test for the non-normally distributed variables. RW= right wrist, LW = left wrist. Normally distributed variables are presented as mean±standard deviation and non-normally distributed ones as median(25-75 percentiles).*

Parameter (distance/points/acceleration)	Healthy (n=16)	CP (n=11)	p
Catch RW distance(m)	40.2±7.8	31.5±7.6	**0.008**
Catch RW average acceleration(m/s^2)	221.6±25.2	191.4±31.4	**0.005**
Catch RW points	229.2±31.2	188.8±47.8	**0.01**
Catch LW distance	42.9±7.5	33.6±9.4	**0.008**
Catch LW average acceleration(m/s^2)	232.4±20.6	196.3±39.9	**0.005**
Catch LW points	221.4±40.3	167.5±57.6	**0.008**
Follow RW distance	17.8±2.3	16.1±2.1	0.07
Follow RW average acceleration(m/s^2)	124.2±14.6	121.7(115.6-127.4)	0.35
Follow RW points	267±14.7	221.8±49.4	**0.0001**
Follow LW distance	17.7±2.4	17.1(15.9-18.5)	0.8
Follow LW average acceleration(m/s^2)	130.4±14.6	124.7±12.1	0.29
Follow LW points	255±16.7	203.1±76.3	**0.0003**
Move RW distance	13.9±4.2	14.1±2.9	0.87
Move RW average acceleration(m/s^2)	100.2±21.7	100±16.9	0.98
Move RW points	156.3±39.3	117±54.3	**0.04**
Move LW distance	14.8±3.76	14.2±2.1	0.59
Move LW average acceleration(m/s^2)	103.9±20.2	108.9(103-113.3)	0.84
Move LW points	158.3±41.2	114.8±51.8	**0.02**
Grab RW average acceleration(m/s^2)	161.1±31.9	154.6±44.5	0.66
Grab LW average acceleration(m/s^2)	163.9±32.3	155.9±42.2	0.58
Grab points	270.7±73.6	248.7±165.1	0.64
Total average acceleration(m/s^2)	154.7±19	143.4±21.6	0.16
Total distance	191.6±34.7	171.2±45.6	0.19
Total points	1557.9±157	1262.4±405	**0.018**

Table 2. *Univariate logistic regression with presence of illness. RW= right wrist, LW = left wrist.*

Parameter (distance/points/acceleration)	Odds ratio	IC 95% interval	P
Catch RW distance	0.84	0.72-0.98	**0.004**
Catch RW average acceleration	0.95	0.92-0.99	**0.007**
Catch RW points	0.97	0.95-0.99	**0.01**
Catch LW distance	0.87	0.77-0.98	**0.006**
Catch LW average acceleration	0.95	0.91-0.99	**0.003**
Catch LW points	0.97	0.96-0.99	**0.007**
Follow RW points	0.94	0.89-0.99	**0.0007**
Follow LW points	0.94	0.91-0.98	**0.0003**
Move LW points	0.97	0.95-0.99	**0.02**
Total points	0.99	0.994-0.999	**0.015**

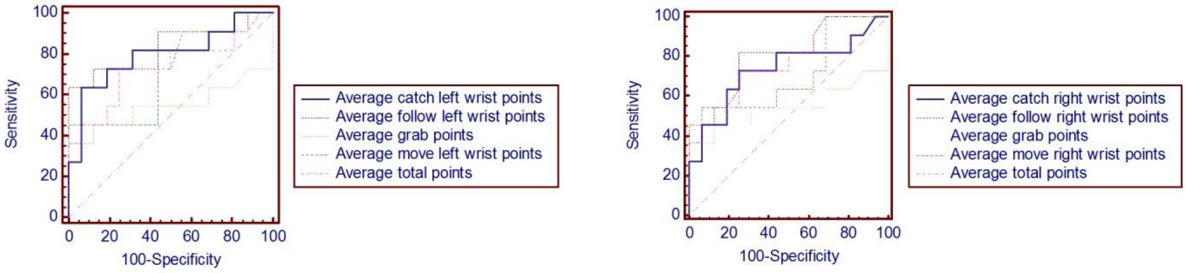

Figure 3. *Comparison of ROC curves for the points in each game for left wrist (left) and in right wrist (right).*

Areas under the ROC curves larger than or equal to 0.8 were found for Catch left wrist points, Follow left and right wrist points. The 95% CI did not contain 0.5 for Catch left and right wrist points, Follow left and right wrist points, Move left wrist points and total points.

Negative correlations were found between the MIRA testing parameters and the MACS stage. The results are shown in Table 3. Statistically significant correlations were found for points in every game except for Grab and Follow left wrist.

4. DISCUSSION

Play is a central part in a child’s life. While in early childhood play is characterised by qualities of exploring, participating and imitating, in ages of middle childhood (6-10 years) structured games and organised play predominate (Tamm and Skär, 2000). Interactive video games based on motion capture using Kinect Xbox 360 sensor proved to be efficient in improving balance and activities of daily living in children with CP after 8 weeks of videogame treatment (Luna-Oliva et al, 2013). The idea of assessing body function and performance in children with neurologic impairments using adapted video games is legitimate since these activities are fun and motivational. Thus, IVG could be used not only as a therapy method for children with neurologic impairments, but also for the assessment of motor skills.

