Interactive System Using Myoelectric Muscle Sensors for the Strengthening Upper Limbs in Children

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Abstract. This work presents a system for strengthening upper limbs in children through an interactive videogame system and the use of myoelectric muscle sensors. The system allows the acquisition of myoelectric signals taken by electrodes placed in the muscles of interest so they are sent to the computer to be visualized in the virtual interface. Several virtual interfaces were developed in the Unity 3D graphical engine in which the degree of difficulty of the videogame can be selected as well as the muscle affectation and the duration of the repetitions of each exercise. User personal data is stored in a data sheet. The data transmission is carried out using Bluetooth wireless technology in charge of establishing a reliable and real-time communication. Tests were performed on 5 users (3 boys and 2 girls) with ages between 6 to 12 years, and the SUS usability test was applied with results (84.5 ± 0.62), which allows to determine that the system has a good acceptance to be used in muscle strengthening.

Keywords: Muscle strengthening, Interactive System, Myoelectric muscle Sensor, Unity 3D.

1 Introduction

Disability in children leads to problems in health, education, social relation and economy as indicated by the World Health Organization (WHO) [1]. In childhood, muscle strengthening and the development of motor skills are decisive to carry out activities in their daily lives. Through this process the child can learn about their environment so, as a consequence, every motor skill plays a fundamental role in the intelligence development [2]. With the growth, every child is reaching achievements in their development, reflected in skills which are done according to their age [3]. The increase in muscular strength and motor skills depend on the physical and psychological properties of the child. Additionally, factors such as tasks difficulty, the possibilities and opportunities of the environment are involved [4].

Studies on physical rehabilitation include people with muscle diseases (myopathy), balance problems, cerebrovascular accidents (CVA), cerebral palsy (CP), spasticity and others [5-7]. In this type of research, several devices have been included that improve the user interaction with a virtual system. One of the main areas of incursion of these kind of devices is medicine as an assistance system of rehabilitation and strengthening oriented to different parts of the body, in which movement is its fundamental basis of development [8,9]. Validity has been demonstrated using haptic devices and feedback of forces together with virtual environments to improve motor skills [10,11].

Innovation in rehabilitation and strengthening systems includes methods composed of sensory devices and virtual systems to support virtual rehabilitation processes. These types of elements are integrated into different systems for manipulating them by analyzing the electrical impulses generated during muscle activities [12,13]. They also participate in studies for the development of effective tools for the treatment of upper and lower extremities. [14-16] In addition, these devices have participated along with virtual systems in the control and effective simulation of prostheses [17].

The inclusion of sensors that measure muscle electrical activity allows the generation of different prototypes and applications associated with the strengthening of upper limbs to analyze problems of mobility, coordination, rigidity and muscle weakness [18]. The fusion with virtual environments forms therapy exercises in friendly, entertaining and immersive environments, turning a repetitive therapy into an interactive training program thus promoting sustained attention and increasing motivation. [19]

Interactive systems that use virtual interfaces represents a great support in the treatment of users with motor problems. Virtual environments provide a motivational system for the user to continue treatment consecutively so, it becomes a distraction for the discomfort caused by disabilities [20-22]. Therefore, these virtual environments provide rehabilitation systems of high relevance and degree of satisfaction that under medical experience demonstrate that the evaluation of the strength and mobility of the isolated muscles of the upper limbs can be useful and collaterally the child can recover from an injury, and thus achieve greater autonomy [10].

Due to different factors, users who suffer from problems in their upper limbs have less ability to explore different environments, social interact and a lower life quality. It means that these disorders cause them to be considered less able than other social groups, preventing them from demonstrating their abilities [23]. Thus to help them, users need to follow a treatment, but in most cases it requires the presence of a professional expert in physical therapy, which means a high-cost and long-term investment [24]. A lot of virtual systems have an increased cost because they use virtual reality headsets along with unnecessary wiring for the integration of other devices and computers [26]. Therefore, this work proposes the development of a low cost interactive system using application boards and economic sensors where the communication is performed wirelessly by using the Bluetooth protocol for the strengthening of upper extremities in children through the use of interactive and controlled videogames through the electrical impulses of the muscles coming from 4 myoelectric muscle sensors placed in the arm and forearm.

