THAIS MASSETTI

Aprendizagem motora em tarefa virtual na Paralisia Cerebral

Dissertação apresentada à Faculdade de Medicina da Universidade de São Paulo para obtenção do título de Mestre em Ciências.

Programa de Ciências da Reabilitação

Orientador: Prof. Dr. Carlos Bandeira de Mello Monteiro

São Paulo

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FACULDADE DE MEDICINA DA UNIVERSIDADE DE SÃO PAULO – FMUSP

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E a todos participantes da pesquisa.

LISTA DE ABREVIATURAS

PC	Paralisia Cerebral
DT	Desenvolvimento Típico
CP	Cerebral Palsy
RV	Realidade Virtual
VR	Virtual Reality
TD	Typically Developing
CE	Constant Error
AE	Absolute Error
VE	Variable Error

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RESUMO - ARTIGO 1

Massetti T. Aprendizagem motora em tarefa virtual na paralisia cerebral [Dissertação]. São Paulo: Faculdade de Medicina, Universidade de São Paulo; 2015.

Com o aumento da acessibilidade à tecnologia, programas de reabilitação para pessoas com paralisia cerebral (PC) usam cada vez mais ambientes de realidade virtual para melhorar o desempenho e a prática motora. Sendo assim, é importante verificar se a melhoria de desempenho em uma tarefa praticada em ambiente com característica virtual pode ser observado quando esta mesma tarefa for praticada em ambiente com característica real. Para analisar esta questão, foram avaliadas 64 pessoas, das quais 32 com PC e 32 com desenvolvimento típico (DT), ambos os grupos submetidos a duas tarefas de *timing* coincidente: a) tarefa em ambiente com característica real (com contato físico), na qual era necessário "interceptar" um objeto virtual que se movimentava na tela do computador, e no momento em que este objeto chegasse ao ponto de interceptação as pessoas deveriam pressionar a barra de espaço no teclado; b) tarefa em ambiente com característica virtual (sem contato físico), na qual as pessoas foram instruídas a "interceptar" o objeto virtual, fazendo um movimento com a mão sob uma webcam (ambiente virtual). Os resultados indicaram que as pessoas com PC apresentaram menor acurácia do que as pessoas com desenvolvimento típico, no entanto melhoraram seu desempenho durante a tarefa. É importante ressaltar que os resultados também mostraram que depois de praticar a tarefa sem contato físico, o desempenho das pessoas com PC na tarefa com contato físico manteve-se pior do que o desempenho de pessoas que praticaram a primeira tarefa com contato físico. Podemos concluir que a utilização de ambientes virtuais para reabilitação motora em pessoas com PC deve ser considerada com cautela, já que o ambiente em que a tarefa é realizada apresenta implicações importantes na aprendizagem desta população.

Descritores: paralisia cerebral; terapia de exposição à realidade virtual; reabilitação; interface usuário-computador; desempenho psicomotor; atividade motora.

ABSTRACT - ARTIGO 1

Massetti T. Transfer of motor learning from virtual to natural environments in individuals with cerebral palsy. [Dissertation]. São Paulo: "Faculdade de Medicina, Universidade de São Paulo"; 2015.

With the growing accessibility of computer-assisted technology, rehabilitation programs for individuals with cerebral palsy (CP) increasingly use virtual reality environments to enhance motor practice. Thus, it is important to examine whether performance improvements in the virtual environment generalize to the natural environment. To examine this issue, we had 64 individuals, 32 of which were individuals with CP and 32 typically developing individuals, practice two coincidence-timing tasks. In the more tangible button-press task, the individuals were required to 'intercept' a falling virtual object at the moment it reached the interception point by pressing a key. In the more abstract, less tangible task, they were instructed to 'intercept' the virtual object by making a hand movement in a virtual environment. The results showed that individuals with CP timed less accurate than typically developing individuals, especially for the more abstract task in the virtual environment. The individuals with CP did – as did their typically developing peers- improve coincidence timing with practice on both tasks. Importantly, however, these improvements were specific to the practice environment, there was no transfer of learning. It is concluded that the implementation of virtual environments for motor rehabilitation in individuals with CP should not be taken for granted but needs to be considered carefully.

Descriptors: cerebral palsy; virtual reality exposure therapy; rehabilitation; user-computer interface; psychomotor performance; motor activity.

RESUMO - ARTIGO 2

Indivíduos com paralisia cerebral apresentam distúrbios motores complexos, o principal sendo um déficit de tônus muscular, que afeta a postura e o movimento; observam-se alterações de equilíbrio e coordenação motora, diminuição de força e perda de controle motor seletivo com problemas secundários de contratura e deformidade óssea. Esta população pode ter dificuldades na aprendizagem de habilidades motoras. O aprendizado de habilidades resulta de exposição repetida e de prática. Devido ao aumento do uso de realidade virtual no processo de reabilitação e a importância do desenvolvimento motor na aprendizagem de indivíduos com paralisia cerebral, há necessidade de estudos nesta área. O objetivo do presente estudo foi investigar os resultados mostrados em estudos anteriores de aprendizagem motora com realidade virtual em pacientes com paralisia cerebral. Inicialmente, 40 estudos foram encontrados, mas 30 artigos foram excluídos por não preencherem os critérios de inclusão. Os estudos mostraram benefícios da utilização da Realidade Virtual em crianças com paralisia cerebral na função motora grossa e melhorias na aprendizagem motora com a possibilidade de transferir para situações da vida real. Portanto, a realidade virtual parece ser uma alternativa promissora e uma opção estratégica para o atendimento dessas crianças. No entanto, existem poucos estudos sobre aprendizagem motora com realidade virtual. Os benefícios em longo prazo do tratamento com realidade virtual ainda são desconhecidos.

Palavras-chave: “Paralisia Cerebral”, “Realidade Virtual” e “Aprendizagem Motora”.

ABSTRACT - ARTIGO 2

Cerebral palsy is a well-recognized neurodevelopmental condition beginning in early childhood and persisting throughout life and is considered the most common non-progressive neurological disease of childhood. Subjects with cerebral palsy present complex motor skill disorders, the primary deficits being abnormal muscle tone, which affects posture and movement, alteration of balance and motor coordination, decrease in strength and loss of selective motor control with secondary issues of contracture and bone deformity. This population may have difficulties in motor skill learning processes. Skill learning is learning as a result of repeated exposure and practice. Due to the increasing use of virtual reality in rehabilitation and the significance of motor development learning of subjects with cerebral palsy, we have recognized the need for studies in this area. The purpose of this study was to investigate the results shown in previous studies for motor learning with virtual reality in patients with cerebral palsy. Initially, 40 studies were found, but 30 articles were excluded, as they did not fulfil the inclusion criteria. The data extracted from the ten eligible studies is summarized. The studies showed benefit from the use of Virtual Reality in children with cerebral palsy in gross motor function and improvements in motor learning with skill transfer to real-life situations. Therefore, virtual reality seems to be a promising resource and a strategic option for care of these children. However, there are few studies about motor learning with virtual reality use. The long term benefits of RV therapy are still unknown.

Keywords: “Cerebral Palsy”, “Virtual Reality” and “Motor Learning”.

SUMÁRIO

1. INTRODUÇÃO

INTRODUÇÃO

A paralisia cerebral (PC) é definida como "um grupo de distúrbios permanentes do desenvolvimento do movimento e da postura, causando limitação da atividade, que são atribuídas a distúrbios não-progressivos que ocorreram no cérebro na fase fetal ou no desenvolvimento infantil (1). A paralisia cerebral é uma deficiência motora que resulta de uma lesão que ocorre no cérebro em desenvolvimento; o distúrbio varia no tempo da lesão, na apresentação clínica, no local e na gravidade das deficiências (2). O resultado desta deficiência é a deterioração física e uma subsequente redução nas atividades de vida diária (3).

As desordens motoras na paralisia cerebral (PC) são frequentemente acompanhadas por perda de funcionalidade e dependência de outras pessoas em diferentes atividades diárias. Para obter maior funcionalidade em atividade e participação social, a maioria das pessoas com PC faz parte de programas de reabilitação contínua, que muitas vezes se concentram em priorizar o movimento adequado e posicionamento dos membros e do corpo (4, 5, 6).

Diante de tantas possíveis alterações motoras e sensoriais, a flexibilidade é essencial na concepção de programas terapêuticos na PC. Considerando que pessoas com alterações neurológicas não apresentam padrões homogêneos, e exigem suportes de aprendizagem uma opção diferenciada na reabilitação é a utilização de tarefas em ambientes virtuais para facilitar e incorporar estratégias de ensino estruturados e sistemáticos (7).

Recentemente, com a crescente acessibilidade da tecnologia assistida por computador, os programas de reabilitação utilizam cada vez mais ambientes de realidade virtual para possibilitar a realização de tarefas funcionais (8-11). As vantagens da realidade virtual (RV) incluem a prática domiciliar, on-line e a interação com outras pessoas, assim como existe a possibilidade de realizar tarefas virtuais sob a supervisão de um profissional (12-14). Shih, Chang e Shih (2010)(15) argumentam que os ambientes virtuais podem permitir que as pessoas com deficiência, quando imersos neste ambiente, podem melhorar significativamente o seu nível de interação.

No entanto, a utilização de tarefas em ambiente de realidade virtual como um programa de intervenção para pessoas com PC é relativamente novo, e embora exista a evolução rápida de pesquisas na área, os seus benefícios e limitações não foram comprovados (10).

Os jogos altamente comercializados, são na maioria das vezes, concebidos para fins de entretenimento ou diversão. São geralmente interfaces e softwares que exigem alto desempenho em testes cognitivos e motores e altos níveis de dificuldade que pode constituir um obstáculo ao paciente ou dificultar a reabilitação do individuo, erroneamente maximizando padrões sensoriais e gerando padrões de mobilidade anormais, entre outras conseqüências. Devido a estes problemas, os pesquisadores estão desenvolvendo jogos projetados especificamente para sistemas de reabilitação (16).

Considerando o uso da RV em pessoas com PC, Brien e Sveistrup (2011)(17) examinaram os efeitos de um programa de treinamento de realidade virtual intensivo no equilíbrio funcional e mobilidade em quatro adolescentes com PC. Durante a intervenção, os participantes interagiram 90 minutos durante 5 dias consecutivos com diferentes tarefas virtuais que foram ajustadas para cada pessoa considerando-se a complexidade. No equilíbrio dinâmico, por exemplo, os participantes foram desafiados com transferências de peso em pé, obrigando-os a executar diferentes tarefas com mudanças de distância de objetos (perto e distante) ou mudanças de posição (agachar ou pular). Verificou-se que entre os participantes, a prática em ambiente virtual melhorou o equilíbrio funcional, com benefícios que permaneceram consistentes até um mês pós-treinamento.

Chen et al. (2007)(18), analisaram quatro crianças com PC em um programa de realidade virtual individualizada, duas horas por semana, durante um período de quatro semanas. Durante a intervenção, as crianças usavam uma luva com sensores para criar movimentos em um ambiente virtual tridimensional (3D). Após a intervenção, três crianças apresentaram mudanças pequenas, mas significativas no alcance cinemático, que mantiveram (parcialmente) por quatro semanas após a intervenção.

Esses resultados demonstram o potencial para propiciar melhoras nas habilidades perceptivo-motora em crianças e adolescentes com PC. No entanto, verifica-se que o número de participantes é relativamente pequeno, e também a generalização para ambientes com características mais reais não foi estudado (19). Da mesma forma, Berry et al. (20) e Howcroft et al. (21) mostraram melhorias na cinemática do movimento em jogos realizados em ambientes virtuais (por exemplo, boliche, boxe e tênis), no entanto, eles não avaliaram a transferência para o meio ambiente real.

No estudo de Gatica-Rojas e Méndez-Rebolledo, afirma que as melhorias observadas em doenças neurológicas foram demonstradas por mudanças na reorganização das redes neurais no cérebro dos pacientes, juntamente com uma melhor função da mão e outras habilidades, contribuindo para a sua qualidade de vida (16).

Apesar de existir suposições de que a melhora de desempenho na aquisição de tarefas em ambientes virtuais pode ser generalizada para o desempenho em ambientes mais reais, são importantes novas investigações. Em ambientes virtuais, os participantes simulam como executar uma tarefa específica. Consequentemente, o desempenho é muitas vezes relativamente abstrato e dirigido aos objetos não palpáveis. É provável, que a melhora de desempenho em ambiente virtual possa provocar diferente organização espaço-temporal do movimento quando praticado em ambiente mais próximo ao real.

Por exemplo, Van der Weel, Van der Meer e Lee (1991) (22) compararam o desempenho de crianças com PC em duas tarefas, que diferiam em graus de abstração. Os resultados apresentados demonstraram que crianças com PC alcançaram um tempo de movimento significativamente mais funcional em tarefa concreta quando comparado ao tempo de realização de tarefa abstrata. A tarefa concreta consistiu em bater em tambor, e a tarefa abstrata foi girar a baqueta “o quanto você conseguir", sendo que ambas exigem a mesma movimentação de pronação e supinação do antebraço. Interessante foi que ao avaliar crianças com desenvolvimento típico, não houve diferença no desempenho nas duas tarefas (23).

Estes resultados corroboram com a abordagem ecológica da percepção e ação (24). A abordagem ecológica sustenta que para cada ação de um movimento especifico é necessário um acoplamento de informações. Estes acoplamentos de informações de movimento são considerados para uma tarefa ou situação específica. Considerando-se a abordagem ecológica, diferentes tarefas ou situações exigem a exploração ou sintonia com diferentes fontes de informação para controlar o movimento (25). Esta informação pode ser comprovada quando se comparam ações similares executadas em ambientes reais com ambientes virtuais, mais abstratos.

