Effectiveness of the virtual reality on cognitive function of children with hemiplegic cerebral palsy: a single-blind randomized controlled trial

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5 authors, including:

Orkun Tahir Aran
Hacettepe University

Sedef Karayazgan Şahin
Hacettepe University

Barkın Köse
Hacettepe University

Zeynep Bahadir
Üsküdar University

Effectiveness of the virtual reality on cognitive function of children with hemiplegic cerebral palsy: a single-blind randomized controlled trial

Orkun Tahir Aran[a], Sedef Şahin[a], Barkın Köse[a], Zeynep Bahadir Ağce[b] and Hülya Kayihan[a]

Cerebral palsy is a term covering non-progressive motor and cognitive impairments caused by lesions of the brain. This study aims to evaluate the effectiveness of virtual reality-based rehabilitation program for children with hemiplegic cerebral palsy on cognitive functions. Ninety children (47 boys, 43 girls) with hemiplegic cerebral palsy were randomized to either study (n = 45; 11.18 ± 3.37 years) or control (n = 45; 11.06 ± 3.24 years) groups. The study group received virtual reality intervention in addition to Traditional Occupational Therapy intervention, and the control group received Traditional Occupational Therapy for 20 sessions. Both groups were evaluated by blinded assessors with Dynamic Occupational Therapy Cognitive Assessment for Children to collect information on cognitive functioning. Both groups' cognitive functions were improved after 10 weeks of interventions. The between-group comparison revealed significantly greater improvements in all subtest of cognitive functions in the virtual reality group than in the Traditional Occupational Therapy group (*P* < 0.001). Our results showed that 10 weeks of virtual reality-based rehabilitation enhanced cognitive functions in children with hemiplegic cerebral palsy. Using virtual reality applications in cognitive rehabilitation was recommended to improve spatial perception, praxis, visuomotor construction and thinking operations in children with cerebral palsy. *International Journal of Rehabilitation Research* XXX: 000–000

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[a]Hacettepe University Faculty of Health Sciences, Occupational Therapy, Ankara, [b]Üsküdar University Faculty of Health Sciences, Occupational Therapy, İstanbul, Turkey

Correspondence to Sedef Şahin, PhD, Hacettepe Universitesi Sağlık Bilimleri Fakültesi Ergoterapi Bölümü, 06100 Samanpazarı, Ankara, Turkey
Tel: +90 312 305 25 60; fax: +90 312 305 25 61;
e-mail: sedefkarayazgan88@hotmail.com

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Introduction

Cerebral palsy (CP) is a well-recognized neurodevelopmental condition beginning in early childhood and persisting through the lifespan. It describes movement and posture development disorders that causing activity limitation, impaired sensation, and cognition that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain (Bax *et al.*, 2005). CP is usually associated with motor impairments; however, disturbances of sensation and perception, global or specific cognitive difficulties, communication disorders, behavioral disorders, and seizures are also present (Bax *et al.*, 2005; Bottcher, 2010).

CP is classified as the type of motor affection (spastic, dyskinetic, or ataxic) and the affected body parts (hemiplegia, diplegia, or tetraplegia) (Stanley *et al.*, 2000; Hagberg *et al.*, 2001; Blondis, 2004). The most frequent form is hemiplegic CP (HCP), where one body side is affected as a result of brain damage that affects one hemisphere (Mutsaarts *et al.*, 2005; Reid *et al.*, 2015). Symptoms of HCP range widely from spasticity, impaired motor organization and functioning, movement impairments, lack of postural control, changes in walk patterns, balance problems, trunk and lower extremity motor control impairments to cognitive and intellectual problems (Picelli *et al.*, 2017).

Lesions in cerebrum caused by CP represent a biological restriction affecting the typical developmental trajectory of different cognitive functions and often resulting in cognitive impairments (Weierink *et al.*, 2013). Many authors described various cognitive impairments that might occur by CP, as altered information processing (Luciana, 2003), decreased focused attention and executive functioning (Mirsky, 1989), memory and learning disorders, altered motor-executive function, memory and language functions (Mirsky, 1989; Bates *et al.*, 1997). Along with all those cognitive function impairments mentioned above, health professionals have been working to increase the functional capacity of children (motor, cognitive, social, educational), caused by CP itself (Richards and Malouin, 2013).