This work is divided in 5 sections where the introduction is included. Section II presents the system methodology, the way of use of the system is presented in section III. Section IV presents evaluations and results, and finally, conclusions and future works are detailed in section V.

2 System Methodology

This section explains the proposal system stages. Fig. 1 shows the block diagram of the whole system.

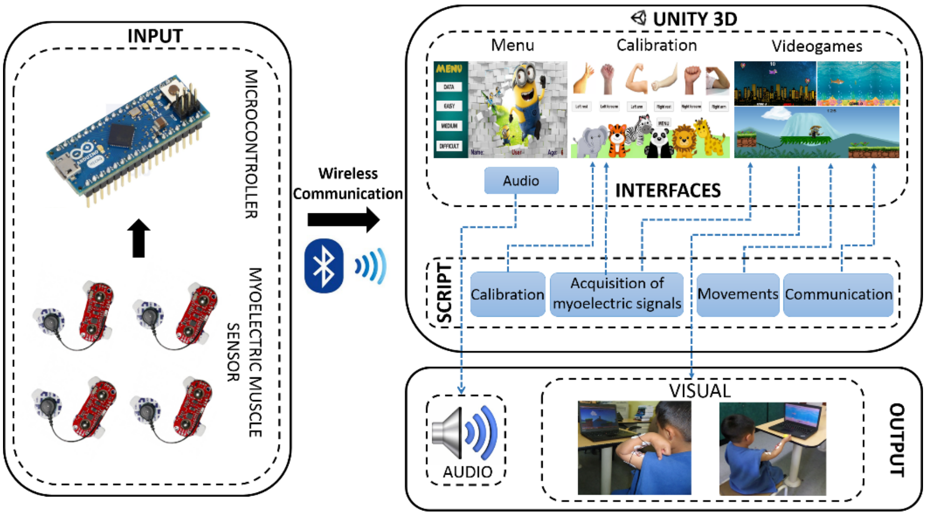
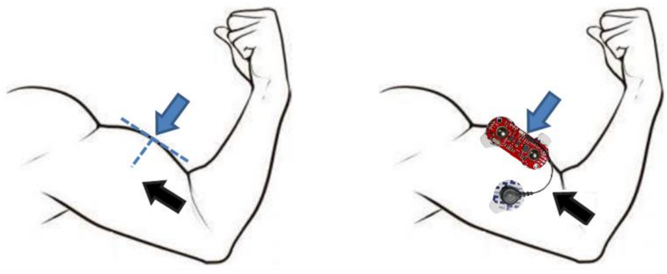


Fig. 1. Block diagram of the strengthening system.

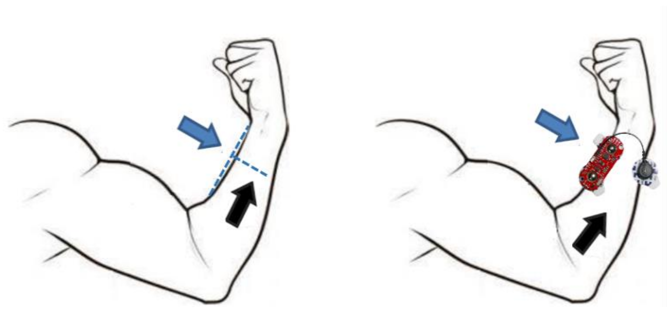
2.1 Signal Acquisition

The contraction and relaxation movements of the arm and forearm muscles from the right and left upper extremities are acquired by myoelectric sensors, these signals contain the information of the muscular activity with the electrical potential generated by the cells of the fiber muscle at a certain time; they are received and conditioned in a micro Arduino board that sends data wirelessly to the computer.

To place the sensors on the skin, disposable surface electrodes are used, which are connected to the sensor through clips facilitating their placement, two of these electrodes are for acquisition of the signals and the third is used as a reference. The position and orientation of the sensors and electrodes have a great effect on the strength and quality of the signal, these must be placed in the center of the muscle and aligned with the orientation of the muscle fibers as seen in Fig. 2a) and 2b). Placing the sensor in other positions means reducing the strength and quality of the myoelectric signal.



a)



b)

Fig. 2. Sensor positioning: a) arm, b) forearm.