Consequentemente, o acoplamento de informações de um movimento que está subjacente a tarefa, por exemplo, bater uma bola real com uma raquete de tênis, pode ou não ser diferente do acoplamento que está subjacente a tarefa mais abstrata e menos tangível de bater uma bola de tênis virtual com um console eletrônico.

As duas tarefas não necessariamente levam a resultados de desempenho semelhantes. Considerando-se os conhecimentos da neuropsicologia, agarrar um objeto real envolve diferentes partes do sistema visual e proprioceptivo, direcionando os atos do executor a realizar a tarefa com precisão e exatidão (26-28).

A utilização de ambientes virtuais para reabilitação motora em pessoas com PC deve ser considerada com cuidado, é importante a realização de pesquisas que ofereçam respaldo e comprovação científica. É possível que a prática de uma tarefa em ambiente com característica virtual (abstrato) pode apresentar pouca transferência a ambientes com característica real (concreto). Para analisar esta questão, este trabalho avaliou pessoas com paralisia cerebral e pessoas com desenvolvimento típico na prática de duas tarefas de *timing* coincidente que diferem na sua forma de execução. Na tarefa com contato físico, os participantes interceptam um objeto virtual, no momento em que o mesmo chega ao ponto alvo pressionando a tecla de espaço do teclado do computador.

Na tarefa sem contato físico, os participantes foram instruídos a interceptar o objeto virtual, fazendo um movimento com a mão na frente de uma webcam (isto é, um gesto) considerado um ambiente com características mais virtuais. O interesse principal é saber se ocorre a melhora de desempenho na tarefa realizada em ambiente virtual (abstrato) e se existe transferência para a tarefa realizada em ambiente real (concreto) e vice-versa. Considerando as observações realizadas, a hipótese é de que os benefícios em melhorar o desempenho em tarefa virtual (abstrata) não influenciam o desempenho ao realizar a tarefa real (concreta), especialmente entre as pessoas com PC.

2. COMITÊ DE ÉTICA

MEDICINA

USP

COMITÊ DE ÉTICA EM PESQUISA

APROVAÇÃO

O Comitê de Ética em Pesquisa da Faculdade de Medicina da Universidade de São Paulo, em sessão de **05/02/2014**, **APROVOU** o Protocolo de Pesquisa nº 400/13 intitulado: **"APRENDIZAGEM MOTORA EM TAREFA VIRTUAL NA PARALISIA CEREBRAL"** apresentado pelo **Departamento de Fisioterapia, Fonoaudiologia e Terapia Ocupacional.**

Cabe ao pesquisador elaborar e apresentar ao CEP-FMUSP, os relatórios parciais e final sobre a pesquisa (Resolução do Conselho Nacional de Saúde nº 466/12).

Pesquisador (a) Responsável: Carlos Bandeira de Mello Monteiro
Pesquisador (a) Executante: Thais Massetti

CEP-FMUSP, 07 de Fevereiro de 2014.

Prof. Dr. Roger Chammas
Coordenador
Comitê de Ética em Pesquisa

Comitê de Ética em Pesquisa da Faculdade de Medicina
e-mail: cep.fm@usp.br

3. ARTIGOS PUBLICADOS

ARTIGO 1

TRANSFER OF MOTOR LEARNING FROM VIRTUAL TO NATURAL ENVIRONMENTS IN INDIVIDUALS WITH CEREBRAL PALSY.

Carlos Bandeira de Mello Monteiro*[1], Thais Massetti[1], Talita Dias da Silva[1], John van der Kamp[2,3], Luiz Carlos de Abreu[4], Claudio Leone[4] and Geert J. P. Savelsbergh[2,5].

[1]School of Arts, Sciences and Humanities, University of São Paulo, São Paulo, Brazil.

[2] MOVE Research Institute Amsterdam, Faculty of Human Movement Sciences, VU University, Van der Boechorststraat 7, 1081 BT, Amsterdam, The Netherlands.

[3]Institute of Human Performance, University of Hong Kong, 111-113 Pokfulam Road, Pokfulam Hong Kong.

[4]School of Public Health, University of São Paulo, Av. Dr. Arnaldo, 715, CEP: 01255-000, São Paulo, Brazil.

[5]Academy for Physical Education, University of Applied Sciences, Dr. Meurerlaan 8, 1067 SM, Amsterdam, The Netherlands.

***Corresponding author:**
University of São Paulo.
School of Arts, Sciences and Humanities
Av. Arlindo Béttio, 1000
Ermelino Matarazzo
03828-000, São Paulo, Brazil
E-mail: carlosfisi@uol.com.br
Telephone: (5511)999530716

ABSTRACT

With the growing accessibility of computer-assisted technology, rehabilitation programs for individuals with cerebral palsy (CP) increasingly use virtual reality environments to enhance motor practice. Thus, it is important to examine whether performance improvements in the virtual environment generalize to the natural environment. To examine this issue, we had 64 individuals, 32 of which were individuals with CP and 32 typically developing individuals, practice two coincidence-timing tasks. In the more tangible button-press task, the individuals were required to 'intercept' a falling virtual object at the moment it reached the interception point by pressing a key. In the more abstract, less tangible task, they were instructed to 'intercept' the virtual object by making a hand movement in a virtual environment. The results showed that individuals with CP timed less accurate than typically developing individuals, especially for the more abstract task in the virtual environment. The individuals with CP did –as did their typically developing peers- improve coincidence timing with practice on both tasks. Importantly, however, these improvements were specific to the practice environment, there was no transfer of learning. It is concluded that the implementation of virtual environments for motor rehabilitation in individuals with CP should not be taken for granted but needs to be considered carefully.

Keywords: Cerebral Palsy; virtual reality; rehabilitation; user-computer interface.

1. Introduction

The motor disorders of individuals with cerebral palsy (CP) are often accompanied by loss of functionality and dependence on others in daily activities. In order to manage these problems, most individuals with CP take part in continuous rehabilitation programs, which often focus on, and sometimes prioritize, the correct movement and positioning of the limbs and the body (Kułak, Okurowska-Zawada, Sienkiewicz, Paszko-Patej & Krajewska-Kułak, 2010; Tsai, Yang, Chan, Huang & Wong, 2002). Recently, with the growing accessibility of computer-assisted technology, rehabilitation programs increasingly use virtual reality environments to enhance dedicated practice (Barton, Hawken, Foster, Holmes & Butler, 2013; Burdea et al., 2013; Mitchell, Ziviani, Oftedal & Boyd, 2012; Riener et al., 2013). The advantages of virtual reality include practice at home (i.e., online), independent or in interaction with others (e.g., e-games), and with or without supervision of a professional (Hurkmans, Van Den Berg-Emons & Stam, 2010; Vissers et al., 2008; Huber et al., 2010). Accordingly, Shih, Chang and Shih (2010) have argued that virtual environments may allow people with disabilities, when immersed, to significantly improve their level of interaction with environment. Yet, virtual reality as an intervention for individuals with CP is relatively new, and although research is rapidly evolving, its benefits and limitations have not been extensively researched (Mitchell et al., 2012). Hence, the present study aimed to add to the knowledge base regarding the learning of perceptual-motor skills in virtual environments in individuals with CP.

In this respect, Brien and Sveistrup (2011) examined the effects of an intensive virtual-reality training program on functional balance and mobility in four adolescents with CP. During the intervention, the participants interacted 90 minutes on 5 consecutive days with virtual objects to perform tasks that were adjusted to the individual in terms of complexity. In dynamic balance, for instance, the participants were challenged to elicit weight shifts while standing in a single-leg stance by encouraging them to reach for distant objects, or to squat, jump and so on. It was found that among the four participants, virtual-reality practice improved functional balance, the changes being retained until one month post-training. In addition, Chen et al. (2007) provided four children with CP with an individualized virtual-reality program for two hours per week over a period of four weeks. During the intervention, the child wore a sensor glove creating movements in a 3-dimensional virtual environment. The children practiced reaching tasks. After intervention, three children showed small but significant changes in reaching kinematics, which were (partially) maintained four weeks after intervention. Together, these results demonstrate the potential to improve perceptual-motor skills in children and adolescents with CP. Yet, the number of participants is relatively small, and also the generalization to natural environments remained largely unanswered (see also Snider, Majnemer & Darsaklis, 2010). Similarly, Berry et al. (2011) and Howcroft et al. (2012) showed improvements in movement kinematics on video games in virtual environments (e.g., bowling, boxing and tennis) among a larger group of children with CP; yet, they did not assess transfer to the natural environment.

It may seem straightforward - certainly for immersing virtual environments - that improvements do generalize to performance in more natural environments. There are some caveats, however. In virtual-environments, participants actually pretend as if they perform a particular task. Consequently, performance is often relatively abstract and directed to intangible objects. It is not unlikely therefore that virtual environment elicit different spatio-temporal organization of the movement than natural environments, especially among participants with movement disorders. For instance, Van der Weel, Van der Meer and Lee (1991) compared the performance of children with CP for two interceptive action tasks that differed in their degrees of abstractness (i.e., more or less representative for an interceptive action that is normally produced in natural environments). They found that CP children achieved a significantly larger range of motion when they were asked to perform a concrete "bang-the-drum"-task with a drumstick than when they were asked to perform a more abstract rotate the drumstick "as-far-as-you-can"-task, requiring exactly the same pronation and supination movements of the forearm. Typically developing nursery-school children, however, did not show different movement patterns for the two tasks (see also Van der Weel, Van der Meer & Lee, 1996).

These findings neatly fit within the ecological approach to perception and action (Gibson, 1979). The ecological approach holds that for each action a specific information-movement coupling is assembled. These information-movement couplings are considered to be task- and situation-specific. The ecological approach holds that different tasks or situations demand the exploitation or attunement to different sources of information to control the movement (e.g., Savelsbergh & Van der Kamp, 2000; Van der Kamp, Oudejans & Savelsbergh, 2003). This may also be true when comparing similar actions in natural and more abstract virtual environments. Consequently, the information-movement coupling that underlies the task of hitting a real ball with a tennis racquet may or may not be distinct from the coupling that underlies the more abstract and less tangible task of hitting a virtual tennis ball with a Wii-console. The two tasks do not necessarily lead to similar performance outcomes. This accords with neuropsychological findings that grasping a real object involves different parts of the visual system than pantomime grasping, in which the performer acts as if they are grasping a real object (Goodale, Jakobson & Keillor, 1994; see also Milner & Goodale, 2008; Van der Kamp, Rivas, van Doorn & Savelsbergh, 2008)

Hence the implementation of virtual environments for motor rehabilitation in individuals with CP should not be taken for granted but needs to be considered carefully. Particularly, practice of a relatively abstract (or less tangible) task may result in different movement outcomes and transfer weakly to the natural environment. To examine this issue, we had individuals with cerebral palsy and typically developing individuals practice two coincidence-timing tasks that differed in their degree of abstractness. In the more tangible button-press task, the children were required to 'intercept' a falling virtual object at the moment it reached the interception point by pressing a key on the computer. In the more abstract, less tangible task, they were instructed to 'intercept' the virtual object by making a hand movement (i.e., a waving gesture) in a virtual environment. We were especially interested to find out to which degree performance and learning of the more abstract task differs from performance and learning on the more tangible task, and to what degree learning on the more abstract task transfers to the more tangible task and vice versa. Based upon the above deliberations, we hypothesized that performance and learning may be relatively degraded for the more abstract task, and that the benefits (i.e., proactive facilitation) from learning the more abstract task first to learning (and performing) the more tangible task would be minimal, if any, especially among individuals with CP.

2. Method

2.1. Participants

A total of 64 individuals participated in this study, 32 of which were with CP (24 males and 8 females, mean age = 19 yrs, ranging between 11-28 yrs.) and 32 typically developing individuals that were matched by age and gender to the individuals with CP. Within the CP-group, there were 10 individuals with diparetic spasticity, 8 with right spastic hemiparesis, 8 with left spastic hemiparesis and 6 with choreoathetosis hemiparetic spasticity. Criteria for inclusion were a medical diagnosis of CP levels I to IV according to the Gross Motor Function Classification System (GMFCS) (Palisano, Cameron, Rosenbaum, Walter & Russell, 2006). This classification was made by a professional physiotherapist that was specialized in CP. Exclusion criteria were the presence of structured osteoarticular deformities, surgery or chemical neuromuscular blockade in upper limbs within less than six months before participation in the experiment and other co-morbidity such as disorders in cognitive function that would prevent comprehension of the experimental instruction. This study was approved by the Ethics Committee for review of research projects of the Escola de Artes, Ciências e Humanidades da Universidade de São Paulo – EACH/USP under protocol number 1033/03. The participants and/or their legal guardians provided written informed consent.

