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Video-game based therapy performed by children with cerebral palsy: a cross-over randomized controlled trial and a cross-sectional quantitative measure of physical activity

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Background. **Previous studies reported controversial results about the efficacy of video-game based therapy (VGT) in improving neurorehabilitation outcomes in children with cerebral palsy (CP).**
Aim. **Primary aim was to investigate the effectiveness of VGT with respect to conventional therapy (CT) in improving upper limb motor outcomes in a group of children with CP. Secondary aim was to quantify if VGT leads children to perform a higher number of movements.**
Design. **A cross-over randomized controlled trial (RCT) for investigating the primary aim and a cross-sectional study for investigating the secondary aim of this study.**
Settings. **Outpatients.**
Population. **Inclusion criteria: clinical diagnosis of CP, age between 4 and 14 years, level of GMFC between I and IV. Exclusion criteria: QI<35, severe comorbidities, incapacity to stand even with an external support.**
Methods. **Twenty-two children with CP (6.89±1.91-year old) were enrolled in a cross-over RCT with 16 sessions of VGT (using Xbox with Kinect device) and then 16 of CT or *vice versa*. Upper limb functioning was assessed using the Quality of Upper Extremities Skills Test (QUEST) and hand abilities using Abilhand-kids score. According to the secondary aim of this study a secondary cross-sectional study has been performed. Eight children with CP (6.50±1.60-year old) were enrolled into a trial in which five wireless triaxial accelerometers were positioned on their forearms, legs and trunk for quantifying the physical activity during VGT *vs.* CT.**
Results. **QUEST scores significantly improved only after VGT (P=0.003), and not after CT (P=0.056). The reverse occurred for Abilhand-kids scores (P=0.165 *vs.* P=0.013, respectively). Quantity of performed movements was three times higher in VGT than in CT (+198%, P=0.027).**
Conclusion. **VGT resulted effective in improving the motor functions of upper limb extremities in children with CP, conceivably for the increased quantity of limb movements, but failed in improving the manual abilities for performing activities of daily living which benefited more from CT.**
Clinical Rehabilitation Impact. **VGT performed using the X-Box with Kinect device could enhance the number of upper limb movements in children with CP during rehabilitation and in turn improving upper limb motor skills, but CT remained superior for improving performances in manual activities of daily living.**

KEY WORDS: Cerebral palsy - Neurorehabilitation - Virtual reality exposure therapy - Children.

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Cerebral palsy (CP) is the most common cause of physical disability in childhood with more than 2 cases in 1000 live births.[1] CP is not an aetiological diagnosis, but rather a clinical descriptive term

which indicates a group of developmental disorders mainly related to movement and posture.[2] These disorders are attributed to non-progressive disturbances that occurred in the developing fetal or neonatal brain.[3] Disability and development should be considered in these children as parallel processes, because limitations in the motor activity of children affected by CP are not the consequence of a loss of ability, but of the failure into acquiring the appropriate motor schemas caused by the arrested normal brain maturation.

Intensive, task-oriented and long-lasting training is necessary to efficiently drive neuroplastic changes towards the development of motor and cognitive abilities.[4] Long and repetitive treatment can be boring for children, whereas it is well know the importance of an active participation of subjects in their own neurorehabilitation for increasing motor and cognitive outcomes.[5-7]

For these reasons, there is a growing interest in video-game based therapies (VGT) to increase the amount of movement performed by children with a high level of participation during therapeutic sessions.[8] In fact, VGT has the potential to improve effectiveness of neurorehabilitation due to: 1) low-cost of commercial consoles; 2) possibility to perform repetitions of functional tasks; 3) adaptability of the virtual environment (therapist can select the game and the difficulty level; home-made game can sometimes be developed with specific therapeutic goals); 4) enhanced stimulation through rich sensory (visual, auditory and sometimes tactile stimuli) and cognitive feedback (events and scores); and 5) capacity to boost the subject's motivation.[9, 10] Despite all these potentialities, there is poor evidence that therapeutic outcomes of VGT are superior to those of conventional therapy (CT).[11]

The results obtained for children with CP are somewhat similar to those obtained with the use of virtual reality in patients with stroke, in which the relatively poor evidence about the superior effectiveness of video-game based rehabilitation led Crosbie *et al.* to state that "virtual reality in stroke rehabilitation is still more virtual than real".[12] However, interest about commercial video-game consoles, especially motivated by their potential to increase the active participation of children in their neurorehabilitation, remains high.