Myoelectric signals provided by sensors are stored in a string data and separated by commas in the Arduino software, these data are sent to the computer through Bluetooth communication. Every string data is separated in the graphic engine Unity 3D through arrays and comparison algorithms programed in the Virtual Studio software so they are can be used for give movement to the virtual interface objects.

This communication type sends real-time data, delete the cables use and provide an ergonomic system for the user.

2.2 Scripts Development

In this section, the Visual Studio software organizes and interprets the received information and through the different scripts the interaction between the virtual objects is done to fulfill the activities proposed in each videogame, these scripts are programmed to respond immediately according to the movements of the objects and the user. In Fig. 3, a flow chart of the management of the received information is shown.

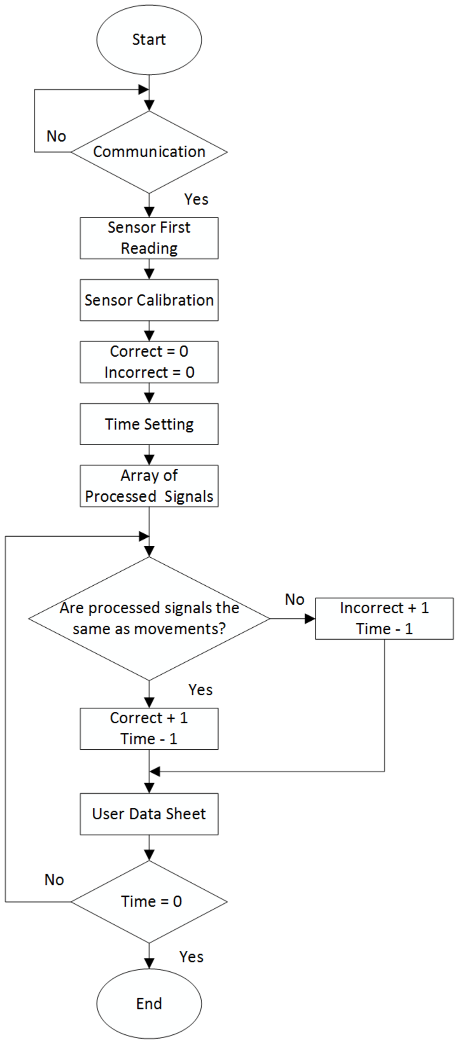


Fig. 3. Flow diagram of the data management.

2.3 Design of Interactive Interface

The virtual interfaces have been developed with the Unity 3D graphics engine to improve and give more reliability to the system, these interfaces give the user interaction between the real world and the virtual world with great visual and auditory appeal because of the combination of hardware and software. These interfaces include interactive videogames to dodge obstacles, collect coins and generate jumps on platforms, where the user first observes and then generates the movements recommended by the therapist based on their injury.

The application contains an interface where you can calibrate each of the sensors, it has images that indicate the movement to be made as seen in Fig. 4. This allows each user to obtain and save a range of minimum and maximum values depending on the strength and physical conditions they have to facilitate their movements.

Fig. 4. Sensor calibration interface.

This application also has a menu that allows the user to record data such as name, age and execution time for each videogame, from 30 to 180 seconds and, select the level of difficulty that can be easy, medium or hard, as shown in Fig. 5.

a) b)

Fig. 5. a) Menu, b) User data.

The easy level (first videogame) presents a virtual city, where the user must avoid balloons. The interface provides the time and the number of successes and mistakes made during the game (as shown in Fig 6a). In addition, these errors are indicated by a collision audio.

The medium level (second videogame) is an underwater environment where the shark must collect coins. The interface specifies the time and the number of collected coins, in this level an audio is displayed each time a coin has been collected (see Fig. 6b).

The hard level (last videogame) has a character that must jump between mobile platforms and platforms that fall. The interface provides information about the execution time (see Fig. 6c). The system delivers important data at the end of each videogame for further analysis.