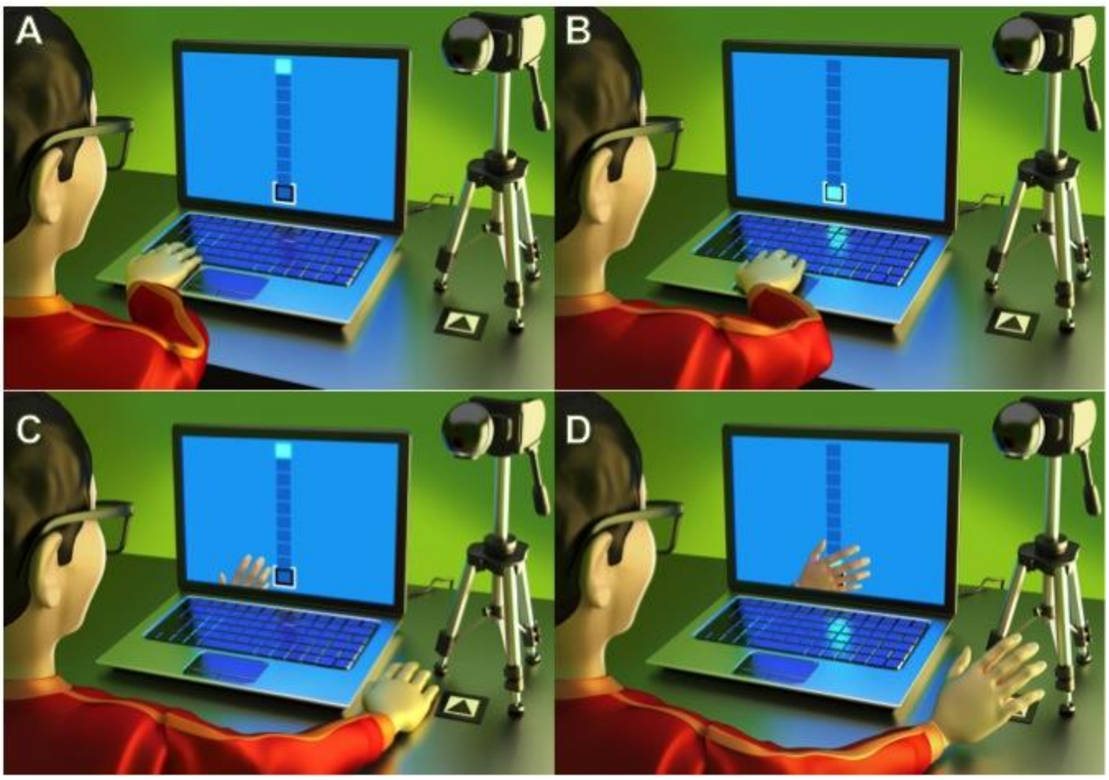
2.2. Material and apparatus

As a precursor to this research, we developed dedicated software[1] that instantaneously superimposes virtual objects over images of the real world captured by a webcam (Microsoft Lifecam VX-800). This allowed us to display the current movement of the participant's hand together with the (pre-programmed) virtual falling object on a monitor in front of the participant.

[1] The accuracy and reliability of this coincidence-timing task was tested by the Department of Electronic System Engineering of the Escola Politécnica da Universidade de São Paulo (see also Silva et al., 2013).

The coincidence-timing task could either have a virtual (i.e., abstract) or a real (more tangible) interface. For the real interface, a keyboard was used. For the virtual interface, the webcam recorded a marker on the table in-between the monitor and the participant. The images were fed into the computer and analyzed online. Using the dedicated software, it was determined whether or not the participant's hand occluded the marker, which was then fed back to the virtual environment. The coincident timing task was based on the Bassin Anticipation Timer (Shea & Ashby, 1981; Overdorf, Page, Schweighardt & McGrath, 2004; Harrold & Kozar, 2002; Corrêa et al., 2005; Santos, Corrêa & Freudenheim, 2003; Williams, 1985; Williams, Jasiewicz & Simmons, 2001). To this end, 10 3D-cubes were displayed simultaneously in a vertical column on a monitor. The cubes turned on (i.e., changed from white to green) and off sequentially (from top to bottom) until the target cube (i.e., the tenth cube) was reached. The task for the participant was to either press the space bar on the keyboard (i.e., tangible button press task, by making contact) or to make a sideward hand gesture as if hitting the target object (i.e., the more abstract gesture task, without making contact) at the exact moment the target cube turned green (Figure 1).

Figure 1: The button press (A-B) and gesture (C-D) coincidence timing tasks



2.3. Procedure and design

Participants performed the task individually in a quiet room with only the experimenter, who gave the instructions, present. The computer and monitor were placed on a table. The participants were seated in chair, which was adjusted in height according to the needs of the individual. Also a footrest was available, if required. After being seated, the experimenter explained the task verbally and gave three demonstrations of how to perform the coincidence timing tasks. The participants were instructed to place the preferred hand (i.e., the less affected hand) on a mark in front of the target (The location was individually adjusted but ranged from 2 to 4 cm from the target cube). Once the first top cube turned on, the individual had to move his or her hand to either touch the target key on the keyboard or to make a hitting gesture in front of the webcam (i.e., occluding the marker), exactly at the moment the bottom target cube turned on. Different sounds were provided as feedback for a hit or miss during acquisition, retention and transfer, the range of error for a hit being -200 to 200 ms.

All participants performed both the button-press and the gesture task. To counterbalance across groups, participants of both the cerebral palsy group (CP-group) and the typically developing group (TD-group) were randomly assigned to the tangible-task-first-group (these participants practiced the button-press task before performing the gesture task) or the abstract-task-first-group (these participants first practiced the gesture task before performing the button-press task). Each participant performed both tasks in blocks, each block consisting of 20 trial acquisitions, 5 trial retentions and 5 trial transfers. Henceforth, the participant performed a total of 60 trials. During acquisition and retention trials, the cube 'dropped' with a speed of 1.78 m/s, while during transfer the speed was increased to 2.02 m/s (Corrêa et al., 2005; Silva et al., 2013).

2.4. Data analysis

The dependent variables used were the constant timing error (CE), absolute timing error (AE) and variable timing error (VE), with timing error defined as the time difference between the time the target cube switched on (arrival time) and the time at which the key touched or the gesture was registered. One participant with CP who started with practice on the more tangible task responded very erratic and was identified as an outlier with respect to variable error. This participant was therefore excluded from the analyses. The dependent variables were submitted to a 2 (group: CP, TD) by 2 (sequence: tangible task first, abstract task first) by 2 (task: button-press, gesture) by 2 (block) MANOVA with repeated measures on the last two factors. For the factor block separate comparisons were made for acquisition (first acquisition block A1 versus final acquisition block A4), retention (A4 versus retention block R) and transfer (R versus transfer block T). Post hoc comparisons were carried out using Tukey-HSD test (p <.05).

3. Results

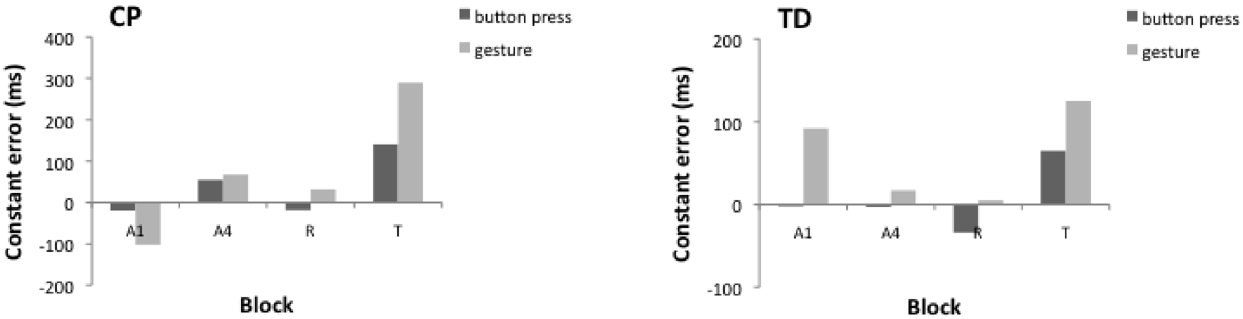
3.1. Acquisition

The MANOVA revealed the following significant effects when comparing timing errors in the first acquisition block A1 to errors in the final acquisition block A4: main effects of group (Wilks □ = .494, $F(3, 57) = 19.4$, $p < .001$, $\eta^2 = .51$), task (Wilks □ = .530, $F(3, 57) = 16.8$, $p < .001$, $\eta^2 = .47$) and block (Wilks □ = .813, $F(3, 57) = 4.38$, $p < .01$, $\eta^2 = .19$). Additional significant interactions were revealed for group by task (Wilks □ = .839, $F(3, 57) = 3.63$, $p < .05$, $\eta^2 = .16$) and group by block (Wilks □ = .870, $F(3, 57) = 2.84$, $p < .05$, $\eta^2 = .13$). The separate follow up RM-ANOVA's for CE, AE and VE are reported in the sections below.

3.1.1. Constant error (CE)

The repeated measures ANOVA for CE only confirmed a significant group by block effect, $F(1, 59) = 7.36$, $p < .01$, $\eta^2 = .11$. Post hoc comparisons indicated that the CP-group responded significantly earlier in A1 (-60 ms) compared to A4 (61 ms), whereas for the TD-group no significant differences occurred between blocks (45 ms and 7 ms, respectively). Put differently, in the first acquisition block A1 the CP-group responded significantly earlier than the TD-group, but in the final acquisition block A4 this difference had disappeared (see Figure 2).

Figure 2: Constant error (ms) as a function of block and task for the CP-group (left panel) and the TD-group (right panel).



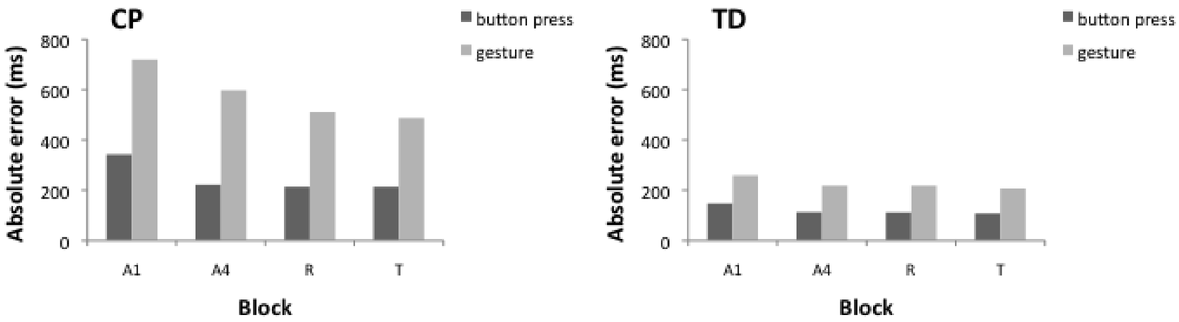
A1-A4: Acquisition blocks; R: retention blocks; T: Transfer Blocks; CP: Cerebral Palsy; TD: typical development.

3.1.2. Absolute error (AE)

The pattern of absolute errors is illustrated in Figure 3. The repeated measures ANOVA for AE showed significant effects for group, $F(1, 59) = 50.1$, $p < .001$, $\eta^2 = .46$, task, $F(1, 59) = 34.2$, $p < .001$, $\eta^2 = .37$, and group by task, $F(1, 59) = 10.4$, $p < .01$, $\eta^2 = .15$. Post hoc comparisons indicated that the button press task resulted in significantly smaller AE than the gesture task. This difference was only significant for the CP-group (282 and 656 ms, resp.) and not for the TD-group (130 and 238 ms)[2]. Put differently, the CP-group had significantly larger AE, but only for the more abstract gesture task. Finally, a main effect for block, $F(1, 59) = 11.5$, $p < .01$, $\eta^2 = .16$, indicated that the AE decreased from the first acquisition block A1 (338 ms) to the final acquisition block A4 (287 ms), irrespective of task and group.

Figure 3: Absolute error (ms) as a function of block and task for the CP-group (left panel) and the TD-group (right panel).

[2] Note that errors exceeding 200 ms were failed interceptions.

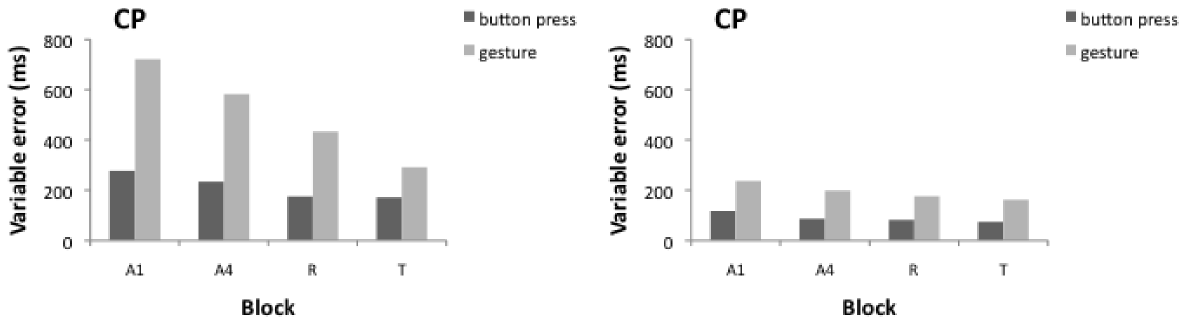


A1-A4: Acquisition blocks; R: retention blocks; T: Transfer Blocks; CP: Cerebral Palsy; TD: typical development.

3.1.3. Variable error (VE)

The pattern of variable errors during acquisition is depicted in Figure 4. Similar to the pattern of absolute errors, the repeated measures ANOVA for VE confirmed significant main effects of group, $F(1, 59) = 35.6$, $p < .001$, $\eta^2 = .38$, and task, $F(1, 59) = 25.8$, $p < .001$, $\eta^2 = .30$. However, the factors interacted as attested by a significant group by task effect, $F(1, 59) = 7.61$, $p <. 01$, $\eta^2 = .11$. Post hoc comparisons indicated that the VE for the button press task (179) was significantly smaller than for the gesture task (435 ms), but only for the CP-group (256 and 652 ms, resp.) and not for the TD-group (102 and 217 ms). In addition, the block main effect, $F(1, 60) = 13.3$, $p < .01$, $\eta^2 = .18$, indicated that the variable error decreased during acquisition (338 and 275, for the first acquisition block A1 and the final acquisition block A4, resp.)

Figure 4: Variable error (ms) as a function of block and task for the CP-group (left panel) and the TD-group (right panel).



A1-A4: Acquisition blocks; R: retention blocks; T: Transfer Blocks; CP: Cerebral Palsy; TD: typical development.

3.2. Retention

The MANOVA comparing the timing errors in the final acquisition and the retention blocks did only reveal a significant main for block (Wilks □ = .822, *F*(3, 57) = 4.13, p < . 05, η^2 = .18)[3]. However, the follow-up ANOVA with repeated measures did not confirm differences between the final acquisition block A4 and the retention block R for the constant, absolute and variable error (see Figures 2-4).

