

# Evaluation of the V-Arcade serious games framework to support upper limbs rehabilitation at home for children with Juvenile Idiopathic Arthritis

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**Abstract**—We present the evaluation of the V-Arcade serious games framework to support hand, wrist and forearm rehabilitation for children with Juvenile Idiopathic Arthritis (JIA). We evaluated the framework in collaboration with the therapists of the De Marchi Pediatric Clinic in Milan. We provided the software at home to three children with JIA, each child performed exercises at home with the framework, the trial lasted for 1 month and a half. The evaluation measures performed at the beginning and the end of each trial include: Evaluation of active and passive ROM (Range Of Motion), Pain assessment with Numerical Rating Scale (NRS), Questionnaires on functional skills: Jamar, Abilhand and CHAQ, and a final interview with the therapist.

**Index Terms**—exergames, serious games, upper limbs rehabilitation, hand rehabilitation, leap motion controller

## I. INTRODUCTION

The Juvenile Idiopathic Arthritis (JIA) defines all the forms of arthritis, with unknown causes, that affect children before the age of 16, and that persist for more than 6 weeks [1]. According to [1, 2] in fact, a period greater than or equal to 6 weeks is reported in the criteria for differentiating chronicity in contrast to reactive arthritis.

The intervention for children with JIA includes intra-articular injections and physiotherapy rehabilitation. Often the rehabilitation process takes long time and it can cause low motivation of the child leading him/her to give up the physical therapy. In addition to low motivation, children have to cope with the pain caused by the disease and with the fear of feeling pain, causing the child to refuse to perform the exercises.

We want to investigate and understand whether, for the new generations, the introduction of rehabilitative elements of a playful and family nature, as video games, adequately calibrated for rehabilitation purposes, can increase compliance with the treatment and functional results. In fact, it is essential

to take into consideration the experiences of pain related to the JIA disease which, especially in childhood, could more easily lead to incorrect performance of the proposed activities and less adherence to treatments.

Technologies, commercially available at accessible prices, have been exploited in the development of serious games to track user's motions, as the RGB-D depth cameras Microsoft Kinect<sup>1</sup> or the Intel Real Sense<sup>2</sup>, or the Leap Motion<sup>3</sup>, a free-hand interaction controller developed to track hand and wrists movements, for hand tracking.

Recently, in literature different approaches with serious games exploiting tracking technologies to support physical rehabilitation have been proposed, trying to find new training methods to increase patients' motivation.

[3] exploited the Kinect device and the Wii Balance board to develop a framework with serious games to track user's body posture, the framework includes a remote monitoring interface that shows user's posture and motion data to the therapists. It aims to support at home elderly physical posture rehabilitation and post stroke rehabilitation.

[4] proposed the development of a serious game exploiting Oculus Rift and the RealSense to support rotator cuff rehabilitation, the user's motion data are saved and stored on a server to be available to the therapists.

[5] study proposed a combined approach with traditional therapy and at home exercises performed playing commercial Xbox 360 games with Kinect, that have been specifically selected by therapists to support upper limbs rehabilitation; as the "Macarena" dance in "Dance Central 3", that involves upper limb joint movements. The results were promising,

<sup>1</sup><https://developer.microsoft.com/it-it/windows/kinect/>

<sup>2</sup><https://www.intelrealsense.com>

<sup>3</sup><https://www.ultraleap.com/product/leap-motion-controller>

[5] reported that the children who played with the games did not complain of fatigue and tried to keep their activity performance high, unlike the control group; results suggests that the children focused on the fun of the games rather than their perception of being treated, increasing their motivation and helping them to cope with the pain and fear of pain. In fact, serious games for rehabilitation can capture the player’s attention and at the same time they can support therapy intervention, combining entertainment with the rehabilitation needs.

In this paper we present the evaluation of the V-Arcade serious games framework to access the effectiveness to support at home physical rehabilitation. We developed the V-Arcade framework in collaboration with the therapists of the De Marchi Pediatric Clinic in Milan. It can be installed on user’s Personal Computer, while hand tracking is performed through Leap Motion Controller.