There are various rehabilitation approaches for CP rehabilitation. Virtual reality (VR) -based rehabilitation is one of the current approaches. VR described as a user-computer interface including real-like interactions of an environment or object through multiple sensorial channels

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(visual and auditory), based on a virtual environment in which the participant feels own presence (Burdea and Coiffet, 2003). There is an increase in the usage of VR in the rehabilitation area in the last two decades due to its intervention and assessment usability (Snider *et al.*, 2010). The advantages of VR can be listed as follows: allowing therapists and researchers to develop and experiment VR oriented assessments and interventions by its technical qualities and affordable costs depending on the technological advances and accessibility (Aran *et al.*, 2017).

VR allows therapists to create a sensory-motor interaction at a certain level between the user and the virtual environment (Tieri *et al.*, 2018). Bohil *et al.* (2011) stated that VR enables researchers to investigate human behavior while they are interacting with a naturalistic environment. VR allows the simulation of a real-like environment which might be dangerous, high-priced, or impossible to create in real-life situations. One other possibility is to decrease the boredom of the participant during conventional rehabilitation (Sanchez-Vives and Slater, 2005). In cognitive rehabilitation, VR applications can facilitate better collaboration than instrument-oriented tests and exercises that are generally considered boring during virtual test testing (Larson *et al.*, 2014).

Many researchers investigated the motor effects of VR on children with CP (Glegg and Levac, 2018; Rathinam *et al.*, 2018). Despite a large number of studies through VR, studies focused on cognitive functions in children with CP are remarkably low in the literature (Larson *et al.*, 2014; Tieri *et al.*, 2018), and current ones focused on visuospatial functioning (Akhutina *et al.*, 2003; Murias *et al.*, 2017), attention and executive functioning (Piovesana *et al.*, 2017). Throughout this knowledge, we conducted a randomized control study aimed to investigate the effectiveness of VR based rehabilitation program on the cognitive functions of children with HCP.

Methods

This study was designed as a single-blind randomized controlled trial of VR-based rehabilitation on cognitive function in children with HCP. The protocol used in this study was approved by the Hacettepe University Ethics Boards and Commissions and written informed consent was obtained from every child and his/her legal guardian.

Participants

Ninety-five children with HCP were screened in the study who had applied to Occupational Therapy Pediatrics Unit at the university between the years 2015 and 2017. Children were regarded as eligible if they met the following inclusion criteria: (1) aged between 7 and 12 years; (2) classified level I or II in Gross Motor Function Classification System; (3) classified level I, II, or III of the Manual Ability Classification System for Children with CP; and (4) able to follow and accept verbal instructions. The exclusion criteria were: (1) had undergone orthopedic surgery or botulinum toxin injection in the past 6 months; (2) diagnosed with auditory or visual disorders; and (3) had participated in another therapy program, such as physiotherapy or speech therapy, during our intervention.

Ninety children were found to be eligible to participate to the study. They were randomly allocated to either the study group [VR intervention + Traditional Occupational Therapy (TOT) intervention] (n = 45) or the control group (TOT intervention) (n = 45) through a simple randomization technique by using sequentially numbered and opaque sealed envelopes. The allocation was performed by the fifth author of this study.

Measurements

The demographic data which includes age, sex, and hemiplegic side of the children were gathered. The Dynamic Occupational Therapy Cognitive Assessment for Children (DOTCA-Ch) was used to assess cognitive functions of children in both the study and control groups at 10-week intervals. These assessments described in detail below were applied by the first author, who was blind to the group allocation process and had 10 years' experience.

Dynamic Occupational Therapy Cognitive Assessment for Children

The DOTCA-Ch is a cognitive assessment tool that is suitable for children aged between 6 and 12 years. DOTCA-Ch, which is adapted from Loewenstein Occupational Therapy Assessment, identifies children's limitations and strengths in primary cognitive areas. The test consists of 22 sub-tests, which are summed in five main titles as orientation, spatial perception, praxis, visuomotor construction, and thinking operations. ICC correlations of tests are in a range between 0.87 and 0.99 for main titles. Application of the DOTCA on typically developing 6–12-year-old children indicated that their performance followed a hierarchical progression, thus making it suitable as a potential assessment tool for children as well as adults. Katz *et al.* (2007) presented cutoff scores of the DOTCA-Ch for different age groups. These scores are ranged between 12–15 for orientation, 8–11 for spatial perception, 19–33 for praxis, 20–28 for visuomotor construction, and 20–24 for thinking operations parts (Katz *et al.*, 2007). The usability of the DOTCA-Ch in children with CP was conducted by Yu in 2004 (Yu, 2004).