3.3. Transfer

The MANOVA indicated differences in timing errors between retention block R and transfer block T (see Figures 2-4). That is, a significant main effect for block was revealed (Wilks □ = .517, *F*(3, 57) = 17.7, p < . 001, η^2 = .48), while the group by block interaction just failed to reach significance (Wilks □ = .874, *F*(3, 57) = 2.73, p = . 052, η^2 = .13). However, the group by block by task by sequence interaction was found significant (Wilks □ = .855, *F*(3, 57) = 3.21, p < . 05, η^2 = .15). The separate follow up RM-ANOVA's for CE, AE and VE are reported in the sections below.

[3] Because we are only interested to what degrees practice effects were relatively permanent (i.e., differences between acquisition and retention), we do not report significant effects that do not involve the factor block (In fact, effects for group and task were similar to what is reported in section *3.1. Acquisition*).

3.3.1. Constant error (CE)

The constant errors during retention block R and transfer block T are shown in Figure 2. For the CE, there were significant effects of block, $F(1, 59) = 52.9$, $p < .001$, $\eta^2 = .47$, and group by block $F(1, 59) = 5.02$, $p < .05$, $\eta^2 = .08$. Post hoc comparisons indicated that the response was relatively delayed in the transfer block T (155 ms) compared to the retention block R (-3 ms). This delay, however, was much more pronounced for the CP-group (i.e., 6 versus 215 ms) than for the TD-group (-14 versus 95 ms), resulting in significantly larger CE for the CP-group than the TD-group in the transfer block T. The significant group by block by task by sequence interaction, $F(1, 59) = 5.13$, $p < .05$, $\eta^2 = .08$, indicated this delay could be attributed to performance on the gesture task by the CP-group that first practiced the abstract task. In other words, in the transfer block CE was larger for the gesture task than for the button press task, but only for the CP-group that started with practice on the gesture task.

3.3.2. Absolute error (AE)

For the absolute error there were no significant effects of block, suggesting that the patterns of absolute errors were no different during transfer as compared to retention (see Figure 3).

3.3.3. Variable error (VE)

The ANOVA with repeated measures for VE confirmed significant effects of block, $F(1, 59) = 5.02$, p < .05, $\eta^2 = .08$, and group by block by task by sequence, $F(1, 59) = 6.81$, $p < .05$, $\eta^2 = .10$. The variable error was smaller (!) in the transfer block T (175 ms) than during the retention block R (216 ms). Post hoc further indicated that the decreased VE in the transfer block T only occurred for the gesture task in the CP-group that started practicing on the abstract gesture task. The remaining three groups did not show significantly reduced VE during transfer.

4. Discussion

The current study investigated motor performance on two coincidence timing tasks in individuals with CP. The tasks were performed in a tangible, natural environment (i.e., not unlike the Bassin Anticipation Timer is normally used, see Shea & Ashby, 1981) and a more abstract virtual environment. Of special interest were performance and learning differences between tasks, and transfer of learning across environments. That is, treatment programs for individuals with CP increasingly use virtual environments (VR) to improve motor functioning. Yet, although these programs are successful in terms of adherence, it remains unclear if increases in motor functioning can be achieved in virtual environments, and if any, if they transfer positively to motor functioning in natural environments. Although similarity in performance and learning, and even proactive facilitation (see Barch, 1953) across environments has often been assumed, it has not been investigated in much detail for individuals with CP (cf. Van der Weel et al., 1991).

The current findings show that typically developing individuals did not encounter much difficulty in performing the two tasks. They were already relatively accurate during the first acquisition trials and maintained similar performance levels during the remainder of the experiment, although they tended to be somewhat late for the gesture task. Also transfer between the two tasks did not significantly affect timing accuracy (i.e., they performed at similar levels irrespective of the task they practiced first). By contrast, individuals with CP were less accurate, particularly on the more abstract gesture task. Importantly, however, performance on the coincidence timing significantly improved, despite the amount of practice being relatively low (i.e., 20 trials), and this improvent was relatively permanent (i.e., was upheld during retention). Timing accuracy after acquisition, however, did still not match accuracy of their typically developing peers: both absolute and variable errors remained larger among the individuals with CP and -on average- were still not within the limits for successful interception.

With regard to transfer to a higher speed, constant error indicated that the response was relatively delayed in the transfer block with higher target speed compared to the retention block and again this delay appeared more pronounced for the CP-group (i.e., 6 versus 215 ms) than for the TD-group (-14 versus 95 ms). In other words, both groups showed a delayed response when the speed was increased. This was especially true on the gesture task among individuals with CP who had started practicing on this more abstract task. They clearly had more trouble adapting to the higher speed. It is not completely clear whether this is a failure to adjust movement speed to object speed (i.e., a perceptual-motor coupling problem) or whether they were incapable of achieving the higher movement speeds (i.e., a motor problem). Interestingly, the variable error showed that this CP-group also became less variable when confronted with the higher movement speed during the transfer block, although only in the gesture task. This lower variability might reflect that they were indeed performing at the upper limits of speed, which would decrease inter-trial variability. However, at present this is mostly speculation; the issue of transfer to different speeds clearly deserves additional experimentation.

In summary, despite the motor difficulties in individuals with CP, it is clear that they can still improve motor performance – at least on the relatively simple tasks of the present study (see also Robert, Guberec, Sveistrup & Levin, 2013; Hung & Gordon, 2013; Gofer-Levi, Silberg, Brezner & Vakil, 2013; Krebs et al., 2012). This of course highlights the relevance of rehabilitation programs, and research to find ways to optimize these programs as much as possible.

The current study, however, also indicates that we should be careful in implementing virtual environments when attempting to enhance motor functioning of individuals with CP in daily natural environment. That is, timing performance of individuals with CP was less accurate on the abstract gesture task than on the more tangible button-press task, while this was not the case among typically developing individuals (i.e., increased absolute and variable errors). Importantly, there were also no indications for positive transfer for the individuals with CP when changing from a virtual to a more natural task environment –as is taken for granted when using virtual environments as rehabilitation tool. The improvements in coincidence timing that were observed were specific to the practice environment: practice on the abstract gesture task did neither facilitate nor interfere with subsequent performance or learning on the more tangible task. Obviously, we do not know if this would also be true for other across task transfers from virtual to natural environment and after more prolonged training periods – future work should scrutinize this-, but if correct and given that individuals with CP tend perform worse in virtual environments (as the current study shows), then we must indeed be cautious in adopting virtual reality environments in CP treatment programs.

Based on the present findings, we can only speculate why performance of the individuals with CP was worse on the more abstract task in the virtual environment, while no such differences were observed for typically developing individuals. Clearly, a task that involves a direct interaction with the environment including physical contact (as in the button-press task) generates a richer pool of information for guiding movement than a more abstract task in a virtual environment (as in the gesture task). Except for visual sources of information, which are available in both tasks, physical contact also generates tactile information that can be used to adapt the movement to environment (i.e., the 'falling cube'). Hence, the two tasks depend on different information-movement couplings. One may speculate, given that individuals with CP have poorer proprioceptive/tactile control (Robert et al, 2013; Wingert, Burton, Sinclair, Brunstrom & Damiano, 2008). Tactile Wingert et al., (2008), that virtual environments leads them to exploit this information source even less than they already normally do (van der Meer & van der Weel, 1999; van Roon, Steenbergen & Meulenbroek, 2005) or become more dependent on other feedback sources (e.g. the error feedback in the current experiment).

5. Conclusion

In conclusion, this study compared performance of individuals with CP on coincidence timing task in more natural and more abstract virtual environments. It showed that timing accuracy was degraded in individuals with CP compared to typically developing individuals, particularly in the more abstract task in the virtual environment. Encouraging, however, the individuals with CP were capable of improving performance, even after the current short bout of practice. This learning, however, was specific to the practice environment. No transfer of learning across task and environments took place. This effect may have important ramifications for the use of virtual environments in motor rehabilitation programs for individual with CP.

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ARTIGO 2

MOTOR LEARNING THROUGH VIRTUAL REALITY IN CEREBRAL PALSY – A LITERATURE REVIEW.

Thais Massetti[I], Talita Dias da Silva[II-III], Denise Cardoso Ribeiro[I], Silvia Regina Pinheiro Malheiros[IV], Alessandro Hervaldo Nicolai Ré[I], Francis Meire Favero[II], Carlos Bandeira de Mello Monteiro[I].

I - Universidade de São Paulo, São Paulo, Brazil

II - Universidade Federal de São Paulo, São Paulo, Brazil

III - Harvard School of Public Health, Cambridge, Massachusetts, USA

IV - Faculdade de Medicina do ABC, Santo André, SP, Brazil

E-mail: thaismassetti@terra.com.br

Phone: 55- 11- 947458932

ABSTRACT

Cerebral palsy is a well-recognized neurodevelopmental condition beginning in early childhood and persisting throughout life and is considered the most common non-progressive neurological disease of childhood. Subjects with cerebral palsy present complex motor skill disorders, the primary deficits being abnormal muscle tone, which affects posture and movement, alteration of balance and motor coordination, decrease in strength and loss of selective motor control with secondary issues of contracture and bone deformity. This population may have difficulties in motor skill learning processes. Skill learning is learning as a result of repeated exposure and practice. Due to the increasing use of virtual reality in rehabilitation and the significance of motor development learning of subjects with cerebral palsy, we have recognized the need for studies in this area. The purpose of this study was to investigate the results shown in previous studies for motor learning with virtual reality in patients with cerebral palsy. Initially, 40 studies were found, but 30 articles were excluded, as they did not fulfil the inclusion criteria. The data extracted from the ten eligible studies is summarized. The studies showed benefit from the use of Virtual Reality in children with cerebral palsy in gross motor function and improvements in motor learning with skill transfer to real-life situations. Therefore, virtual reality seems to be a promising resource and a strategic option for care of these children. However, there are few studies about motor learning with virtual reality use. The long term benefits of RV therapy are still unknown.

KEYWORDS: cerebral palsy, virtual reality and motor learning.

INTRODUCTION

Cerebral palsy (CP) is a well-recognized neurodevelopmental condition beginning in early childhood and persisting throughout life; it is considered the most common non-progressive neurological disease of childhood.[1] Motor disorders of individuals with CP are often accompanied by loss of functionality and dependence on others for many of the daily activities. Inactivity leads to a cycle of de-conditioning that results in the impairment of multiple physiological systems. The result is physical deterioration and subsequent further reduction in daily function.[2]

Papavasiliou[3] states that subjects with CP present complex motor skill disorders, the primary deficits being abnormal muscle tone which affects posture and movement, alteration of balance and motor coordination, decrease in strength and loss of selective motor control with secondary issues of contracture and bone deformity. All of these particular disorders of CP hinder performance of motor abilities and consequently prevent the learning of daily skills.

According to Savion-Lemieux et al[4] motor skill learning is the process by which motor skills come to be effortlessly performed through practice and as a result of repeated exposure and practice. Considering motor skill learning, little is known about the effects of developmental disorders, such as CP, on the ability to acquire new skills.

Motor learning is a phenomenon that refers to inside changes, relatively permanent, leading to the acquired ability to perform motor skills. Such changes occur in order to ensure that the objective is achieved and they derive from experience and practice, resulting in the acquisition, retention and transfer of motor skills[5]. However, motor learning can be measured by improvements in performance, which can be seen to increase and correct errors of execution and to decrease the duration of the task.

The socio-cultural context in which the action is assumed to be performed influences the child's learning process and the child's opportunity to develop strategies for action. Action requires interpretation and creativity, but is not always explicit or even conscious. A child acts in different situations depending on its knowledge, experience, and understanding of the situation[3].

In this sense, a current possibility for evaluating motor learning is related to interactive computer systems, such as virtual reality (VR). The use of video games with a VR device has been gaining ground in the rehabilitation process.

VR refers to a simulated interactive environment. According to Leon et al.[6] VR aims to create a visual, auditory and sometimes tactile and olfactory environment that appears real and enables the human user to become immersed in the interactive experience.

Some authors have reviewed studies on cerebral palsy and VR; Snider et al.[7] carried out a literature review observing the results of VR as a therapeutic modality for children with CP. The research was performed with no time limitation and systematized, using 11 articles for results. They noted a shortage of well-designed studies investigating the benefits of VR therapy in the rehabilitation of children with CP. A relevant point of this study was the difficulty in presenting scientific evidence, mainly because most studies are experimental and observational with small samples.

Michelle et al.[8] reviewed VR in pediatric neurorehabilitation, using evidence published in the last decade. Thirteen articles were located among the findings on the use of VR in CP; they also observed that the studies located had small samples and that their levels of scientific significance were low. They suggested that future approaches be performed with more homogeneous groups and standardization of methodology, probably by well-designed clinical tests.

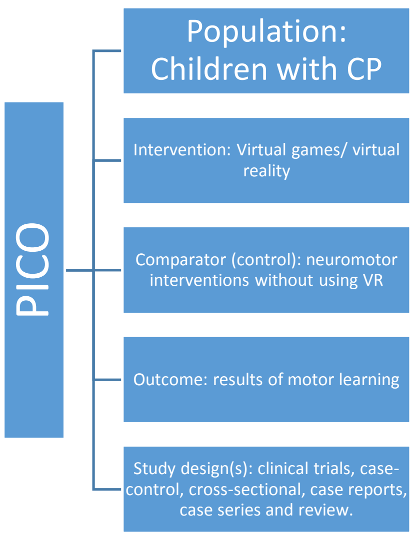
On the other hand, Sveistrup et al.[9] located 12 articles on CP that observed the results of intervention programs that used virtual reality. In the results they observed the impact of VR; however they found that the studies ranged widely in terms of improvement scale, task duration and number of participants. Although still preliminary, these results suggest that the simple application of virtual reality has a significant impact on physical and psychosocial variables.