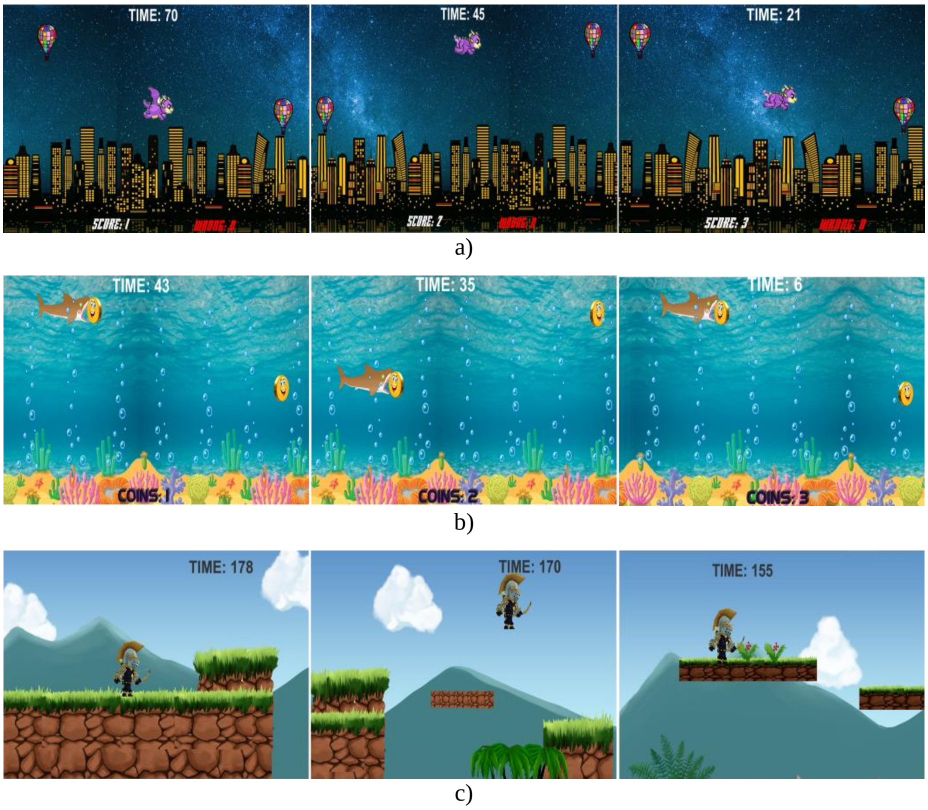


Fig. 6. a) Easy level, b) Medium level, c) Hard level.

3 Interactive System Way of Use

To use the interactive system, users must place the vest and sensors in the foreseen zones. For the correct placement of the stuff mentioned above it is suggested to: i) clean the skin in the area where the sensors will be located to eliminate impurities, and ii) fit the electrodes in the sensor connectors and place them in the desired muscle. To place the sensor, it must be taken into account that two of the connected electrodes are in the center of the muscle and the other is located in the posterior part of the muscle. Then the back of the electrodes should be peeled off to expose the adhesive and apply it to the skin, the reference electrode should not be placed near the target muscle.

In the developed interface, each sensor must be calibrated to obtain the initial movement values of each upper extremity of the user. In the main screen you select the level of the videogame you want to play.

For the first videogame, slight movements of the left and right arms are required alternately and repetitively. For the second videogame, several series of opening and closing of the hands must be performed, while the third videogame will be a combination of precise and coordinated exercises of contraction and relaxation of the arms and hands muscles.

In the proposed system, the therapist is the one in charge of adjusting the time of each videogame to perform the indicated exercises. The system delivers a data sheet indicating the number of successes and errors, with these data the therapist can perform a controlled follow-up to the user and, in addition, there is an auditory and visual feedback that allows a better cognitive development.

Is important to remember that the first strengthening session is the one and only which has to be supervised by the therapist, the other ones could be performed from the user home without any face-to-face assistance and with a more flexible schedule for him. Travel costs will also be considerable reduced because there is no need to move continuously to a rehabilitation center to take every session and pay for it but, instead users can do the rehabilitation with close relatives making it more confidence for the patient when strengthening his upper limbs.