When we applied the DOTCA-Ch, we divided the application into two parts to prevent cognitive overload and boredom of the children for lasts nearly 90 minutes.

Interventions

In reviewing of the literature on the duration of VR interventions, the researchers stated that a total of 720 minutes of treatment (equal to 16 sessions of 40–45 minutes) over a period of at least 8 weeks should be sufficient

(Palisano *et al.*, 2012; Ravi *et al.*, 2017). With this information, we chose to perform interventions in children with HCP (study/control) over 10 weeks, twice a week, and for a 45-minute session.

Virtual reality setting

Microsoft Kinect for PC was used for the VR setting to detect three-dimensional movements of the participants. Interventions were held in a 20 m^2 room, with children standing approximately 1.5 m away from the monitoring output (65″ flat led screen tv). Additionally, the surface of the room was covered with soft tiles to prevent injuries in case of any falling, as VR games used in the study included jumping, leaning forward or to the left and right sides, and kicking a football.

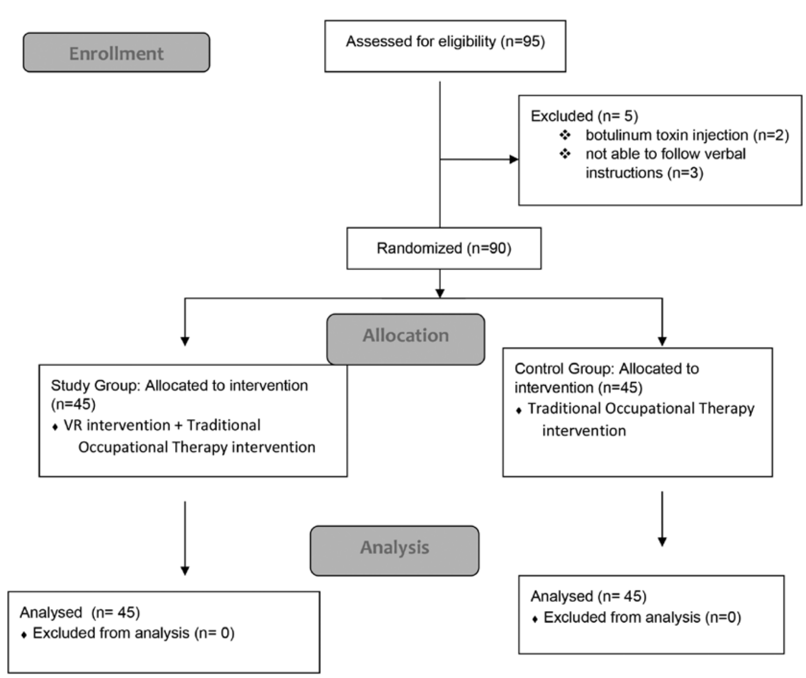
Four different games that were playable via Kinect for PC were used in this study which were commercially purchasable online (Fig. 2). First, all authors individually observed all games to determine the required cognitive functions to have games to be performed successfully. After completion of observation and determination of the functions, two meetings were held to discuss the requirements and to reach a consensus. The last meeting was held between the authors to make a final statement. Cognitive requirements of the games were as follows:

(1) Jet Run is a racing game, in which the player's avatar is controlled by trunk movements and jumping. This game requires the player to use his/her visual-spatial processing skills, praxis, perception, reaction time, and spatial orientation.
(2) Boxing trainer is a boxing game in which the player virtually punches pads at different sides of the screen. This game needs visual processing skills, reaction time, praxis, contra-lateral perception, and cognitive time management (racing against time).
(3) Air challenge is an air diving game that requires the player to keep his/her shoulders in abduction or flexion to continue the game. The player controls the game with shoulder and trunk movements. Among all similar requirements, this game has a different cognitive requirement, which is mirroring. Game avatar moves in the opposite direction; while the player moves his arm to left, the avatar goes to the right.
(4) Superkick is a penalty shootout game that requires visual processing skills, reaction time, praxis, contra-lateral perception, and cognitive time management (racing against time).

Since all games require similar cognitive functions, we kept all the games to enhance the motivation and concentration of the children to prevent boredom.