Due to the increasing use of VR in rehabilitation, the importance of motor learning in the development of those with CP and the need for current knowledge in this field, the objective of this work was to review the literature on themes relating to motor learning, VR and CP. The purpose of this study was to investigate the results shown in previous studies on motor learning with VR use in patients with cerebral palsy. We believe that the results will offer references for intervention and future scientific research.

METHOD

Figure 1 illustrates the search strategy used to locate and compare different works. It is based on PICO's and follows the method previously used by Snider et al.[7]

Figure 1 - Representation of the search strategy - PICOs



A bibliographic review was performed without time limitation. The research was carried out using PubMed. Considering keywords, we included articles that showed the three terms cerebral palsy, virtual reality and motor learning.

Increase confidence in the selection of articles, all potentially relevant articles having been reviewed independently by two researchers, who after reading through all of them, reached consensus to establish which articles fulfilled the inclusion criteria[10].

There are many currently used scales that help with the evaluation of studies, the most common in the rehabilitation area being the PEDro[11] scale. This scale was developed by the Physiotherapy Evidence Database to be used in experimental studies and has a total score of 10 points, including evaluation criteria of internal validity and presentation of statical analysis used.[11]

In order to demonstrate the methodological quality of the studies an was considered to present a good level of evidence if it attained a score equal to or higher than 6 according to the PEDro evaluation scale. This criterion was based on the work by Snider at al,[7] which considers studies scoring 9–10 on the PEDro scale as methodologically 'Excellent', scoring 6–8, as 'Good', 4–5, as 'Fair' and below 4, as 'Poor'.

RESULTS

Initially, 40 studies were found, 30 articles were excluded as not fulfilling the inclusion criteria (Figure 2). The data extracted from the ten eligible studies are summarized in Tables 1 and 2. The PEDro scale results are shown in Table 3.

Figure 2. Flow chart of search strategy and selection process.

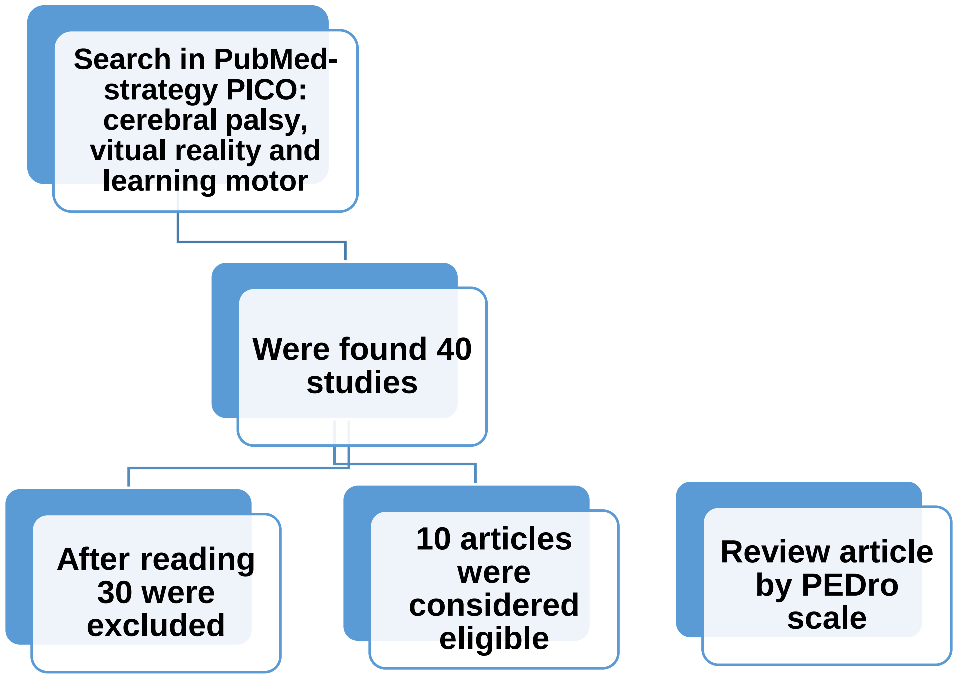


Table 1. Articles related to virtual reality and motor learning.

TYPE OF ARTICLE	
Experimental study	2
Pilot study	2
Case control	2
Review	2
Clinical trial	2

Table 2. Synthesis of manuscripts on virtual reality and motor learning.

C. Gordon et al. 2012[12]	Due to the lack of a comparative group, it is difficult to say whether the changes observed in gross motor function were due to the training programme, a learning effect or natural changes. However, these results indicate that there may be some potential for training with the Nintendo Wii to have an impact on gross motor function, and research studies should be conducted to explore this hypothesis.
Howcroft J. et al. 2012[13]	While all games may encourage motor learning to some extent, AVGs can be strategically selected to address specific therapeutic. Active video game (AVG) play for physical activity promotion and rehabilitation therapies in children with cerebral palsy (CP), through a quantitative exploration of energy expenditure, muscle activation, and quality of movement. AVG play via a low-cost,

	commercially available system can offer an enjoyable opportunity for light to moderate physical activity in children with CP.
Marie Brien, et al. 2011[14]	Results showed improvements in motor learning with skill transfer and integration into real-life situations. Functional balance and mobility in adolescents with cerebral palsy classified at GMFCS level I improve with intense, short duration VR intervention, and changes are maintained at 1-month post-training.
Leon M Straker et al. 2011[6]	Improvements in performance in VR are useful if they lead to improvements in real-world performance. This suggests VR games could improve real-world motor skills in children and could increase children's confidence, which would be additionally beneficial. VR electronic games may improve these children's skills by providing gross motor practice involving a high level of visual-spatial integration, but in a context which is private, and provides strong motivation through enjoyment of the game and the challenge of self-competition. However this will only occur if the nature of the movement required is suitable.
Michelle Wang, Denise Reid. 2011[8]	Using VR as an educational and therapeutic tool allows instructors and therapists to offer both flexibility and control when administering treatments, increasing the probability of skill transfer and ensuring safety during learning.
Golomb M. R. et al. 2010[15]	Improved function appears to be reflected in functional brain changes. Use of remotely monitored virtual reality video game tele-rehabilitation appears to produce improved hand function and forearm bone health (as measured by DXA and pQCT) in adolescents with chronic disability who practice regularly.
Shira Yalon-Chamovitz, Patrice L. (Tamar) Weiss. 2008[16]	The participants demonstrated clear preferences, initiation and learning. The VR-based activities were perceived by the participants to be enjoyable and successful. They performed consistently and maintained a high level of interest throughout the intervention period. VR appears to provide varied and motivating opportunities for leisure activities among young adults with intellectual and physical disabilities. Its ease of use and adaptability make it a feasible option for this population.
H. Sveistrup et al. 2004[9]	The impact of VR exercise participation ranged from improvements in clinical measures of functional balance and mobility, time on task, as well as participant and care provider perceptions of enjoyment, independence and confidence. Although still preliminary, the data suggest that simple applications of virtual reality have significant impacts on physical and psychosocial variables. Possibilities for and benefits of home and community-based access to virtual reality-based programs are explored.
Luanda André Collange	The combination of transcranial stimulation and physical therapy resources will provide the training for a specific task with multiple rhythmic repetitions of the phases of the gait cycle, providing rich sensory stimuli with a modified excitability

Grecco et al. 2013[17]	threshold of the primary motor cortex, to enhance local synaptic efficacy and potentiate motor learning. The combination physical therapy resources will provide the training of a specific task with multiple repetitions of the phases of the gait cycle, promoting rich sensory proprioceptive and visual) stimuli with a modified threshold of excitability of the primary motor cortex (enhanced local synaptic efficacy), thereby potentiating motor learning.
De Mello Monteiro CB et al. 2014	With the growing accessibility of computer-assisted technology, rehabilitation programs for individuals with cerebral palsy (CP) increasingly use virtual reality environments to enhance motor practice. The results showed that individuals with CP timed less accurate than typically developing individuals, especially for the more abstract task in the virtual environment. The individuals with CP did—as did their typically developing peers—improve coincidence timing with practice on both tasks. Importantly, however, these improvements were specific to the practice environment; there was no transfer of learning.

Table 3. PEDro scale results.

Score	Number of articles
2	3
3	1
5	1
6	2
8	1
Not applicable	2

DISCUSSION

Due to the importance of motor learning and the advance of technology in the use of virtual tasks in rehabilitation programs in people with CP, the main objective of this work was to carry out a review of this subject.

One of the characteristics observed in the studies found was the number of people evaluated. Most studies included in this review had small sample sizes, which limited the extent to which results could be generalized and could impact the assessed outcomes. It is necessary to ensure that the sample represents the population. It is obviously important to use sample calculus to determine the number of necessary elements in order to obtain valid results, because an increase in the sample size will lead to increased accuracy in the population estimates. In the studies found, the number of participants was between 3 and 64 subjects. The research of de Mello Monteiro et al.[20], included 64 individuals, 32 with CP and 32 normally developing individuals; all were observed practicing two coincidence-timing tasks. In the more tangible button-press task, the individuals were required to ‘intercept’ a falling virtual object at the moment it reached the interception point by pressing a key. In the more abstract, less tangible task, they were instructed to ‘intercept’ the virtual object by making a hand movement in a virtual environment. Results showed that individuals with CP scored less accurately than normal controls. However improvements in performance were specific to the practice environment; there was no transfer of learning.

Yalon-Chamovitz et al[16] evaluated the largest number of participants, 33 people with CP including 23 males and 10 females with a diagnosis of CP and moderate or mild mental disabilities. This study had subjects in the experimental group and in the control group, but the experimental group and the control group were composed of the same population, decreasing the comparison effect. The fact that the control group did not present a number equal to or larger than the intervention group also reduces the confidence of the results. on The other hand, Howcroft et al. (2012)[13] evaluated 17 people with CP, but did not use a control group. In spite of the fact that discrepancies at baseline between the control and intervention groups were not always considered, the use of a control group always provides interesting data.

The studies of Gordon et al.[12], Golomb et al.[15] and Brien et al.[14] included much lower numbers of participants and no control groups. Brien et al.[14] state that studies with larger samples are necessary to increase validity and trust, and that groups with differences between CP subpopulations and with more homogeneous demographic groups (gender, age), would collectively lead to better results, because the study noted limitations in performing statistical analysis and possible difficulties in generalizing the observed outcomes.

Among the reviewed studies, some important convergence points can be found relating to gross motor function and the impact on CP. Straker et al.[6], Gordon et al.[12] and Brien et al.[14] claim that virtual reality can improve motor ability in this population.

Further investigation is necessary to examine the effectiveness of different training protocols for intense VR interventions in children in younger age groups, at different levels of motor function.[14] Moreover, additional research is needed to determine the intensity, frequency, and duration of the VR intervention required to best affect functional balance and mobility in children and adolescents with CP.[14]

Brien et al.[14] hypothesized that complex balance and coordination skills in walking performance, walking speed, endurance, stair climbing and descent would be improved in these children and that these improvements would be maintained at one week and one month following the end of training with VR. Results from their study support two major findings: (i) the data suggest that functional balance and mobility in adolescents with CP can improve with an intense, short duration VR intervention and (ii) improvements in outcome measures are maintained for at least one month following VR training[14].

It is difficult to say whether the changes observed in gross motor function were due to the training program, to a learning effect or to natural changes.[12] However, these results indicate that there may be some potential for training with a VR environment (like Nintendo Wii) to have an impact on gross motor function, and research studies should be conducted to explore this hypothesis.[12]

The VR environment provides vibrotactile, visual (for example by way of the on-screen avatar), auditory, cognitive (for example, through game scores and performance) and feedback to the user[13]. Grecco et al.[17] reported that feedback provided by the image generates positive reinforcement, thereby facilitating the practice and perfection of the exercises. Gordon et al.[12] and Straker et al.[6] reported that the training of these patients with VR devices may have a positive impact, because of the high level of visual and spacial integration.

Considering motor learning, Howcroft et al.[13] report that motor learning depends on factors such as improvement (in performance), consistency (uniformity in the results of a task) and stability. The learning of a motor task includes many principles of learning. Through practice, the individual has the opportunity to experience alternatives in finding solutions to a given motor problem. Practice is fundamental to the learner for the acquisition of motor skills. The objectives can result in stable and accurate performance and ability to overcome difficulties imposed by environmental or physical factors pre-established by the pathology already present.

Generally, children learn cognitive and motor skills by training and through reasoning.[18] Training implies acquiring habits of mind and behaviour that have been shaped by others, enabling the child to acquire the skills required to fit in.[18]

Using VR as an educational and therapeutic tool allows instructors and therapists to offer both flexibility and control when administering treatments, increasing the probability of skill transfer and ensuring safety during learning[8]. Flexibility is essential when designing therapeutic programs because children with neurodevelopmental disorders are not only heterogeneous, but also require extra learning support.[8] The treatment programs for individuals with CP increasingly use virtual environments (VR) to improve motor functioning. Yet, although these programs are successful in terms of adherence, it remains unclear if increases in motor functioning in virtual environments transfer positively to motor functioning in natural environments.[20]

Three studies included in this review, Straker et al,[6] Golomb et al[15] and Grecco et al[17] believe that motor learning can be potentiated with VR, with transfer of motor abilities and real-life integration and observed that VR can also be an important educational and therapeutic tool. Forms of physical therapy seek to promote motor learning through the administration of functional training and multiple sensory stimuli.[17]

Although it is clear that VR systems rely on hardware and software, their use in all rehabilitation situations requires clinicians to make decisions about the appropriateness of the intervention for the patient, implementation of treatment parameters and progression through different levels of the game or task.[19]

There is evidence to confirm that VR is a promising tool in the treatment of such children.[17] The potential uses of VR are vast, yet validation of findings is necessary as the current body of research is dominated by low quality evidence. Despite the benefits, this review shows that more research must be realized to confirm these findings, especially considering the training transfer from VR to a real environment.