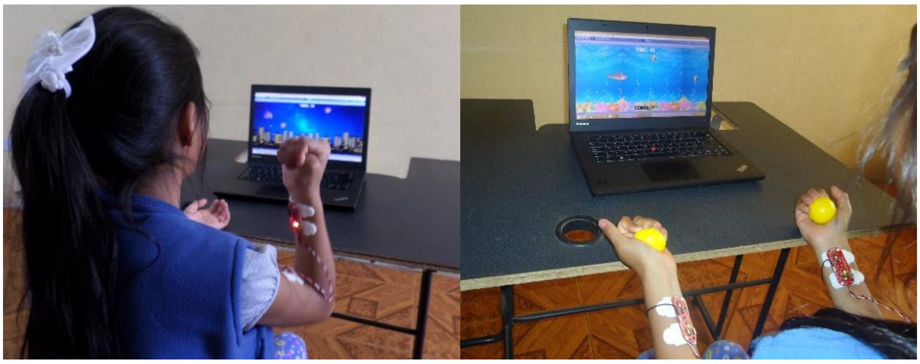
After many home sessions, it is necessary to visit the therapist in order to check the user progress where he can go forward to a more intensive treatment or gradually reduce the intense of every session because of a good response of his limbs.

4 Tests and Results

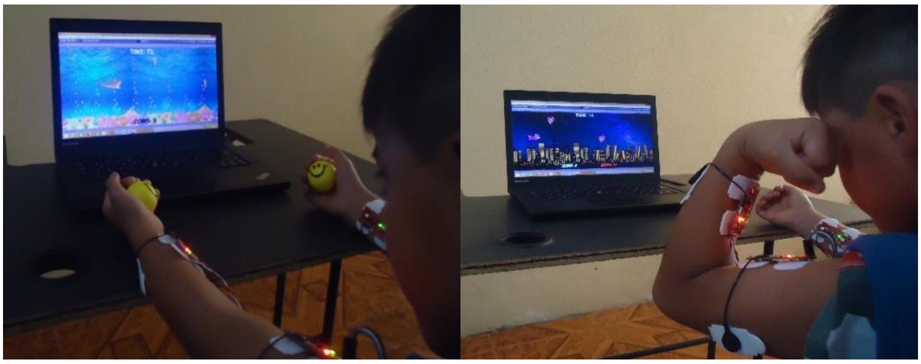
4.1 Test

The system was tested by 5 users (3 boys and 2 girls) with ages between 6 and 12 years. Users receive information on the functionality of the system through a brief explanation, then they use the interactive system according to the procedure detailed in section 3. The following inclusion criterion was used: children over 5 years and under 13 years of age and having some muscular disease (myopathy). The exclusion criterion was: to have visual and auditive deficiency. In Fig. 7 the tests carried out by the users in the interactive system are presented.

a)



b)



c)

Fig. 7. Tests made in the Interactive system.

4.2 Results

At the end of each videogame, the results are displayed in a text file that is automatically generated with the user's name as shown in Fig. 8.

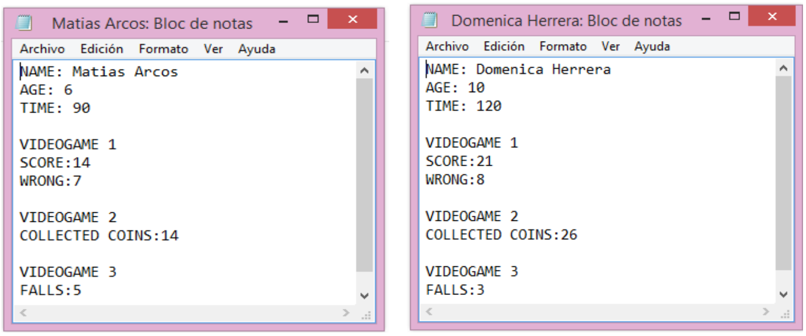


Fig. 8. Users text file.

In addition, the SUS evaluation test, also known as the System Usability Scale created by John Brooke in 1986 [25], was applied to users. It is a reliable, simple and precise tool that allows determining the user's acceptance. Information has a great importance to determine safety, sensation and discomfort when using an interactive system. The questions posed to users about the interactive system and the results of the usability test are presented in Table 1.