We provided the software and the Leap Motion at home to children with their parents, each child performed exercises at home playing with the serious games for 1 month and a half. The children met periodically the therapist at the De Marchi Clinic to monitor the progresses achieved during the rehabilitation process. At the beginning and at the end of the treatment, the therapist performed the evaluation of the following measures: (i) active and passive ROM (Range Of Motion) [6], (ii) Pain assessment with Numerical Rating Scale (NRS) [7], (iii) Questionnaires on functional skills: Jamar (Juvenile Arthritis Multidimensional Assessment Report) [8, 9], Abilhand [10] and CHAQ (Child Health Assessment Questionnaire)[11]. We chose these questionnaires because, as exposed by [12], they are a powerful tool for assessing the functional status and quality of life of children with JIA. In addition, at the end of the treatment, the therapist performed a final interview with fixed questions with the child and the parents for a descriptive evaluation of satisfaction.

## II. MATERIALS AND METHODS

### A. The Serious Games Framework

The V-Arcade framework, described in details in [13], contains (i) the application for the children with four serious games ; (ii) the application for the therapists in which the specialist can monitor children’s progresses and he/she can generate custom levels of each serious game; and (iii) a server to store data.

The four serious games are: Rich Race, Music Beats, Alien Invasion and Shooting Gallery; and each serious game offers different upper limbs rehabilitation exercises: radial and ulnar deviation, flexion and extension and, pronation and supination for forearms training [14]. Each serious game offers training with different types of exercises, as shown in “Fig. 1”.

The therapists application includes a level editor, that allows to personalize the game levels individually for the specific needs of each child, and a replay module to view the playback of each children’s exercise. The therapist can generate personalized levels customizing the duration of the exercise, the range of motion and the hand movement to be performed.

	Radial/Ulnar Dev.	Flexion/Extension	Pronation/Supination
Rich race	✓	✓	✓
Music beats		✓	
Shooting gallery	✓	✓	
Alien invasion	✓	✓	✓

Fig. 1. Physiotherapy exercises involved in the video games

The framework was developed with Unity 3D<sup>4</sup> and it supports both Windows and MacOS systems with tracking through the Leap Motion Controller with V2 SDK (that supports both OS systems). The framework setup requires to the user to position the Leap Motion on the desktop in front of the PC. When the user plays, the hand data are collected through the Leap Motion SDK and then stored on a server, as well as the custom levels are saved on the server when generated by the therapist; so that the child can play at home and the therapist can create personalized levels remotely.

### B. Experimental Setup

The therapists recruited three children with JIA, aged between 9 and 13 years old, to perform the rehabilitation of the upper limbs with V-Arcade serious games. We performed two initial meetings with each child, and him/her parents, individually, at the presence of one computer scientist and one therapist. In the first meeting, the therapist performed the evaluation of ROM [6], the NRS [7], and the Jamar [8, 9], Abilhand [10] and CHAQ [11] questionnaires. In the second meeting, we installed the serious games in the personal PC of the child; we have provided the child with a Leap Motion and we explained to the child’s parents how to use the software and the Leap Motion. The use of the video game was recommended by the therapist for at least 3/4 times a week for 1 month and a half and with a single session lasting about 15/20 minutes. At the beginning of the trial, the therapist created personalized levels of the serious games for each child.

After 45 days the therapist evaluates again the ROM, NRS and the questionnaires. For details on questionnaires and their results, please contact the corresponding author.

In addition, the therapist performed a final interview with fixed questions with the child and the parents for a descriptive evaluation of satisfaction. The questions are shown in “Table. I”, while the plots of the interview results are represented in “Fig. 2”. The plots show an overall acceptance of the system: the children perceived the serious games as effective, engaging and fun. In the next section the results are exposed in details.