In terms of reliability, all of the three parameters (total distance, total average acceleration and total points) had good intraclass correlation coefficients (greater than 0.83). Internal consistency tested with the Cronbach alpha coefficient was high (0.97).

The repeatability of the MIRA testing schedule, assessed by Bland Altman plots, revealed that more than 95% of the data plots were placed within the ±2 standard deviations from the mean difference between the two testing sessions for the total average acceleration, total distance and total points. All data plots for points in each of the 7 games were placed within the ±2 standard deviations from the mean difference between the two testing sessions, suggesting that this was the most reliable parameter of the three. However, the clinical significance of the differences between measurements is yet to be determined in a further study on a larger number of participants and using more game sessions/participant in order to minimize the impact of the learning effect.

Table 3. *Correlations between the MIRA testing parameters and the MACS stages. Pearson's r for normally distributed variables and Spearman's r_s for non-parametric variables.*

RW= right wrist, LW = left wrist.

	Correlation coefficients PCI group n=11		
Parameter distance/points/acceleration (measure unit)	r/r_s	95% IC	P
Catch RW distance (m)	-0.63	-0.9- -0.06	**0.03**
Catch RW average acceleration (m/s^2)	-0.09	-0.7- -0.54	0.78
Catch RW points	-0.74	-0.93- -0.25	**0.009**
Catch LW distance (m)	-0.65	-0.9- -0.09	**0.03**
Catch LW average acceleration (m/s^2)	-0.64	-0.89- -0.07	**0.033**
Catch LW points	-0.69	-0.9- -0.14	**0.02**
Follow RW distance (m)	-0.7	0.92- -0.14	**0.016**
Follow RW average acceleration (m/s^2)	-0.31	-0.77-0.35	0.35
Follow RW points	-0.81	-0.95- -0.43	**0.002**
Follow LW distance (m)	-0.7	-0.92- -0.23	**0.01**
Follow LW average acceleration (m/s^2)	-0.5	-0.85-0.14	0.11
Follow LW points	-0.36	-0.78- -0.31	0.27
Move RW distance (m)	-0.56	-0.87-0.05	0.07
Move RW average acceleration (m/s^2)	-0.09	-0.65-0.54	0.7
Move RW points	-0.6	-0.88- -0.002	**0.049**
Move LW distance (m)	-0.59	-0.88-0.17	0.056
Move LW average acceleration (m/s^2)	-0.15	-0.69-0.49	0.66
Move LW points	-0.5	-0.86- 0.08	**0.05**
Grab RW average acceleration (m/s^2)	-0.53	-0.86-0.1	0.09
Grab LW average acceleration (m/s^2)	-0.5	-0.48-0.13	0.1114
Grab points	-0.5	-0.85-0.13	0.1
Total average acceleration (m/s^2)	-0.57	-0.87-0.05	0.07
Total distance (m)	-0.69	-0.91- -0.14	**0.02**
Total points	-0.68	-0.91- -0.14	**0.021**

Except for the Move game, the points, the average acceleration and the distance were higher in the second examination versus the first one for all children. For two of the MIRA testing games these differences reached statistical significance. These data suggest that a learning effect may be present for all children. Thus, children should probably play several times the MIRA testing games in order to reach their best motor performance. The learning effect was not present in the Move game, which was inspired from the clinical tests for dyskinesia, requiring slow motion, well coordinate movements.

The validity of the MIRA testing schedule is supported by the negative correlation between the MACS classification and the total points achieved. Thus, a higher score was associated to a lower MACS stage. Total points and points in each game except for Grab were statistically significantly higher in the healthy group compared to the CP group. The univariate logistic regression revealed that all the scores gained in each game except for Grab and Move right wrist were associated with the risk of having cerebral palsy. In the ROC curve analysis, satisfactory areas under the curve (higher than 0.8) were found for Catch left wrist points, Follow left and right wrist points. The Grab game showed the smallest area under the ROC curve, associated with the lowest sensitivity and specificity for CP.

One limitation of the current study is the relatively small number of participants. Children with CP and intellectual disabilities are unfit for assessment of motor skills with movement-based IVG and those with MACS stage 4 and 5 are cannot use their hands independently, so they are unable to play. Further studies on a larger number of participants are needed to support our findings.

To our knowledge, this is the first study that aims to develop an occupational therapy scoring system for the assessment of the bilateral upper limb function and performance in children with cerebral palsy using adapted interactive video games and the Kinect 360 Xbox sensor. A future study will test the therapeutic effects of the MIRA games in children with cerebral palsy and will focus on a new version of the MIRA testing schedule in which the Grab game will be excluded.

5. CONCLUSIONS

The scoring of the MIRA testing interactive video games adapted for children with neurologic impairments using the Microsoft's Kinect 360 Xbox sensor of motion seems to be a reliable and valid occupational therapy tool for the assessment of the bilateral upper limb function and performance in children with cerebral palsy. Of all games, Grab seemed to be the least appropriate for this purpose.

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