The control group received only TOT intervention twice a week for 10 weeks. TOT consisted of neurodevelopmental therapy administered by the third author. The therapy aimed to promote the active use of the extremities of the child and to improve motor and cognitive

Fig. 1



Consort Diagram

Fig. 2

Four different game images from Kinect PC

functions. TOT used to enhance the independence in activities of daily living by supporting the development of cognitive function, communication and interaction skills, and self-determination skills. The study group also received TOT interventions in addition to their VR interventions.

Statistical analysis

Data were analyzed using IBM Statistical Package for the Social Sciences version 21.0. Quantitative data were described as mean ± SD (X ± SD), and qualitative data were described in percentage values. The normality of data was evaluated with visual (histogram and stem-leaf plots) and analytic (Kolmogorov–Smirnov/Shapiro–Wilk tests) methods. Mann–Whitney *U* and Chi-square tests were used to compare the group in terms of age, gender, hemiparetic and dominant extremities. A Wilcoxon signed-rank test was used to test the mean differences between the beginning and end of the intervention process. The Mann–Whitney *U* test was used to determine whether the differences and changes between the scores in the study and control groups were statistically significant. Significance was set at an alpha level of 0.05. Cohen's *d* [(mean 1 − mean 2) ÷ SD 1] was used to determine the effect size and magnitude of difference between the assessments; this test estimates effect sizes as small (0.2), medium (0.5), large (0.8), and very large (1.3) (Ferguson, 2009; Sullivan and Feinn, 2012).

Power sampling adequacy was calculated with GPower 3.1. It was found that 43 participants for each group would indicate 80% power of the study with *P*-value below 0.05. Therefore, we completed our study with 90 participants to ensure 80% power of the study.

Results

This study included 90 children with HCP, divided into two groups (study and control) of 45 children. The mean age was 11.18 ± 3.37 years (min 7; max 12 years) in the study group and 11.06 ± 3.24 (min 7; max 12 years) years in the control group (Fig. 1). Both groups were statistically identical in terms of age, sex, hemiparetic side, and pre-intervention assessment scores ($P > 0.05$) (Tables 1 and 2). Both groups' DOTCA-Ch scores were below cut-off scores before the interventions.

The cognitive functions for both groups (except for orientation and thinking operations subtests in the control group) improved after 10 weeks of intervention ($P < 0.05$) (Table 3). The levels of increase in all subtests in the study group were found to be higher than in the

Table 1 Demographic characteristics of the children

	Study group	Control group	*P* value	χ^2
Age (mean ±SD)	11.18 ± 3.37	11.06 ± 3.24	0.697	
Sex (n)	22 female 23 male	21 female 24 male	-	0.39
Hemiparetic side (n)	35 right 10 left	33 right 12 left	-	0.37
GMFCS	Level I – 28 HCP Level II – 17 HCP	Level I – 31 HCP Level II – 14 HCP	-	0.26
MACS	Level I – 14 HCP Level II – 26 HCP Level III – 5 HCP	Level I – 12 HCP Level II – 29 HCP Level III – 4 HCP	-	0.42

χ^2, Chi-square test; GMFCS, gross motor functional classification system; HCP, hemiplegic cerebral palsy; MACS, manual ability classification system; p, Mann–Whitney *U* test.

Table 2 Pre-intervention group similarities of groups in DOTCA-Ch scores

		Study group	Control group	
		X ± SD	X ± SD	*P* value
DOTCA-Ch	Orientation	3.81 ± 2.26	3.09 ± 2.15	0.851
	Spatial perception	8.72 ± 2.09	8.90 ± 1.79	0.759
	Praxis	5.27 ± 2.09	5.09 ± 1.55	0.689
	Visuomotor construction	15.72 ± 8.51	15.54 ± 8.75	0.972
	Thinking operations	17.63 ± 9.30	17.45 ± 9.39	0.923

Table 3 Comparison of The Dynamic Occupational Therapy Cognitive Assessment for Children scores in the groups