<sup>4</sup><https://unity.com>

TABLE I  
QUESTIONS OF SATISFACTION INTERVIEW

Attribute	Range
Fun and enjoying	0 low - 10 high
Boring	0 low - 10 high
Easy to use	0 low - 10 high
Perceived as effective	0 low - 10 high

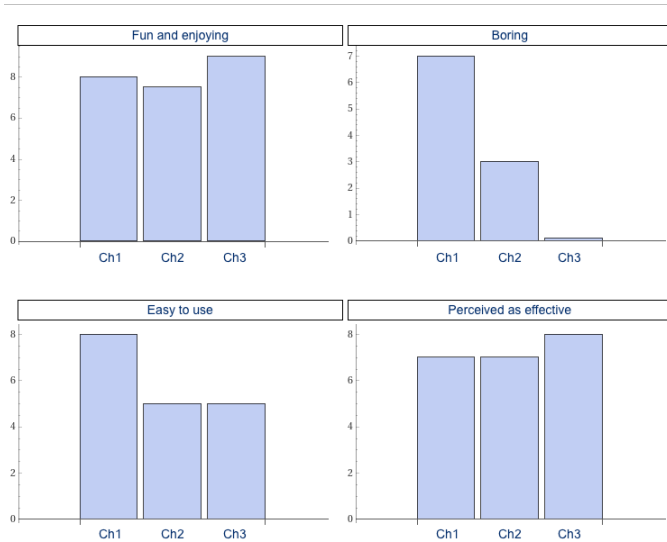


Fig. 2. Results of final interview of satisfaction

### III. RESULTS

**Child 1.** The child 1 is a 13 years old child with JIA and joint involvement of the right wrist. The therapist generated personalized levels taking into account the child's greater difficulty to perform flexion and supination, with respect to the extension and pronation.

After 45 days the therapist repeated the assessment with the questionnaires, ROM and NRS, and performed the final interview. From the interview it emerged that the child has always been constant in performing the exercises at home, he/she performed them independently 4/5 times a week. In addition, it emerged that the video games were perceived as fun and easy to use. The child perceived the framework as effective: he/she reported to feel less rigid in the flexion movement of the wrist, so that he/she returned to write without the use of the protective band. However, in the long run, the use of the framework was sometimes perceived by the child as monotonous and boring due to the low variety of serious games available: since the child needed to focus on supination, he/she mostly played with the two serious games that offered that exercise and no with the others.

"Table. II" shows ROM active joint test and NRS results of the symptomatic right wrist before and after the trial, while "Table. III" shows ROM passive joint test results. From the analysis of the ROM active joint test emerges a 5 degrees improvement in flexion and extension movements with pain

symptoms passing from a NRS 6 to 4. Pronation is increased by 10 degrees as well as supination but without improvement of painful symptoms that persist at NRS 6. From the ROM passive joint test, on the other hand, there is an increase of 10 degrees in the flexion and extension movements without improvement of the painful symptoms that remains at NRS 6; there were no increase in supination movement, remaining limited to 30 degrees with pain of NRS 6.

From the Jamar questionnaire it emerged that the patient had improvements in functional activities, he/she acquired the ability to open and close a tap or open a jar; There are also improvements in the evaluation of the quality of life, passing from having difficulties every day or often, to having difficulties only sometimes, for example in taking care of oneself and in carrying out school activities. Pain as a general symptom significantly got better from a score of 9 to a score of 5. On the other hand, the child reported to feel morning stiffness of the hand that was absent in the first evaluation. However, the index related to the of activity of the disease remained unchanged, and, according to the therapists, this result is due to the relapse phase of the disease during the final re-evaluation.

From the Abilhand questionnaire it emerged that the patient was able to carry out all the required activities easily both at the initial and final evaluation, therefore no significant changes are found.

From the CHAQ questionnaire it has been found that the patient in the final evaluation no longer had any difficulty in dressing, tidying up, in performing personal hygiene tasks and in carrying out household activities, compared to the first evaluation; some difficulty remains in taking heavy objects from shelves placed above the child's head. The pain symptom was reduced from a score of 75/100 to a score of 40/100 and the overall evaluation has also improved from 80/100 to 40/100 (in a scale from 0 as very good to 100 as very low results).