Table 1. SUS results

Question	Result (N = 5)	
	Mean	SD
1. I think I would like to use this Virtual Reality system frequently	4.2	0.75
2. I found the Virtual Reality system to be unnecessarily complex	2	0.63
3. I thought that the Virtual Reality system was easy to use	4.4	0.8
4. I think I would need the support of a technical person to be able to use this Virtual Reality system	2.6	0.49
5. I found that the various functions in this Virtual Reality System were well integrated	4.4	0.8
6. I thought there was too much inconsistency in this Virtual Reality system	1.6	0.49
7. I would imagine that most people would learn to use this Virtual Reality system very quickly	4.6	0.49
8. I found the Virtual Reality system to be very cumbersome to use	1.6	0.49
9. I felt very confident using the Virtual Reality system	4.6	0.49
10. I needed to learn a lot of things before I could get going with this Virtual Reality system	2.2	0.75

GLOBAL SCORE(total)	84.5	0.62

The result of the SUS test carried out by five users after using the interactive system is: (84.5 ± 0.62). If the result obtained is greater than 68%, the system responds to an acceptable usability for muscle strengthening.

The present work is focused in developing videogames with the use of the Unity 3D Software, also we measure its usability in children who have different pathology which doesn't allow them to perform normal movements of the upper limbs; hence, there are no experimental results which show the force increasing of the affected limb.

5 Conclusions and Future Work

An interactive system for strengthening upper extremities using myoelectric sensors and Bluetooth wireless communication was developed, the virtual interfaces are designed in the Unity 3D graphics engine and are made up of three interactive videogames that allow the generation of movements such as arms contraction and relaxation and the opening and closing of hands. In addition, the system has visual and auditory feedback which provides the user a better cognitive development.
This is an innovative and alternative system to the classic strengthening techniques and causes great interest in users when developing motor skills to achieve greater autonomy. The results obtained in the SUS questionnaire indicate that the system has an acceptance to be used in the strengthening of upper limbs.

As future work, the aim is to design a control system capable of acquiring and processing the myoelectric signals produced by the forearm of a child with the purpose of controlling a hand-held myoelectric prosthesis.

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References

1. World Health Organization: World report on disability (2011).
2. Feldman, H.M., Chaves-Gnecco, D., Hofkosh, D.: Developmental-behavioral pedia-trics. In: Zitelli, B.J., McIntire S.C., Norwalk A.J. (eds.) Atlas of Pediatric Diagnosis. 6th ed. Philadelphia, PA: Elsevier Saunders, chap 3, (2012).
3. Newell, K.: Constraints on the development of coordination. In Wade, M.G., Whiting, H.T. (eds.): Motor Development in Children: Aspects of Coordination and Control. Dordrecht, Nijhoff (1986).
4. Kakebeeke, T. H., Lanzi, S., Zysset, A. E., Arhab, A., Messerli-Bürgy, N., Stuelb, K., & Munsch, S.: Association between Body Composition and Motor Performance in Preschool Children. Obesity Facts, 10(5), 420-431, (2017).
5. S. A. Pérez, J. A. G. Gómez, E. Olmo y A. M. Soler, «A Virtual Fine Rehabilitation System for Children with Cerebral Palsy: Assesment of the Usability of a Low-Cost System,»