As suggested by Morone *et al.*[13, 14] with regard to robotic rehabilitation, this study does not tackle the scientific question "*is this device effective?*", rather it aims to find "*who can benefit from this device?*" and "*in what could this device be effective?*".

The primary aim of this study was to investigate the effectiveness on upper limb motor outcomes of a video-game based training in respect of CT, using the commercial-console Xbox (Sony) with the Kinect motion capture device. The secondary aim was to quantify if the VGT led children to perform an increased amount of movement, as hypothesized in several previous studies but not yet measured. Two different protocols were used to achieve the two aims: a cross-over randomized trial and a cross-sectional experimental study.

Materials and methods

Both the following trials were designed in accordance with the Declaration of Helsinki and following amendments, obtaining the approval of the local ethics committee. Informed consent of either parents or legal guardian was obtained.

Cross-over randomized controlled trial VGT vs. CT

Twenty-two children, consecutively admitted to the rehabilitation services of Fondazione Santa Lucia, in a period of 1-year were enrolled in the study if matching the following inclusion criteria: clinical diagnosis of CP, level of GMFC between I and IV, age between 4 and 14 years. Potential participants were excluded if they showed: incapacity to understand the instructions and to execute the task (Intelligence Quotient lower than 35), severe comorbidities, incapacity to stand even with an external support. Only children without Xbox with Kinect at home have been enrolled for avoiding a possible contamination effect.

Subjects were randomly assigned to one of two groups, VC (pre video-game, post conventional training) or CV (pre conventional, post video-game training). Their usual therapy (aside from this study) consisted of two 1-hour sessions every week. In addition to these sessions they performed 16 30 minutes sessions, twice a week for 8 weeks.

During the CT period participants performed a neurodevelopmental treatment based on Bobath concepts.[15] The treatment was tailored on their individual rehabilitative goals, and designed for promoting neuromotor learning, for favoring a more

functional muscle tone, for improving postural alignment by specific handling techniques, and for favoring a better active participation and practice of specific, relevant, functional skills.[16, 17] At the same time, treatment also involved task-oriented exercises encouraging child in acquiring motor skills for independency in daily living. Similarly to VGT, also CT was performed in ludic form, involving the child in specific games for enhancing his/her compliance and participation to rehabilitative session.

During VGT period they played a video-game of the console X-box using the Kinect device for motion capture. The selection of the Xbox console (Microsoft) was based on to combine it with the Kinect, a full-body 3D motion capture system enabling the user to control the avatar and to interact with the virtual environment without the need for a game controller, through a natural user interface mainly using gestures and body movements. Specific games were selected by their therapist to reproduce similar motor exercises requested in the CT.

Video-games were selected on the basis of the therapeutic approach of improving: 1) the active range of motion of the paretic upper limb; 2) the control of upper limb joints; 3) the visuo-manual coordination; 4) the sensorial and proprioceptive feedback of the position and orientation of upper limb segments; 5) the management of simultaneous multiple stimuli in accordance to a neurocognitive approach in developing correct motor strategies. According to these aims we have selected six games. In each session, therapist could choose to use one or more of these games. Three games were included into the Kinect Adventures Package. In "Space pops" the subject is asked to pop bubbles appearing in the virtual environment by touching them. Subject should flap arms for flying around the virtual environment, and put arms back down for descending. In "20.000 Leaks", the child is asked to stop the water from filling the tank by placing a hand, or a foot, or any other body parts over a leak opened on a wall of an underwater glass tank. In "Rally Ball" balls will shoot down a lane towards the avatar, and the child must hit the balls back with a part of body and destroy targets at the end of the lane. Other three games were included into the Kinect Sports Package and were virtual simulation of three sports: boxe and volley mainly (but not only) involving bimanual movements, and bowling in which the child was asked to throw the virtual ball towards the pins with the paretic upper limb.