TABLE II  
TABLE OF ROM ACTIVE AND PAIN NRS OF RIGHT WRIST OF CHILD 1 BEFORE AND AFTER THE INTERVENTION, THE VALUES IMPROVED ARE IN BOLD

	Deg. before	NRS before	Deg. after	NRS after
Flexion	55°	6	<b>60°</b>	<b>4</b>
Extension	50°	6	<b>55°</b>	<b>4</b>
Radial	20°	0	20°	0
Ulnar	30°	0	30°	0
Pronation	80°	0	<b>90°</b>	0
Supination	20°	6	<b>30°</b>	6

**Child 2.** The child 2 is a 10 years old child with JIA and joint involvement of the right wrist, in particular regarding flexion and extension. The therapist, generated personalized levels principally targeting flexion, extension and supination.

From the final interview with the patient and the mother it was found that the framework was not used every day for family organization problems but 2-3 times a week for a duration of about 20 minutes a day. The child did not complain of pain during the games but only after completing

TABLE III

TABLE OF ROM PASSIVE AND PAIN NRS OF RIGHT WRIST OF CHILD 1 BEFORE AND AFTER THE INTERVENTION, THE VALUES IMPROVED ARE IN BOLD

	<i>Deg. before</i>	<i>NRS before</i>	<i>Deg. after</i>	<i>NRS after</i>
Flexion	60°	6	<b>70°</b>	6
Extension	55°	6	<b>65°</b>	6
Radial	20°	0	20°	0
Ulnar	35°	0	35°	0
Pronation	90°	0	90°	0
Supination	30°	6	30°	6

the 20 minutes session, with a score 1/2 on the NRS scale. From the final interview it emerges that the video games appeared fun, effective and not boring, the diversity between the individual games and levels was appreciated and it was easy to use; the only negative side that emerged concerns the problem of interrupting the functioning of the video game which sometimes happened (probably due to the Leap Motion that did not detected the hand), but apart from this, both the mother and the child considered it a good home treatment solution. The child liked the games, and the mother reported that since the child liked to use the framework, she found it to be a good treatment solution at home, and she would like to continue to use the V-Arcade.

“Table. IV” shows ROM active joint test and NRS results of the symptomatic right wrist, while “Table. V” shows ROM passive joint test results. The analysis of the ROM active joint test on the symptomatic right wrist shows a clear improvement in the joint range, in particular by 25 degrees, in flexion, extension and ulnar deviation movements with associated lowering of painful symptoms; a 5 degrees improvement in pronation emerges while the supination movement remains limited, but the child reported reduced painful symptoms. From the analysis of the ROM passive joint test, there is an improvement of 5 degrees in flexion and supination movements, an increase of 10 degrees in extension and 15 degrees in ulnar deviation. The painful symptomatology decreased considerably in all movements.

From the Jamar questionnaire it emerged that the patient no longer had difficulty taking care of himself/herself, in carrying out school activities. He/she did not had pain due to the disease, he/she was not sad and was not dissatisfied of the physical appearance. The child however reported that sometimes showed nervousness and he/she had difficulty staying with him/her playmates. The current state of health voice of the Jamar questionnaire reports a final score of 3.5 compared to the initial evaluation of 7 (the range goes from 0 = feeling very good, to 10 = feeling very bad). The morning joint stiffness disappeared, the pain also significantly got better, from a score of 7 to a score of 3.5. The Abilhand questionnaire showed the maximum score both at the initial and final evaluation, in fact the patient showed no difficulty in carrying out any of the proposed activities. Also from the CHAQ questionnaire it emerges that the patient had no difficulty in dressing, eating, in personal hygiene and in manual handling; compared to

the first evaluation, the patient was able to carry out without any difficulty some housework tasks such as making the bed, vacuuming or washing dishes. The pain significantly got better from a score of 60/100 to 20/100; as the global evaluation that changed from a score of 50/100 to a better score of 20/100; consequently the global score changed from 0.5/3 in the first meeting to 0.2/3.