Recent Advances in Information Systems and Technologies, Advances in Intelligent Systems and Computing, pp. 619-627, (2017).
6. V. Booth, T. Masud, L. Connell y F. Bath-Hextall, «The effectiveness of virtual reality interventions in improving balance in adults with impaired balance compared with standard or no treatment: a systematic review and meta-analysis,» Clinical Rehabilitation, pp. 419-431, (2014).
7. B. Bonnechère, Serious Games in Physical Rehabilitation: From Theory to Practice, Brussels: Springer, (2017).
8. S. F. Atashzar, M. Shahbazi, O. Samotus, M. Tavakoli, M. S. Jog and R. V. Patel, «Characterization of Upper-Limb Pathological Tremors: Application to Design of an Augmented Haptic Rehabilitation System.» In IEEE Journal of Selected Topics in Signal Processing, vol. 10, no. 5, pp. 888-903, Aug. (2016).
9. T. T. Jiang, Z. Q. Qian, Y. Lin, Z. M. Bi, Y. F. Liu and W. J. Zhang.: Analysis of virtual environment haptic robotic systems for a rehabilitation of post-stroke patients, In: 2017 IEEE International Conference on Industrial Technology (ICIT), pp. 738-742, IEEE, Toronto, ON, Canada (2017).
10. V. Andaluz, P. Salazar, M. Escudero, C. Bustamante, M. Silva y Q. Washington.: Virtual Reality Integration with Force Feedback in Upper Limb Rehabilitation, Advances in Visual Computing, pp. 259–268, (2016).
11. V. Andaluz, P. Cartagena, J. Naranjo, J. Agreda y S. López.: Virtual Environments for Motor Fine Skills Rehabilitation with Force Feedback, Augmented Reality, Virtual Reality, and Computer Graphics, pp. 94–105, (2017).
12. W.-S. Kim.: Development and Validation of Assessment Tools Using Robotic and Virtual Reality Technologies in Stroke Rehabilitation, Seoul, August (2016).
13. D. J. Berger y A. d'Avella.: Towards a Myoelectrically Controlled Virtual Reality Interface for Synergy-Based Stroke Rehabilitation, Converging Clinical and Engineering Research, pp. 965-969, (2017).
14. L. A. Bolgla, M. F. Cruz, L. H. Roberts, A. M. Buice y T. S. Pou, «Relative electromyographic activity in trunk, hip, and knee muscles during unilateral weight bearing exercises: Implications for rehabilitation,» Physiotherapy Theory and Practice, (2016).
15. S. Dorsch, L. Ada y C. G. Canning, «EMG-triggered electrical stimulation is a feasible intervention to apply to multiple arm muscles in people early after stroke, but does not improve strength and activity more than usual therapy: a randomized feasibility trial,» Clinical Rehabilitation, pp. 482-490, (2014).
16. R. S. Calabrò, A. Naro, M. Russo, A. Leo y R. D. Luca, «The role of virtual reality in improving motor performance as revealed by EEG: a randomized clinical trial,» Journal of NeuroEngineering and Rehabilitation, (2017).
17. D. Blana, T. Kyriacou, J. M.Lambrecht y E. K.Chadwick, «Feasibility of using combined EMG and kinematic signals for prosthesis control: A simulation study using a virtual reality environment,» Journal of Electromyography and Kinesiology, pp. 21-27, (2016).
18. M. Hoda, B. Hafidh and A. El Saddik.: Haptic glove for finger rehabilitation, pp. 1-6. 2015 IEEE International Conference on Multimedia & Expo Workshops (ICMEW), Turin (2015).
19. L. Connelly, Y. Jia, M. L. Toro, M. E. Stoykov, R. V. Kenyon and D. G. Kamper.: A Pneumatic Glove and Immersive Virtual Reality Environment for Hand Rehabilitative Training After Stroke. In IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 18, no. 5, pp. 551-559, Oct (2010).
20. M. K. Gunel, O. K. Kara, C. Ozal y D. Turker.: Virtual Reality in Rehabilitation of Children with, Ankara: INTECH (2014).

21. A. S. Won, J. Bailey, J. Bailenson, C. Tataru y I. A. Yoon.: Immersive Virtual Reality for-Pediatric Pain, Children, (2017).
22. T. Garner.: Applications of Virtual Reality, Echoes of Other Worlds: Sound In Virtual Reality, pp. 299-361, (2018).
23. R. J. M. Lemmens, H. A. M. Seelen, A. A. A. Timmermans, M. L. A. P. Schnackers, A. Eerden, R. J. E. M. Smeets, Y. J. M. Janssen-Potten.: To What Extent Can Arm–Hand Skill Performance—of Both Healthy Adults and Children—Be Recorded Reliably Using Multiple Bodily Worn Sensor Devices?. In IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 23, no. 4, pp. 581-590, July (2015).
24. X. Wen, F. Duan, Y. Yu, J. T. C. Tan, X. Cheng.: Design of a multi-functional system based on virtual reality for stroke rehabilitation. In: 11th World Congress on Intelligent Control and Automation, pp. 2412–2417. IEEE, Shenyang, China (2014).
25. Z. Sharfina, H. B. Santoso.: An Indonesian adaptation of the System Usability Scale (SUS). In: 2016 International Conference on Advanced Computer Science and Information Systems (ICACSIS), pp. 145-148, IEEE, Malang, Indonesia (2016).
26. Jannink, M. J., Van Der Wilden, G. J., Navis, D. W., Visser, G., Gussinklo, J., & Ijzerman, M. A low-cost video game applied for training of upper extremity function in children with cerebral palsy: a pilot study. Cyberpsychology & behavior, 11(1), 27-32, (2008).