CONCLUSION

The studies showed the benefits of the use of VR in children with CP in gross motor function and improvements in motor learning with skill transfer to real-life situations. Therefore, it seems to be a promising resource and a strategic option for care of these children.

However, there are few studies about motor learning with use of VR. The long-term benefits of VR therapy are still unknown. The published studies need to be better designed and with rigorous methodology. Further research of higher methodological rigour is required. A high quality random clinical trial with a large sample is needed to determine that the use of VR for people with CP can be better than traditional rehabilitation interventions.

AUTHORS' CONTRIBUTIONS

All authors participated in the acquisition of data and revision of the manuscript. All authors determined the design, interpreted the data and drafted the manuscript. All authors read and gave final approval for the version submitted for publication.

DECLARATION OF INTEREST

The author reports no conflict of interest. The author alone is solely responsible for the content and writing of this paper.

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4. CONTRIBUIÇÃO DOS ARTIGOS PUBLICADOS

CONTRIBUIÇÃO DOS ARTIGOS PUBLICADOS

Os trabalhos publicados contribuem para o esclarecimento da utilização da Realidade Virtual em pessoas com Paralisia Cerebral. Apesar das dúvidas existentes sobre benefícios da utilização de tarefas virtuais em programas de reabilitação, os resultados demonstram perspectivas positivas. Porém, ambientes virtuais devem ser usados com cautela principalmente na tentativa de transferir aprendizagem motora para o ambiente real.

5. CONCLUSÕES

CONCLUSÕES

Diante dos resultados dos trabalhos publicados podemos enfatizar que os benefícios do uso de Realidade Virtual em crianças com PC são bastante promissores. Verificou-se melhoras na função motora grossa e aprendizagem motora com a transferência de habilidades na mudança da tarefa. Desta forma, a utilização da RV na reabilitação de pessoas com PC é uma opção e estratégia interessante para organização de futuros programas terapêuticos.

No entanto, a pouca quantidade de trabalhos que analisaram a aprendizagem motora com uso de RV direciona para a necessidade de novos estudos. Os benefícios a longo prazo da intervenção por meio de tarefas virtuais ainda são desconhecidos sendo fundamental a existência de novas pesquisas baseadas em projetos bem planejados e com metodologia rigorosa.

Considerando os resultados da pesquisa comparando ambiente virtual e real por meio de tarefa de timing coincidente virtual, os resultados obtidos indicaram que as pessoas com PC apresentaram menor acurácia do que as pessoas com desenvolvimento típico, no entanto melhoraram seu desempenho durante a tarefa. É importante ressaltar que os resultados também mostraram que depois de praticar a tarefa sem contato físico, o desempenho das pessoas com PC na tarefa com contato físico manteve-se pior do que o desempenho de pessoas que praticaram a primeira tarefa com contato físico. Podemos concluir que a utilização de ambientes virtuais para reabilitação motora em pessoas com PC deve ser considerada com cautela, já que o ambiente em que a tarefa é realizada apresenta implicações importantes na aprendizagem motora.

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7. ANEXOS

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Research in Developmental Disabilities

Transfer of motor learning from virtual to natural environments in individuals with cerebral palsy

Carlos Bandeira de Mello Monteiro [a,*], Thais Massetti [a], Talita Dias da Silva [a], John van der Kamp [b,c], Luiz Carlos de Abreu [d], Claudio Leone [d], Geert J.P. Savelsbergh [b,e]

[a] *School of Arts, Sciences and Humanities, University of São Paulo, São Paulo, SP, Brazil*
[b] *MOVE Research Institute Amsterdam, Faculty of Human Movement Sciences, VU University, Van der Boechorststraat 7, 1081 BT Amsterdam, The Netherlands*
[c] *Institute of Human Performance, University of Hong Kong, 111-113 Pokfulam Road, Pokfulam, Hong Kong*
[d] *School of Public Health, University of São Paulo, Av. Dr. Arnaldo, 715, CEP: 01255-000 São Paulo, SP, Brazil*
[e] *Academy for Physical Education, University of Applied Sciences, Dr. Meurerlaan 8, 1067 SM Amsterdam, The Netherlands*

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User–computer interface

ABSTRACT

With the growing accessibility of computer-assisted technology, rehabilitation programs for individuals with cerebral palsy (CP) increasingly use virtual reality environments to enhance motor practice. Thus, it is important to examine whether performance improvements in the virtual environment generalize to the natural environment. To examine this issue, we had 64 individuals, 32 of which were individuals with CP and 32 typically developing individuals, practice two coincidence-timing tasks. In the more tangible button-press task, the individuals were required to 'intercept' a falling virtual object at the moment it reached the interception point by pressing a key. In the more abstract, less tangible task, they were instructed to 'intercept' the virtual object by making a hand movement in a virtual environment. The results showed that individuals with CP timed less accurate than typically developing individuals, especially for the more abstract task in the virtual environment. The individuals with CP did—as did their typically developing peers—improve coincidence timing with practice on both tasks. Importantly, however, these improvements were specific to the practice environment; there was no transfer of learning. It is concluded that the implementation of virtual environments for motor rehabilitation in individuals with CP should not be taken for granted but needs to be considered carefully.

1. Introduction

The motor disorders of individuals with cerebral palsy (CP) are often accompanied by loss of functionality and dependence on others in daily activities. In order to manage these problems, most individuals with CP take part in continuous rehabilitation programs, which often focus on, and sometimes prioritize, the correct movement and positioning

* Corresponding author at: University of São Paulo, School of Arts, Sciences and Humanities, Av. Arlindo Béttio, 1000, Ermelino Matarazzo 03828-000, São Paulo, Brazil. Tel.: +55 11 999530716.
E-mail addresses: carlosfisi@uol.com.br, carlosmonteiro@usp.br (C.B. de Mello Monteiro).

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of the limbs and the body (Kułak, Okurowska-Zawada, Sienkiewicz, Paszko-Patej, & Krajewska-Kułak, 2010; Tsai,Yang, Chan, Huang, & Wong, 2002). Recently, with the growing accessibility of computer-assisted technology, rehabilitation programs increasingly use virtual reality environments to enhance dedicated practice (Barton, Hawken, Foster, Holmes, & Butler, 2013; Burdea et al., 2013; Mitchell, Ziviani, Oftedal, & Boyd, 2012; Riener et al., 2013). The advantages of virtual reality include practice at home (i.e., online), independent or in interaction with others (e.g., e-games), and with or without supervision of a professional (Hurkmans,Van Den Berg-Emons, & Stam, 2010; Huber et al., 2010; Vissers et al., 2008). Accordingly, Shih, Chang, and Shih (2010) have argued that virtual environments may allow people with disabilities, when immersed, to significantly improve their level of interaction with the environment. Yet, virtual reality as an intervention for individuals with CP is relatively new, and although research is rapidly evolving, its benefits and limitations have not been extensively researched (Mitchell et al., 2012). Hence, the present study aimed to add to the knowledge base regarding the learning of perceptual-motor skills in virtual environments in individuals with CP.

In this respect, Brien and Sveistrup (2011) examined the effects of an intensive virtual-reality training program on functional balance and mobility in four adolescents with CP. During the intervention, the participants interacted for 90 min on five consecutive days with virtual objects to perform tasks that were adjusted to the individual in terms of complexity. In dynamic balance, for instance, the participants were challenged to elicit weight shifts while standing in a single-leg stance by encouraging them to reach for distant objects, or to squat, jump and so on. It was found that among the four participants, virtual-reality practice improved functional balance, the changes being retained until one month post-training. In addition, Chen et al. (2007) provided four children with CP with an individualized virtual-reality program for 2 h per week over a period of four weeks. During the intervention, the child wore a sensor glove creating movements in a three-dimensional virtual environment. The children practiced reaching tasks. After intervention, three children showed small but significant changes in reaching kinematics, which were (partially) maintained four weeks after intervention. Together, these results demonstrate the potential to improve perceptual-motor skills in children and adolescents with CP. Yet, the number of participants is relatively small, and also the generalization to natural environments remained largely unanswered (see also Snider, Majnemer, & Darsaklis, 2010). Similarly, Berry et al. (2011) and Howcroft et al. (2012) showed improvements in movement kinematics on video games in virtual environments (e.g., bowling, boxing and tennis) among a larger group of children with CP; yet, they did not assess transfer to the natural environment.

It may seem straightforward—certainly for immersing virtual environments—that improvements do generalize to performance in more natural environments. There are some caveats, however. In virtual-environments, participants actually pretend as if they perform a particular task. Consequently, performance is often relatively abstract and directed to intangible objects. It is not unlikely therefore that virtual environments elicit different spatio-temporal organization of the movement than natural environments, especially among participants with movement disorders. For instance, Weel, Van der Meer, and Lee (1991) compared the performance of children with CP for two interceptive action tasks that differed in their degrees of abstractness (i.e., more or less representative of an interceptive action that is normally produced in natural environments). They found that CP children achieved a significantly larger range of motion when they were asked to perform a concrete "bang-the-drum"-task with a drumstick than when they were asked to perform a more abstract rotate the drumstick "as-far-as-you-can"-task, requiring exactly the same pronation and supination movements of the forearm. Typically developing nursery-school children, however, did not show different movement patterns for the two tasks (see also Weel, Van der Meer, & Lee, 1996).

These findings neatly fit within the ecological approach to perception and action (Gibson, 1986). The ecological approach holds that for each action a specific information–movement coupling is assembled. These information–movement couplings are considered to be task- and situation-specific. The ecological approach holds that different tasks or situations demand the exploitation or attunement to different sources of information to control the movement (e.g., Savelsbergh & Van der Kamp, 2000; Van der Kamp, Oudejans, & Savelsbergh, 2003). This may also be true when comparing similar actions in natural and more abstract virtual environments. Consequently, the information–movement coupling that underlies the task of hitting a real ball with a tennis racquet may or may not be distinct from the coupling that underlies the more abstract and less tangible task of hitting a virtual tennis ball with a Wii-console. The two tasks do not necessarily lead to similar performance outcomes. This accords with neuropsychological findings that grasping a real object involves different parts of the visual system than pantomime grasping, in which the performer acts as if they are grasping a real object (Goodale, Jakobson, & Keillor, 1994; see also Milner & Goodale, 2008; Van der Kamp, Rivas, van Doorn, & Savelsbergh, 2008).

Hence the implementation of virtual environments for motor rehabilitation in individuals with CP should not be taken for granted but needs to be considered carefully. Particularly, practice of a relatively abstract (or less tangible) task may result in different movement outcomes and transfer weakly to the natural environment. To examine this issue, we had individuals with cerebral palsy and typically developing individuals practice two coincidence-timing tasks that differed in their degree of abstractness. In the more tangible button-press task, the children were required to 'intercept' a falling virtual object at the moment it reached the interception point by pressing a key on the computer. In the more abstract, less tangible task, they were instructed to 'intercept' the virtual object by making a hand movement (i.e., a waving gesture) in a virtual environment. We were especially interested to find out to which degree performance and learning of the more abstract task differ from performance and learning on the more tangible task, and to what degree learning on the more abstract task transfers to the more tangible task and vice versa. Based upon the above deliberations, we hypothesized that performance and learning may be relatively degraded for the more abstract task, and that the benefits (i.e., proactive facilitation) from learning the more

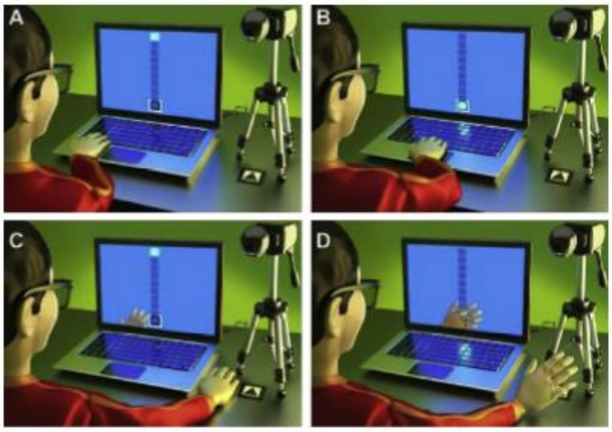

Fig. 1. The button press (A and B) and gesture (C and D) coincidence timing tasks.

abstract task compared to learning (and performing) the more tangible task would be minimal, if any, especially among individuals with CP.

2. Method

2.1. Participants

A total of 64 individuals participated in this study, 32 of which were with CP (24 males and 8 females, mean age = 19 years, ranging between 11 and 28 years) and 32 typically developing individuals that were matched by age and gender to the individuals with CP. Within the CP group, there were 10 individuals with diparetic spasticity, 8 with right spastic hemiparesis, 8 with left spastic hemiparesis and 6 with choreoathetosis hemiparetic spasticity. Criteria for inclusion were a medical diagnosis of CP levels I to IV according to the Gross Motor Function Classification System (GMFCS) (Palisano, Cameron, Rosenbaum, Walter, & Russell, 2006). This classification was made by a professional physiotherapist who specialized in CP. Exclusion criteria were the presence of structured osteoarticular deformities, surgery or chemical neuromuscular blockade in upper limbs within less than six months before participation in the experiment and other comorbidities such as disorders in cognitive function that would prevent comprehension of the experimental instruction. This study was approved by the Ethics Committee for review of research projects of the Escola de Artes, Ciências e Humanidades da Universidade de São Paulo—EACH/USP under protocol number 1033/03. The participants and/or their legal guardians provided written informed consent.

2.2. Material and apparatus

As a precursor to this research, we developed dedicated software[1] that instantaneously superimposes virtual objects over images of the real world captured by a webcam (Microsoft Lifecam VX-800). This allowed us to display the current movement of the participant's hand together with the (pre-programmed) virtual falling object on a monitor in front of the participant.