TABLE IV

TABLE OF ROM ACTIVE AND PAIN NRS OF RIGHT WRIST OF CHILD 2 BEFORE AND AFTER THE INTERVENTION, THE VALUES IMPROVED ARE IN BOLD

	<i>Deg. before</i>	<i>NRS before</i>	<i>Deg. after</i>	<i>NRS after</i>
Flexion	40°	3	<b>65°</b>	<b>1</b>
Extension	45°	2	<b>70°</b>	<b>1</b>
Radial	20°	0	20°	0
Ulnar	20°	0	<b>45°</b>	0
Pronation	85°	0	<b>90°</b>	0
Supination	35°	4	35°	<b>1</b>

TABLE V

TABLE OF ROM PASSIVE AND PAIN NRS OF RIGHT WRIST OF CHILD 2 BEFORE AND AFTER THE INTERVENTION, THE VALUES IMPROVED ARE IN BOLD

	<i>Deg. before</i>	<i>NRS before</i>	<i>Deg. after</i>	<i>NRS after</i>
Flexion	65°	3	<b>70°</b>	<b>0</b>
Extension	60°	2	<b>70°</b>	<b>0</b>
Radial	20°	0	20°	0
Ulnar	30°	0	<b>45°</b>	0
Pronation	90°	0	90°	0
Supination	40°	4	<b>45°</b>	<b>1</b>

**Child 3.** The child 3 is a 9 years old child with JIA and joint involvement of the right and left wrists. The framework was installed on the patient’s computer and the therapist generated custom game levels taking into account the higher difficulty in performing flexion and extension of the right wrist and flexion, extension, ulnar deviation, radial deviation and supination of the left wrist. The exercises in the games involve one hand per time, so the therapist specified to the child which of the two hands to use for each exercise assigned. The therapist could monitor if the child used the suggested hand in the therapist application.

From the final interview it emerged that the child used the video games constantly under the supervision of the mother for a total of 4/5 weekly sessions lasting 15/20 minutes per session.

The mother in final interview reported that both the child and the parent have positively accepted the video game proposal as home support for rehabilitation. The only negative note of the video games was on a technical level, since some times the video game stopped (probably due to the Leap Motion that did not detected the hand). The patient specified that the “Shooting Gallery” game was the easiest, while the most difficult was “Alien Invasion”.

“Table. VI” shows ROM active joint test and NRS results of the right wrist. From the results of the initial and final

ROM active joint tests it emerges that the pain disappeared from the right wrist for all movements with the exception of extension and ulnar deviation which remained 1. The ROM test of in flexion, ulnar deviation and pronation resulted in a joint improvement for only 5 degrees, while in extension there is an increase of 10 degrees.

“Table. VIII” shows ROM active joint test and NRS results of the left wrist. On the left wrist the pain significantly reduced when performing all the movements, in particular in radial deviation and supination. There is an increase of 20 degrees in flexion, 10 degrees in supination and 5 degrees in radial and ulnar deviation, however pronation worsened by 10 degrees, probably the child performed less exercises on pronation with respect to others, but it will be deepened with further studies. There is no improvement in extension.

“Table. VII” and “Table. IX” shows respectively ROM passive joint test results of right wrist and left wrist. The ROM passive joint tests resulted in normal values the first and the last session, no differences were observed. The pain symptoms of the right wrist reduced, passing from NRS 2 to 0. In the left wrist the pain remained 2 in flexion, the pain in supination increased from 0 to 1.

From the Jamar questionnaire it emerges that the patient had an improvement in the quality of life: at the first evaluation the child had difficulties in carrying out school activities, in being together with the peers, he/she had difficulty taking care of himself/herself. The child complained of pain during the day because of the illness, and he/she felt dissatisfied and he/she felt nervous or sad. In the final evaluation it emerges that these difficulties encountered every day or often have not been found anymore. Even the current state of health, the pain and the level of disease improved despite the initial score itself being positive.

The Abilhand questionnaire shows improvements in carrying out activities of daily life that in the first evaluation the patient had assessed as difficult to perform, while in the last evaluation they were reported as easy. For example he/she is now able to turn a key in the lock, close an automatic button, write a sentence, open a jar, cut meat and open a packet of chips.

From the CHAQ questionnaire the therapist observed improvements in the activities of daily life, in fact from the last evaluation the patient reported that he/she was able to dress independently without difficulty, to wash him/her hair, to cut him/her fingernails and to pull a heavy object down from a shelf. The pain score also improved from 20/100 to 5/100, the the global evaluation got better from 35/100 to 5/100, and consequently the total score improved from 1.17/3 to 0.17/3.