During VGT the physiotherapist was close to the child, verbally encouraging the child especially in using the affected limb and for avoiding possible falls (no fall events were recorded during treatment). Risk of epilepsy was avoided by the use of conventional monitor using technology of light emitting diode at 100Hz, the same frequency at which these children watch television at their houses.

A team of six therapists (including physiotherapists and therapists of childhood neuro- and psycho-motricity) has been involved in this study and they have preliminary been trained for optimizing the use of VGT and CT with respect to the planned neurorehabilitative aim. Both the interventions (CT and VGT) were aimed at favoring the same functional movements.

Assessment of outcomes was performed at the beginning (T0) and at the end (T1) of the first phase of treatment, and at the beginning (T2) and at the end (T3) of the second phase, as shown in Figure 1.

The primary outcome measure was the improve-

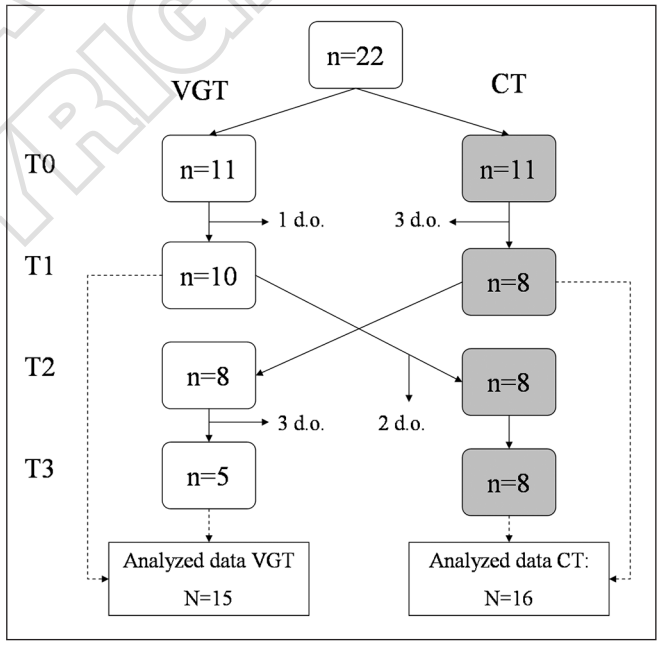

Figure 1.—Consort flow-chart of the study with n indicating the number of subjects performing video-game therapy (VGT) or conventional therapy (CT) in each phase of the study.
d.o.: drop-outs; N: number of subjects who completed at least one of VGT or CT phases.

ment of the quality of upper limb functions, assessed by Quality of Upper Extremities Skills Test (QUEST).[18, 19] QUEST evaluates four domains: upper limb dissociated movements (of shoulder, elbow, wrist and fingers); grasp function, protective upper limb extension and weight bearing. Secondary outcomes were: hand abilities evaluated in terms of Abilhand-kids Score,[20] and visual-motor integration evaluated by Visual-Motor Integration functioning scale (VIM).[21] A trained physical therapist, blind to child allocation, administered QUEST and VIM. Abilhand-kids is a specific tool developed for children with CP, formed by 21 items, mostly bimanual, rated by the parents, for this reason it was not a blind assessment. Wilcoxon signed rank test was used for comparing scores pre and post intervention with an alpha level of significant set at 0.05.

Cross-sectional experimental study: physical activity monitoring during video-game based vs. *conventional rehabilitation*

Eight children (mean age: 6.50±1.60 years, 3 right hemiparesis, 5 left hemiparesis) were involved in the second study. Inclusion and exclusion criteria matched those of the cross-over RTC.