The coincidence-timing task could either have a virtual (i.e., abstract) or a real (more tangible) interface. For the real interface, a keyboard was used. For the virtual interface, the webcam recorded a marker on the table in-between the monitor and the participant. The images were fed into the computer and analyzed online. Using the dedicated software, it was determined whether or not the participant's hand occluded the marker, which was then fed back to the virtual environment. The coincident timing task was based on the Bassin Anticipation Timer (Corrêa et al., 2005; Harrold & Kozar, 2002; Overdorf, Page, Schweighardt, & McGrath, 2004; Santos, Corrêa, & Freudenheim, 2003; Shea & Ashby, 1981; Williams, 1985; Williams, Jasiewicz, & Simmons, 2001). To this end, 10 3D cubes were displayed simultaneously in a vertical column on a monitor. The

[1] The accuracy and reliability of this coincidence-timing task was tested by the Department of Electronic System Engineering of the Escola Politécnica da Universidade de São Paulo (see also Silva et al., 2013).

cubes turned on (i.e., changed from white to green) and off sequentially (from top to bottom) until the target cube (i.e., the tenth cube) was reached. The task for the participant was to either press the spacebar on the keyboard (i.e., tangible button press task by making contact) or to make a sideward hand gesture as if hitting the target object (i.e., the more abstract gesture task, without making contact) at the exact moment the target cube turned green (Fig. 1).

2.3. Procedure and design

Participants performed the task individually in a quiet room with only the experimenter, who gave the instructions, present. The computer and monitor were placed on a table. The participants were seated in chair, which was adjusted in height according to the needs of the individual. Also a footrest was available, if required. After being seated, the experimenter explained the task verbally and gave three demonstrations of how to perform the coincidence timing tasks. The participants were instructed to place the preferred hand (i.e., the less affected hand) on a mark in front of the target. (The location was individually adjusted but ranged from 2 to 4 cm from the target cube.) Once the first top cube turned on, the individual had to move his or her hand to either touch the target key on the keyboard or to make a hitting gesture in front of the webcam (i.e., occluding the marker), exactly at the moment the bottom target cube turned on. Different sounds were provided as feedback for a hit or miss during acquisition, retention and transfer, the range of error for a hit being −200 to 200 ms.

All participants performed both the button-press and the gesture task. To counterbalance across groups, participants of both the cerebral palsy group (CP group) and the typically developing group (TD group) were randomly assigned to the tangible-task-first-group (these participants practiced the button-press task before performing the gesture task) or the abstract-task-first-group (these participants first practiced the gesture task before performing the button-press task). Each participant performed both tasks in blocks, each block consisting of 20 trial acquisitions, 5 trial retentions and 5 trial transfers. Henceforth, the participant performed a total of 60 trials. During acquisition and retention trials, the cube 'dropped' with a speed of 1.78 m/s, while during transfer, the speed was increased to 2.02 m/s (Corrêa et al., 2005; Silva et al., 2013).

2.4. Data analysis

The dependent variables used were the constant timing error (CE), absolute timing error (AE) and variable timing error (VE), with timing error defined as the time difference between the time the target cube switched on (arrival time) and the time at which the key touched or the gesture was registered. One participant with CP who started with practice on the more tangible task responded very erratically and was identified as an outlier with respect to variable error. This participant was therefore excluded from the analyses. The dependent variables were submitted to a 2 (group: CP, TD) by 2 (sequence: tangible task first, abstract task first) by 2 (task: button-press, gesture) by 2 (block) MANOVA with repeated measures on the last two factors. For the factor block, separate comparisons were made for acquisition (first acquisition block A1 versus final acquisition block A4), retention (A4 versus retention block R) and transfer (R versus transfer block T). Post hoc comparisons were carried out using Tukey-HSD test ($p < 0.05$).

3. Results

3.1. Acquisition

The MANOVA revealed the following significant effects when comparing timing errors in the first acquisition block A1 to errors in the final acquisition block A4: main effects of group (Wilks $\Lambda = 0.494$, $F(3,57) = 19.4$, $p < 0.001$, $\eta^2 = 0.51$), task (Wilks $\Lambda = 0.530$, $F(3,57) = 16.8$, $p < 0.001$, $\eta^2 = 0.47$) and block (Wilks $\Lambda = 0.813$, $F(3,57) = 4.38$, $p < 0.01$, $\eta^2 = 0.19$). Additional significant interactions were revealed for group by task (Wilks $\Lambda = 0.839$, $F(3,57) = 3.63$, $p < 0.05$, $\eta^2 = 0.16$) and group by block (Wilks $\Lambda = 0.870$, $F(3,57) = 2.84$, $p < 0.05$, $\eta^2 = 0.13$). The separate follow up RM-ANOVA's for CE, AE and VE are reported in Section 3.1.1 to section 3.1.3.

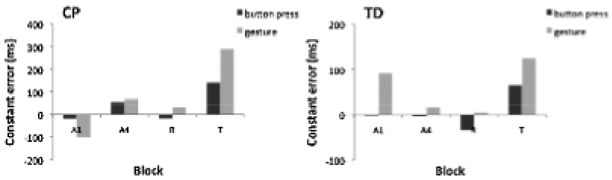

Fig. 2. Constant error (ms) as a function of block and task for the CP group (left panel) and the TD group (right panel). A1–A4: acquisition blocks; R: retention blocks; T: transfer blocks; CP: cerebral palsy; TD: typical development.

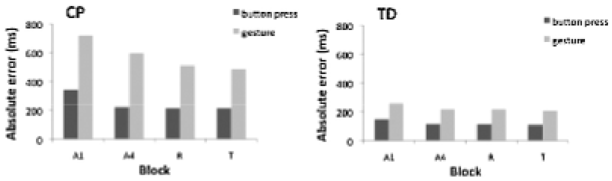

Fig. 3. Absolute error (ms) as a function of block and task for the CP group (left panel) and the TD group (right panel). A1–A4: acquisition blocks; R: retention blocks; T: transfer blocks; CP: cerebral palsy; TD: typical development.

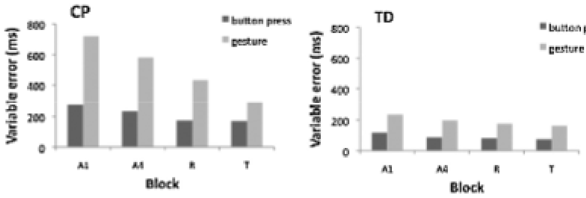

Fig. 4. Variable error (ms) as a function of block and task for the CP group (left panel) and the TD group (right panel). A1–A4: acquisition blocks; R: retention blocks; T: transfer blocks; CP: cerebral palsy; TD: typical development.

3.1.1. Constant error (CE)

The repeated measures ANOVA for CE only confirmed a significant group by block effect, $F(1,59) = 7.36$, $p < 0.01$, $\eta^2 = 0.11$. Post hoc comparisons indicated that the CP group responded significantly earlier in A1 (−60 ms) compared to A4 (61 ms), whereas for the TD group no significant differences occurred between blocks (45 and 7 ms, respectively). Put differently, in the first acquisition block A1 the CP group responded significantly earlier than the TD group, but in the final acquisition block A4 this difference had disappeared (see Fig. 2).

3.1.2. Absolute error (AE)

The pattern of absolute errors is illustrated in Fig. 3. The repeated measures ANOVA for AE showed significant effects for group, $F(1,59) = 50.1$, $p < 0.001$, $\eta^2 = 0.46$, task, $F(1,59) = 34.2$, $p < 0.001$, $\eta^2 = 0.37$, and group by task, $F(1,59) = 10.4$, $p < 0.01$, $\eta^2 = 15$. Post hoc comparisons indicated that the button press task resulted in significantly smaller AE than the gesture task. This difference was only significant for the CP group (282 and 656 ms, respectively) and not for the TD group (130 and 238 ms).[2] Put differently, the CP group had significantly larger AE, but only for the more abstract gesture task. Finally, a main effect for block, $F(1,59) = 11.5$, $p < 0.01$, $\eta^2 = 0.16$, indicated that the AE decreased from the first acquisition block A1 (338 ms) to the final acquisition block A4 (287 ms), irrespective of task and group.

3.1.3. Variable error (VE)

The pattern of variable errors during acquisition is depicted in Fig. 4. Similar to the pattern of absolute errors, the repeated-measures ANOVA for VE confirmed significant main effects of group, $F(1,59) = 35.6$, $p < 0.001$, $\eta^2 = 0.38$, and task, $F(1,59) = 25.8$, $p < 0.001$, $\eta^2 = 0.30$. However, the factors interacted as attested by a significant group by task effect, $F(1,59) = 7.61$, $p < 0.01$, $\eta^2 = 0.11$. Post hoc comparisons indicated that the VE for the button press task (179) was significantly smaller than for the gesture task (435 ms), but only for the CP group (256 and 652 ms, respectively) and not for the TD group (102 and 217 ms). In addition, the block main effect, $F(1,60) = 13.3$, $p < 0.01$, $\eta^2 = 0.18$, indicated that the variable error decreased during acquisition (338 and 275, for the first acquisition block A1 and the final acquisition block A4, respectively).

3.2. Retention

The MANOVA comparing the timing errors in the final acquisition and the retention blocks did only reveal a significant main for block (Wilks $\Lambda = 0.822$, $F(3,57) = 4.13$, $p < 0.05$, $\eta^2 = 0.18$).[3] However, the follow-up ANOVA with repeated measures

[2] Note that errors exceeding 200 ms were failed interceptions.

[3] Because we are only interested to what degrees practice effects were relatively permanent (i.e., differences between acquisition and retention), we do not report significant effects that do not involve the factor block (in fact, effects for group and task were similar to what is reported in Section 3.1).

did not confirm differences between the final acquisition block A4 and the retention block R for the constant, absolute and variable error (see Figs. 2–4).

3.3. Transfer

The MANOVA indicated differences in timing errors between retention block R and transfer block T (see Figs. 2–4). That is, a significant main effect for block was revealed (Wilks $\Lambda = 0.517$, $F(3,57) = 17.7$, $p < 0.001$, $\eta^2 = 0.48$), while the group by block interaction just failed to reach significance (Wilks $\Lambda = 0.874$, $F(3,57) = 2.73$, $p = 0.052$, $\eta^2 = 0.13$). However, the group by block by task by sequence interaction was found significant (Wilks $\Lambda = 0.855$, $F(3,57) = 3.21$, $p < 0.05$, $\eta^2 = 0.15$). The separate follow-up RM-ANOVAs for CE, AE and VE are reported in Section 3.3.1 to section 3.3.3.

3.3.1. Constant error (CE)

The constant errors during retention block R and transfer block T are shown in Fig. 2. For the CE, there were significant effects of block, $F(1,59) = 52.9$, $p < 0.001$, $\eta^2 = 0.47$, and group by block $F(1,59) = 5.02$, $p < 0.05$, $\eta^2 = 0.08$. Post hoc comparisons indicated that the response was relatively delayed in the transfer block T (155 ms) compared to the retention block R (−3 ms). This delay, however, was much more pronounced for the CP group (i.e., 6 versus 215 ms) than for the TD group (−14 versus 95 ms), resulting in significantly larger CE for the CP group than the TD group in the transfer block T. The significant group by block by task by sequence interaction, $F(1,59) = 5.13$, $p < 0.05$, $\eta^2 = 0.08$, indicated this delay could be attributed to performance on the gesture task by the CP group that first practiced the abstract task. In other words, in the transfer block CE was larger for the gesture task than for the button press task, but only for the CP group that started with practice on the gesture task.

3.3.2. Absolute error (AE)

For the absolute error there were no significant effects of block, suggesting that the patterns of absolute errors were no different during transfer as compared to retention (see Fig. 3).

3.3.3. Variable error (VE)

The ANOVA with repeated measures for VE confirmed significant effects of block, $F(1,59) = 5.02$, $p < 0.05$, $\eta^2 = 0.08$, and group by block by task by sequence, $F(1,59) = 6.81$, $p < 0.05$, $\eta^2 = 0.10$. The variable error was smaller (!) in the transfer block T (175 ms) than during the retention block R (216 ms). Post hoc further indicated that the decreased VE in the transfer block T only occurred for the gesture task in the CP group that started practicing on the abstract gesture task. The remaining three groups did not show significantly reduced VE during transfer.

4. Discussion

The current study investigated motor performance of two coincidence timing tasks in individuals with CP. The tasks were performed in a tangible, natural environment (i.e., not unlike the Bassin Anticipation Timer is normally used; see Shea & Ashby, 1981) and a more abstract virtual environment. Of special interest were performance and learning differences between tasks, and transfer of learning across environments. That is, treatment programs for individuals with CP increasingly use virtual environments (VR) to improve motor functioning. Although these programs are successful in terms of adherence, it remains unclear if increases in motor functioning can be achieved in virtual environments, if any, and if they transfer positively to motor functioning in natural environments. Although similarity in performance and learning, and even proactive facilitation (see Barch, 1953) across environments have often been assumed, it has not been investigated in much detail for individuals with CP (cf. Van der Weel et al., 1991).

The current findings show that typically developing individuals did not encounter much difficulty in performing the two tasks. They were already relatively accurate during the first acquisition trials and maintained similar performance levels during the remainder of the experiment, although they tended to be somewhat late for the gesture task. Also transfer between the two tasks did not significantly affect timing accuracy (i.e., they performed at similar levels irrespective of the task they practiced first). In contrast, individuals with CP were less accurate, particularly on the more abstract gesture task. Importantly, however, performance of the coincidence timing significantly improved, despite the amount of practice being relatively low (i.e., 20 trials), and this improvement was relatively permanent (i.e., was upheld during retention). Timing accuracy after acquisition, however, did not still match accuracy of their typically developing peers: both absolute and variable errors remained larger among the individuals with CP and—on average—were still not within the limits for successful interception.