	Study group				Control group			
DOTCA-Ch	Pre-intervention (X ± SD)	Post- intervention (X ± SD)	*P* value	Effect size	Pre-intervention (X ± SD)	Post- intervention (X ± SD)	*P* value	Effect size
Orientation	3.81 ± 2.26	4.44 ± 2.15	<0.05[a]	0.56	3.09 ± 2.15	3.68 ± 3.18	0.054	0.27
Spatial perception	8.72 ± 2.09	9.99 ± 1.77	<0.05[a]	0.60	8.90 ± 1.79	9.41 ± 2.88	<0.05[a]	0.28
Praxis	5.27 ± 2.09	7.09 ± 1.77	<0.01[b]	0.87	5.09 ± 1.55	5.99 ± 1.32	<0.05[a]	0.58
Visuomotor construction	15.72 ± 8.51	20.64 ± 7.77	<0.01[b]	0.57	15.54 ± 8.75	18.16 ± 8.93	<0.05[a]	0.29
Thinking operations	17.63 ± 9.30	19.45 ± 8.33	<0.05[a]	0.41	17.45 ± 9.39	19.04 ± 8.24	0.059	0.16

Dotca-Ch, The Dynamic Occupational Therapy Cognitive Assessment for Children.
[a]$P < 0.05$.
[b]$P < 0.01$.

Table 4 The dynamic occupational therapy cognitive assessment for children changes and comparisons between groups

DOTCA-Ch	Study group (X ± SD)	Control group (X ± SD)	*P* value
Orientation	0.63 ± 0.11	0.59 ± 1.03	0.044[a]
Spatial perception	1.27 ± 0.32	0.51 ± 1.09	0.0001[b]
Praxis	1.82 ± 0.32	0.9 ± 0.23	0.0001[b]
Visuomotor construction	4.92 ± 0.74	2.62 ± 0.18	0.0001[b]
Thinking operations	1.82 ± 0.97	1.59 ± 1.15	0.036[a]

Dotca-Ch, The Dynamic Occupational Therapy Cognitive Assessment for Children.
[a]$P < 0.05$.
[b]$P < 0.01$

control group ($P < 0.05$) (Table 3). Comparisons between the groups revealed significantly greater improvements in cognitive functions in the study group than in the control group ($P < 0.001$) (Table 4).

Comparisons of the changes over time in cognitive function within and between the groups, as well as the degrees of impact, are shown in Table 3. Comparing the two groups, the degree of impact on praxis was strong (Cohen's $d > 0.80$), while the degree of impact on some subscales in the DOTCA-Ch was moderate (0.30–0.80). However, the degrees of impact in the control group were smaller (Cohen's $d < 0.30$) than those in the study group (Table 3). However, scores after interventions were still below base values of cutoff scores except spatial perception and visuomotor construction subtest scores of the study group.

Discussion

This study was planned to investigate the effectiveness of VR based rehabilitation on cognitive functions in children with HCP. Our results showed that 10 weeks of intervention increased cognitive functions, such as orientation, spatial perception, praxis visuomotor construction, and thinking operations of children. Additionally, the VR group showed better acquisition in cognitive functions than the control group.

Spatial orientation and navigation were multi-dimensional cognitive processes, and their development following early brain injury could provide a unique insight into brain plasticity (Murias *et al.*, 2017). Belmonti *et al.* (2015) stated that children with CP performed spatial orientation tasks worse than the age-matched healthy control group. Akhutina *et al.* (2003) showed significant changes in spatial orientation in their experiment group which received VR based orientation training and conventional rehabilitation. Ten weeks of VR and TOT intervention improved children's spatial orientation. However, we thought that the improvements were insignificant for this study because the games that were used in this study did not include any orientation task. Also, the questions that test spatial orientation in the DOTCA-Ch consist of 'where are we now?' 'Which floor we are at?' etc. We believe, in 10 weeks, children learned the answers to these questions.

Many children with CP have visual-spatial perceptual impairments (Andersen, 2011; Menken *et al.*, 1987; Akhutina *et al.*, 2003; Ortibus *et al.*, 2009; Stadskleiv *et al.*, 2017). Ego *et al.* (2015) indicated that children with visual-perception impairments were ranged from 40% to 50%, with unclear knowledge of the effect of CP subtype, although the neurological affection caused by CP may be associated with visual perception abilities. Choi *et al.* (2018) discussed the effects of VR on visuospatial perception in their randomized control pilot study, and they stated that improvement in visual perception was developed due to visual feedback from the VR system, which provides a variety of visual stimuli through dynamic tasks. In 10 weeks, both groups had improvements in visual-spatial perception where the VR group had better improvements. As mentioned, early VR provides various types of visual feedback, and these feedbacks improved the perception skills of HCP children. We believe practitioners might get better results in visual perception skills by incorporating VR interventions into occupational therapy interventions.