Five wireless triaxial accelerometers (Trigno, Delsys®) were fixed with biadhesive tape on the skin of children on the following segments: posterior part of forearms, posterior part of shanks, and posterior part of lower trunk in correspondence of the centre of mass (L2-L3), as shown in Figure 2.

Acceleration time-courses were recorded during 5 continuous minutes of VGT and 5 minutes of conventional therapy. The root mean square (RMS) of acceleration was computed for each device on the signals, low-pass filtered (2nd order Butterworth, threshold frequency 20Hz) and after the mean substraction for removing the contribution of gravity acceleration (in this case RMS coincides with standard deviation of the signal).[22] The RMSs of trunk were compared between the two conditions by a coupled t-test. For the other four RMS a repeated measure analysis of variance was performed using therapy condition (VGT *vs.* CT), side (affected *vs.* healthy side) and level (upper *vs.* lower limbs) as within subject factors. Threshold of significance was set at 0.05 for all the performed analyses, but post-hoc analyses in which Bonferroni correction was applied.

Figure 2.—Set-up of the physical activity monitoring performed using 5 wearable wireless accelerometers during a VGT-session (only 3 are visible in the picture). The accelerometers were place on the external part of forearms, on the back part of shanks (as shown in the picture), and on the lower part of back trunk in correspondence of L2-L3.

Results

Cross-over randomized controlled trial

Twenty-two children with CP were enrolled in this study and randomized in two groups, VG and CG, of eleven subjects each. The mean age of these children was 6.89±1.91 years, and their mean GMFM-88 was 84.6±19.8%. Four subjects dropped out in the first period (between T0 and T1), 2 in the wash-out phase (between T1 and T2) and 3 in the second period (between T2 and T3). Fifteen participants completed the VGT (10 in the first period and 5 in the second), and 16 completed the CT (8 in each period). The drop-out rate was quite high (9 out of 22=41%), but similar in the two groups (VGT:

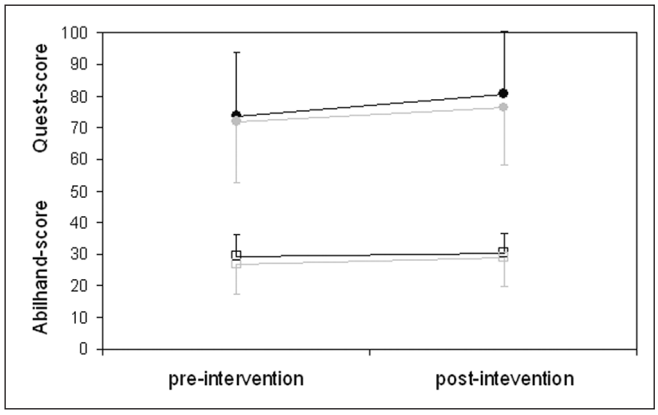

Figure 3.—Mean and standard deviations of Quest-scores (filled circles) and Abilhand-scores (empty squares) pre- and post- intervention for the period with VGT (black) and that with only CT (grey).

4/11=36%; CT: 5/11=45%). The reasons for dropping out were mainly independent by rehabilitative protocols: 3 children changed rehabilitation centres for being closer to their houses, 2 children had familiar problems and definitely stopped rehabilitation, 2 children had measles during training and needed to stop rehabilitation for a long period, and one child had a fracture of wrist occurred out of hospital. Only for one child the reason was quite interconnected with the protocol: he used an external exoskeleton for standing up in front of the kinect. A part of this exoskeleton was broken (out of hospital) confining him for many weeks to wheelchair. Kinect resulted unable to recognize movements of a sitting person.

Figure 3 reports mean and standard deviations of the scores of Quest and Abilhand-kids in the VGT and CT periods. QUEST scores significantly improved in the VGT period (P=0.003, from 76±21 to 81±20), but not in CT (P=0.056). The change in QUEST-score in VGT was mainly due to improvements in grasping (median increment +5%) and upper limb dissociated movements (+3%).