#### IV. CONCLUSION AND FUTURE WORK

The goal of our work is to evaluate the V-Arcade framework. We recruited three children with JIA, aged between 9 and 13 years old, that performed upper limbs rehabilitation exercises using the framework and the Leap Motion Controller. The overall satisfaction showed that children positively accepted to use the serious games at home, and that it was perceived

TABLE VI

TABLE OF ROM ACTIVE AND PAIN NRS OF RIGHT WRIST OF CHILD 3 BEFORE AND AFTER THE INTERVENTION, THE VALUES IMPROVED ARE IN BOLD

	<i>Deg. before</i>	<i>NRS before</i>	<i>Deg. after</i>	<i>NRS after</i>
Flexion	70°	2	<b>75°</b>	<b>0</b>
Extension	50°	3	<b>60°</b>	<b>1</b>
Radial	20°	2	20°	<b>0</b>
Ulnar	35°	2	<b>40°</b>	<b>1</b>
Pronation	80°	2	<b>85°</b>	<b>0</b>
Supination	80°	2	35°	<b>0</b>

TABLE VII

TABLE OF ROM PASSIVE AND PAIN NRS OF RIGHT WRIST OF CHILD 3 BEFORE AND AFTER THE INTERVENTION, THE VALUES IMPROVED ARE IN BOLD

	<i>Deg. before</i>	<i>NRS before</i>	<i>Deg. after</i>	<i>NRS after</i>
Flexion	90°	2	90°	<b>0</b>
Extension	70°	2	70°	<b>0</b>
Radial	20°	2	20°	<b>0</b>
Ulnar	35°	2	35	<b>0</b>
Pronation	90°	2	90°	<b>0</b>
Supination	80°	2	80	<b>0</b>

TABLE VIII

TABLE OF ROM ACTIVE AND PAIN NRS OF LEFT WRIST OF CHILD 3 BEFORE AND AFTER THE INTERVENTION, THE VALUES IMPROVED ARE IN BOLD, THE VALUES GOT WORSE ARE UNDELINED

	<i>Deg. before</i>	<i>NRS before</i>	<i>Deg. after</i>	<i>NRS after</i>
Flexion	55°	2	<b>75°</b>	<b>1</b>
Extension	60°	3	60°	<b>2</b>
Radial	15°	3	<b>20°</b>	<b>0</b>
Ulnar	30°	2	<b>35°</b>	2
Pronation	90°	2	<u>80°</u>	<b>0</b>
Supination	70°	3	<b>80°</b>	<b>0</b>

TABLE IX

TABLE OF ROM PASSIVE AND PAIN NRS OF LEFT WRIST OF CHILD 3 BEFORE AND AFTER THE INTERVENTION, THE VALUES IMPROVED ARE IN BOLD, THE VALUES GOT WORSE ARE UNDELINED

	<i>Deg. before</i>	<i>NRS before</i>	<i>Deg. after</i>	<i>NRS after</i>
Flexion	90°	2	90°	2
Extension	70°	0	70°	0
Radial	20°	0	20°	0
Ulnar	35°	0	35°	0
Pronation	90°	0	90°	0
Supination	80°	0	80°	<u>1</u>

by the children and their parents as a good home treatment solution. In addition all the children performed the exercises with dedication, almost every day, and they perceived the serious games as effective, it is significant to notice that Child 1 after playing with the serious games started writing again without the protective band, that he/she previously needed to use. The active and passive ROM tests scores of children improved after the intervention, as well as the pain caused by the disease was reduced. Even when the therapist observed no improvement in ROM, in all cases parents and children reported a significant improvement in quality of life. All

the children reported being able to do new tasks, such as opening a jar, which they previously found difficult, and the children reported an increase in self-confidence, which led to an improvement in good feelings, as well as improvement of their relationship with their peers. Future enhancements to the V-Arcade framework include developing more serious games to offer a wider range of games, each covering multiple physiotherapy exercises, to ensure variety. In addition, the framework can be extended with new serious games to support new exercises with the Leap Motion Controller, for instance to support finger rehabilitation, or new exercises for upper limbs that exploit different input devices as RGB-D camera for body tracking.

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