Praxis is defined as a finalized intentional goal-directed motor behavior (Le Gall *et al.*, 2012). According to Goldenberg (2013), a praxis deficit could affect many domains of movements: imitation of meaningless gestures, imitating personal expression gestures, and real tool use. Studies showed that children with CP had praxis impairments (Mutsaarts *et al.*, 2007; Ghasia *et al.*, 2008); however, we found no intervention studies on praxis in our literature survey. Motor imitation and praxis improvements are thought to be explained with neural feedback theory, and VR is one of the good sources of visual and auditory feedback. According to the theory, mirror neurons might be firing 'during action observation not because they are driven by the visual input but because they are part of a generative model that is predicting the sensory input' (Cameirão *et al.*, 2010; Kommalapati and Michmizos, 2016). In our study, after 10 weeks of intervention, motor imitation of children was improved significantly and showed greater improvements than the control group. We believe, similar to current literature, that inputs provided through VR improved motor imitation of the children via sensory feedback (auditory, visual, motor) and learning mechanisms.

Visuomotor construction assesses the ability to process visual stimuli and to construct/draw a reproduction; DOTCA-Ch subtests include copying, drawing, and building. Additionally, Katz *et al.* (2007) stated that visuomotor construction tests in DOTCA-Ch also assess immediate and delayed memory. Copying, drawing and building shapes that were requested in DOTCA-Ch were visuomotor construction tests require visual perception and motor organization (praxis). In this study, we observed visuomotor construction improvement after 10 weeks of VR intervention. Moderate correlations between visuomotor construction, praxis and spatial perception tests of DOTCA-Ch were stated by Katz *et al.* (2007); thus, we think that improvements of spatial perception and praxis affected visuomotor construction. VR games used in this study did not include drawing, copying shapes or other constructional tasks, but we think that tasks like recognizing shapes (e.g. in sky diving game, children need to dive through circles to obtain points) which is required to complete the game successfully, improved children's visuomotor abilities.

Executive functions are defined as the ability to control impulses, predict results, set goals, plan results, monitor results, and use feedback, and are considered to regulate both immediate behavior and planning towards long-term goals (Laporta-Hoyos *et al.*, 2019). Studies of executive functioning in CP have shown that children with CP perform significantly worse than typically developing children (Anderson, 2010; Pereira *et al.*, 2018). Anderson (2010) described domains of executive functioning; attentional control, cognitive flexibility, goal setting, and information processing. Studies focused on executive functions and VR, mostly focused on the assessment of the function (Parsons and Rizzo, 2008; Lalonde *et al.*, 2013; Laporta-Hoyos *et al.*, 2019), and we found no VR intervention studies focused on executive functioning. DOTCA-ch evaluates executive functioning in the 'thinking operations' test (Katz *et al.*, 2007). Both groups in our study showed significant increase in thinking operations sub-test, and the VR group showed a greater increase and effect size than the control group. We believe that VR games that we used required several executive functions according to Anderson's domains: (1) attention control to continue playing game, react game changes and challenges, finish the game in proper time; (2) cognitive flexibility to react to game changes and challenges, compete with opponents, learning the game by making mistakes and correcting them, learn to compensate deficiencies occurred by CP; (3) goal setting to finish the games, breaking previous scores; (4) information processing to process visual-auditory inputs, complete the games in given times, etc. We believed that these requirements to play the games correctly challenged the children and improved their executive functions tested by DOTCA-Ch. It was thought to use VR interventions in addition to TOT interventions might be beneficial to increase the executive functions of children with HCP. However, since the literature stated that executive functions are multi-dimensional cognitive skills (Weierink *et al.*, 2013; Laporta-Hoyos *et al.*, 2019), DOTCA-Ch might not be sufficient to evaluate all domains of executive functions. We suggest further studies to use multiple executive functioning tests to get more detailed results.

There were several limitations of this study. First, the cognitive test we used might not provide enough information about cognitive states of children rather than using multiple cognitive tests together. One other limitation, we were not sure how challenging were the games for the children. We believe that they were enough to provide changes in cognitive functions; however, we were not sure rather if we had used more challenging games to provide better result or less challenging games to provide similar results in cognitive functions. We suggest further studies to compare games in different challenging levels.

The VR based rehabilitation for 10 weeks in this study showed better improvements than TOT intervention praxis, visuomotor construction, spatial perception, and executive functions in children with HCP. VR provide good support to TOT intervention; therefore, the use of different VR systems is recommended in cognitive rehabilitation processes and cognitive research.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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