The reverse result occurred for Abilhand-kids scores that significantly improved after CT (P=0.013, from 27±10 to 29±10), but not after VGT (P=0.165). Both these improvements, of about 5 QUEST-points after VGT and of about 2 Abilhand-points achieved the respective minimal clinically important differences reported in literature.[23, 24]

No significant changes were observed in terms of VMI scores, neither in the VGT (P=0.674), nor in the CT (P=0.362) periods.

Physical activity monitoring during VGT vs. *CT*

The quantity of limb performed movements resulted about three times higher during VGT than during conventional therapy (+198±180%). This difference was statistically significant as shown by the results of the analysis of variance (F=10.940, P=0.027). No statistically significant differences were noted between upper and lower limbs (F=0.753, P=0.411). In general, hemiparetic side was moved less than healthy side (-18±8%, F=39.303, P<0.001). We did not find any significant effect of interactions between factors, except between therapy and side (F=7.202, P=0.028). *Post-hoc* analysis revealed that in VGT the paretic side was moved -20±13% less than the other side (P=0.001), while this difference was non significant in CT (-10±28%, P=0.295). The analysis of trunk accelerations showed that the quantity of movements during VGT was about five times higher than that performed during conventional therapy (+394±323%, F=13.193, P=0.007).

Discussion

This study was divided into two parts, a cross-over randomized trial aiming to investigate the effectiveness of a VGT on motor upper limb abilities, and a cross-sectional experimental quantitative monitoring of physical activity performed by children during the VGT *vs.* CT.

The results of the cross-over longitudinal trial showed that VGT was more effective to significantly and clinically improve the quality of upper extremity skills, in particular grasping and dissociated movements, evaluated by QUEST, but CT resulted more effective in improving the manual abilities involved in performing activities of daily living, evaluated by Abilhand.

It should be observed that QUEST is a scale evaluating the capacity of moving upper limbs in children with CP, covering four main domains with most of the items related to dissociated movements of each single upper limb joint, and others related to grasping function, weight bearing and protective extensions.[18, 19] Conversely, Abilhand Scale was developed as a measure of manual ability [20] exploring a representative inventory of manual activities in which a certain degree of dexterity was needed.

These differences imply that QUEST is more focused on the capacity of general movements of hand and upper limb, whereas Abilhand is more focused on activities of daily living.

The results of our experiment on the quantity of performed movements helped in explaining the results of our cross-over longitudinal trial. In fact, the limb movements performed during VGT were about three times those performed during conventional therapy, and it could be the reason of the improvement into the QUEST Score. Finger fine movements were not recorded, but the used videogames were all controlled by gross limb and hand movements, and it could explain the main improvements in grasping and upper limb dissociated movements (mainly practiced for example in bowling and rally ball games, respectively). However, the manual abilities strictly related to activities of daily living seemed to benefit more by fine hand exercising and finger movements typical of CT. It is also possible that the use of other optoelectronic devices, more specifically designed for capturing the movements of hands in respect of the Kinect,[25] as well as specifically developed games reproducing activities of daily living could favour the effect of VGT on performances related to manual ADL.

Our results about an improvement of quality of upper movements after VGT were in line with previous case-reports [26-28] and more extensive studies.[29, 30] The fact that Abilhand-scores did not change was also in line with another study [31] reporting that neither this score, nor the score of Melbourne Assessment of Upper Limb Function changed after VGT for children with CP, while a significant increase of convenience in using hands/arms during performance of daily activities was found (in that study VGT was performed using Nintendo Wii® console).

Luna-Oliva *et al.*[8] reported the results of a study conducted on children with CP, showing that a protocol with VGT performed with Kinect Xbox significantly improved gross motor functions, qualities in daily life activities, reaching and walking abilities, and also hand functions. They evaluated hand functions using the Jebsen-Taylor test. A large observational study [32] reported as Abilhand-kids scale was less sensitive to changes than Jebsen-Taylor test. However, in our study, Abilhand scale highlighted the significant effects of CT and not of VGT. As above stated, probably also the choice of games of VGT is fundamental.

We did not find significant improvements in visual-motor integration function, neither during VGT nor during CT. Unfortunately, comparisons with previous results are limited by the fact that this function was poorly investigated in previous trials involving VGT, whereas further studies should take into account also this aspect.

Despite most of the authors agree in suggesting that the compliance of children with CP increased during VGT, may increase in turn the intensity of rehabilitation and hence the motor outcomes, our study was the first one measuring, using 5 wearable triaxial accelerometers, the quantity of physical activity performed during VGT in respect of CT. As stated above, it is conceivable that the improvements obtained in terms of quality of upper limb movements were related to the higher quantity of movements performed during VGT, in accordance with the principles of the need of task-oriented, repeated and intensive movements during neurorehabilitation.[4] Also our CT included task-oriented exercises, but it resulted significantly less intensive than VGT. Hurkmans *et al.*[33] also suggested for adults of CP the use of video-games for promoting a more active and healthful lifestyle. Robert *et al.*[34] investigated the increase of heart rate in children with CP due to the high quantity of movements hypothesized during VGT, finding that heart rate increases of the same amount in children with CP and those with typical development performing VGT.

The main limitation of our study is the reduced sample size involved into the randomized controlled trial, also due to a high drop-out rate during the entire protocol. The reduced sample size could be a bias especially at the light of the wide variability of age range and clinical features (despite our cross-over designed allowed to perform comparisons within subjects). The high drop-out rate was probably due to the fact that our study was a longitudinal one involving young children. The reasons of dropping-out in fact were not related to the two administered treatments, but for one case: a child needing exoskeleton for standing in front of the Kinect sensor. When the child could not more use that orthosis, he could not perform VGT. Hence, the need of a standing posture is a limit for VGT using Kinect in children unable to stand not even using an external device. Another limit refers to the fact that

Abilhand-kids is a questionnaire filled by parents not blind toward the treatment received by their children. Despite it is an intrinsic limitation of the use of this scale, and hence of our study, we supposed that parents did not have any interests in preferring a treatment more the other one, and hence we hoped they filled the questionnaire in the most objective (not-biased) way as possible. Further, despite the primary aim of this study was to investigate the effectiveness on upper limb motor outcomes of a video-game based training, another limit could be considered the absence of an assessment of lower limb motor function improvement. In fact, our experimental intervention could ameliorate also lower limb functions, standing balance and gait, but we did not assess these features. At the same time, it should be noted that some other consoles for video-game based therapy could be more focused in balance training, such as the Wii-Fit Balance Board of Nintendo.[30] Analogously, we did not perform a gait assessment, mainly because the proposed video-games (and in general those available for Xbox involving the use of Kinect) did not require forward and backward locomotion.

Despite the above limitations, our study was important also because it was the first one in which not only motor outcomes were evaluated after VGT but also quantity of movements were measured. Furthermore, although not directly assessed, all the children showed a high level of participation, compliance and interest in using video-games during their therapy. According to this good participation and to the results of our study, we suggested to parents to continue at home the VGT under the same modalities of clinical settings (such as using the same videogames, not leaving the child alone, encouraging the child to use the paretic limb and so on). Further studies should assess the effects of home VGT. In fact, it could provide an add-on to therapy performed in clinical settings, enhancing the daily time in which children with CP are active from a motor and also a cognitive point of view. This aspect can be crucial in a population often exposed to an inactive lifestyle.[35] Being the Kinect a tool for motion capture, in the future, it could be also used for monitoring offline the home VGT, for correcting the child's performances or for progressively adapting the therapy, for example increasing the difficulty of the proposed games.

Conclusions

In conclusion we found that VGT is a feasible and well-accepted exercise to be performed by children with CP as a complementary strategy to CT in order to increase the amount of paretic arm movements. It is likely efficacious at improving the quality of upper limb movement. Further studies are needed to understand whether it may be regarded as a useful means also for improving the independence in activities and instrumental activities of daily living.

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