With regard to transfer to a higher speed, constant error indicated that the response was relatively delayed in the transfer block with higher target speed compared to the retention block and again this delay appeared more pronounced for the CP group (i.e., 6 versus 215 ms) than for the TD group (−14 versus 95 ms). In other words, both groups showed a delayed response when the speed was increased. This was especially true for the gesture task among individuals with CP who had started practicing on this more abstract task. They clearly had more trouble adapting to the higher speed. It is not completely clear whether this is a failure to adjust movement speed to object speed (i.e., a perceptual–motor coupling problem) or whether they were incapable of achieving the higher movement speeds (i.e., a motor problem). Interestingly, the variable error showed that this CP group also became less variable when confronted with the higher movement speed during the transfer block, although only in the gesture task. This lower variability might reflect that they were indeed performing at the upper limits of speed, which would decrease inter-trial variability. However, at present this is mostly speculation; the issue of transfer to different speeds clearly deserves additional experimentation.

In summary, despite the motor difficulties in individuals with CP, it is clear that they can still improve motor performance—at least on the relatively simple tasks of the present study (see also Gofer-Levi, Silberg, Brezner, & Vakil, 2013; Hung & Gordon, 2013; Krebs et al., 2012; Robert, Guberec, Sveistrup, & Levin, 2013). This of course highlights the relevance of rehabilitation programs and research to find ways to optimize these programs as much as possible.

The current study, however, also indicates that we should be careful in implementing virtual environments when attempting to enhance motor functioning of individuals with CP in daily natural environment. That is, timing performance of individuals with CP was less accurate for the abstract gesture task than for the more tangible button-press task, while this was not the case among typically developing individuals (i.e., increased absolute and variable errors). Importantly, there were also no indications for positive transfer for the individuals with CP when changing from a virtual to a more natural task environment—as is taken for granted when using virtual environments as rehabilitation tools. The improvements in coincidence timing that were observed were specific to the practice environment: practice of the abstract gesture task did neither facilitate nor interfere with subsequent performance or learning of the more tangible task. Obviously, we do not know if this would also be true for other across task transfers from virtual to natural environment and after more prolonged training periods—future work should scrutinize this—but if correct and given that individuals with CP tend to perform worse in virtual environments (as the current study shows), then we must indeed be cautious in adopting virtual reality environments in CP treatment programs.

Based on the present findings, we can only speculate why performance of the individuals with CP was worse for the more abstract task in the virtual environment, while no such differences were observed for typically developing individuals. Clearly, a task that involves a direct interaction with the environment including physical contact (as in the button-press task) generates a richer pool of information for guiding movement than a more abstract task in a virtual environment (as in the gesture task). Except for visual sources of information, which are available in both tasks, physical contact also generates tactile information that can be used to adapt the movement to the environment (i.e., the 'falling cube'). Hence, the two tasks depend on different information–movement couplings. One may speculate, given that individuals with CP have poorer proprioceptive/tactile control (Robert et al., 2013; Wingert, Burton, Sinclair, Brunstrom, & Damiano, 2008). Tactile Wingert et al. (2008), that virtual environments lead them to exploit this information source even less than they already do (van der Meer & van der Weel, 1999; Roon, Steenbergen, & Meulenbroek, 2005) or become more dependent on other feedback sources (e.g., the error feedback in the current experiment).

5. Conclusion

In conclusion, this study compared the performance of individuals with CP for coincidence timing task in more natural and more abstract virtual environments. It showed that timing accuracy was degraded in individuals with CP compared to typically developing individuals, particularly in the more abstract task in the virtual environment. Encouraging, however, the individuals with CP were capable of improving performance, even after the current short bout of practice. This learning, however, was specific to the practice environment. No transfer of learning across task and environments took place. This effect may have important ramifications for the use of virtual environments in motor rehabilitation programs for individuals with CP.

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REVIEW

Motor learning through virtual reality in cerebral palsy – a literature review

Thais Massetti,[I] Talita Dias da Silva,[II,III] Denise Cardoso Ribeiro,[I] Silvia Regina Pinheiro Malheiros,[IV] Alessandro Hervaldo Nicolai Ré,[I] Francis Meire Favero,[II] Carlos Bandeira de Mello Monteiro[I]

[I]Universidade de São Paulo, São Paulo, Brazil [II]Universidade Federal de São Paulo, São Paulo, Brazil [III]Harvard School of Public Health, Cambridge, Massachusetts, USA [IV]Faculdade de Medicina do ABC, Santo André, SP, Brazil

Cerebral palsy is a well-recognized neurodevelopmental condition beginning in early childhood and persisting throughout life. It is considered the most common non-progressive neurological disease of childhood. Subjects with cerebral palsy present complex motor skill disorders, the primary deficits being abnormal muscle tone that affects posture and movement, alterations of balance and of motor coordination, decrease in strength and loss of selective motor control, with secondary issues of contracture and bone deformity. This population may have difficulties in motor skill learning processes. Skill learning is learning as a result of repeated exposure and practice. Due to the increasing use of virtual reality in rehabilitation and the significance of motor development learning of subjects with cerebral palsy, we have recognized the need for studies in this area. The purpose of this study was to investigate the results of previous studies on motor learning using virtual reality with patients with cerebral palsy. Initially, 40 studies were found, but 30 articles were excluded, as they did not fulfil the inclusion criteria. The data extracted from the ten eligible studies is summarized. The studies showed benefits from the use of virtual reality in children with cerebral palsy in gross motor function and improvements in motor learning with skill transfer to real-life situations. Therefore, virtual reality seems to be a promising resource and a strategic option for care of these children. However, there are few studies about motor learning with virtual reality use. The long term benefits of virtual reality therapy are still unknown.

KEYWORDS: cerebral palsy; virtual reality and motor learning.

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E-mail: thaismassetti@terra.com.br

INTRODUCTION

Cerebral palsy (CP) is a well-recognized neurodevelopmental condition beginning in early childhood and persisting throughout life. It is considered the most common non-progressive neurological disease of childhood.[1] Motor disorders of individuals with CP are often accompanied by loss of functionality and dependence on others for many daily activities. Inactivity leads to a cycle of de-conditioning that results in the impairment of multiple physiological systems. The result is physical deterioration and subsequent further reduction in the performance of daily function.[2]

Papavasiliou[3] states that subjects with CP present complex motor skill disorders. The primary deficits include abnormal muscle tone that affects posture and movement, alteration of balance and motor coordination, decrease in strength and loss of selective motor control, with secondary issues of contracture and bone deformity. All of these particular disorders of CP hinder performance of motor abilities and consequently prevent the learning of daily skills.

According to Savion-Lemieux et al[4], motor skill learning is the process by which motor skills come to be effortlessly performed through practice and as a result of repeated exposure and practice. Considering motor skill learning, little is known about the effects of developmental disorders, such as CP, on the ability to acquire new skills.

Motor learning is a phenomenon that refers to relatively permanent neuromotor changes leading to the acquired ability to perform motor skills. Such changes ensure that the objective is achieved. They are derived from experience and practice, resulting in the acquisition, retention and transfer of motor skills.[5] However, motor learning can be measured by improvements in performance, which can be seen to increase and correct errors of execution and to decrease the duration of the task.

The socio-cultural context in which the action is assumed to be performed influences the child's learning process and the child's opportunity to develop strategies for action. Action requires interpretation and creativity, but is not always explicit or even conscious. A child acts in different situations depending on his/her knowledge, experience, and understanding of the situation[3].

In this sense, a current possibility for evaluating motor learning is related to interactive computer systems, such as

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virtual reality (VR). The use of video games with a VR device has been gaining ground in rehabilitation processes.

VR refers to a simulated interactive environment. According to Leon et al.[6] VR aims to create a visual, auditory and sometimes tactile and olfactory environment that appears real and enables the human user to become immersed in the interactive experience.

Some authors have reviewed studies on cerebral palsy and VR; Snider et al.[7] carried out a literature review observing the results of VR as a therapeutic modality for children with CP. The research was performed with no time limitation and systematized, using 11 articles for results. They noted a shortage of well-designed studies investigating the benefits of VR therapy in the rehabilitation of children with CP. A relevant point of this study was the difficulty in presenting scientific evidence, mainly because most studies are experimental and observational with small samples.

Michelle et al.[8] reviewed VR in pediatric neurorehabilitation, using evidence published in the last decade. Thirteen articles were located, among them findings on the use of VR in CP; they also observed that the located studies had small samples and that their levels of scientific significance were low. They suggested that future approaches be performed with more homogeneous groups and standardized methodology, probably through well-designed clinical tests.

On the other hand, Sveistrup et al.[9] located 12 articles on CP that observed the results of intervention programs that used virtual reality. In the results they observed the impact of VR; however they found that the studies ranged widely in terms of improvement scale, task duration and number of participants. Although still preliminary, these results suggest that the simple application of virtual reality has a significant impact on physical and psychosocial variables.

Due to the increasing use of VR in rehabilitation, the importance of motor learning in the development of those with CP and the need for current knowledge in this field, the objective of this work was to review the literature on themes relating to motor learning, VR and CP. The purpose of this study was to investigate the results shown in previous studies on motor learning with VR use in patients with cerebral palsy. We believe that the results will offer references for intervention and future scientific research.

METHOD

Figure 1 illustrates the search strategy used to locate and compare different works. It is based on PICO's and follows the method previously used by Snider et al.[7]

A bibliographic review was performed without time limitation. The research was carried out using PubMed. Considering keywords, we included articles that showed the three terms cerebral palsy, virtual reality and motor learning.

To increase the confidence in the selection of articles, all potentially relevant articles were reviewed independently by two researchers. In the end, a consensus established which articles fulfilled the inclusion criteria.[10]

There are many currently used scales that help with the evaluation of studies, the most common in the rehabilitation area being the PEDro[11] scale. This scale was developed by the Physiotherapy Evidence Database to be used in experimental studies and has a total score of 10 points, including evaluation criteria of internal validity and presentation of statical analysis used.[11]

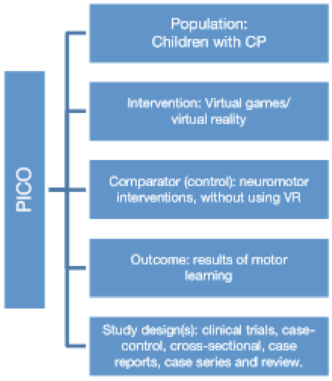

Figure 1 - Representation of the search strategy – PICOs.

In order to evaluate methodological quality, a study was considered to present a good level of evidence if it attained a score equal to or higher than 6 according to the PEDro evaluation scale. This criterion was based on the work by Snider at al,[7] which considers studies scoring 9–10 on the PEDro scale as methodologically 'Excellent', scoring 6–8, as 'Good', 4–5, as 'Fair' and below 4, as 'Poor'.

RESULTS

Initially, 40 studies were found, 30 articles were excluded as not fulfilling the inclusion criteria (Fig. 2). The data extracted from the ten eligible studies are summarized in Tables 1 and 2. The PEDro scale results are shown in Table 3.

DISCUSSION

Due to the importance of motor learning and the advance of technology in the use of virtual tasks in rehabilitation programs for people with CP, the main objective of this work was to carry out a review of this subject.

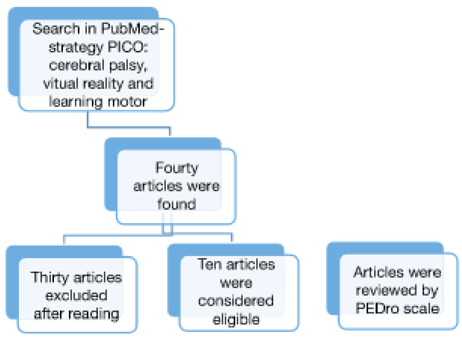

Figure 2 - Flow chart of search strategy and selection process.

Table 1 - Articles related to virtual reality and motor learning.

Type of article	
Experimental study	2
Pilot study	2
Case control	2
Review	2
Clinical trial	2

One of the characteristics observed in the ten selected studies was the number of people evaluated. Most had small sample sizes, which limited the extent to which results could be generalized and could impact the assessed outcomes. It is necessary to ensure that the sample represents the population. It is obviously important to use sample calculation to determine the number of necessary elements in order to obtain valid results, because an increase in the sample size will lead to increased accuracy in the population estimates. In the studies found, the number of participants was between 3 and 64 subjects. The research of de Mello Monteiro et al.[20] included 64 individuals, 32 with CP and 32 normally developing individuals; all were observed practicing two coincidence-timing tasks. In the more tangible button-press task, the individuals were required to 'intercept' a falling virtual object at the moment it reached the interception point by pressing a key. In the more abstract, less tangible task, they were instructed to 'intercept' the virtual object by making a hand movement in a virtual

Table 2 - Synthesis of manuscripts on virtual reality and motor learning.

C. Gordon et al. 2012[12]	Due to the lack of a comparative group, it is difficult to say whether the changes observed in gross motor function were due to the training programme, a learning effect or natural changes. However, these results indicate that there may be some potential for training with the Nintendo Wii to have an impact on gross motor function, and research studies should be conducted to explore this hypothesis.
Howcroft J. et al. 2012[13]	While all games may encourage motor learning to some extent, AVGs can be strategically selected to address specific therapeutic. Active video game (AVG) play for physical activity promotion and rehabilitation therapies in children with cerebral palsy (CP), through a quantitative exploration of energy expenditure, muscle activation, and quality of movement. AVG play via a low-cost, commercially available system can offer an enjoyable opportunity for light to moderate physical activity in children with CP.
Marie Brien, et al. 2011[14]	Results showed improvements in motor learning with skill transfer and integration into real-life situations. Functional balance and mobility in adolescents with cerebral palsy classified at GMFCS level I improve with intense, short duration VR intervention, and changes are maintained at 1-month post-training.
Leon M Straker et al. 2011[6]	Improvements in performance in VR are useful if they lead to improvements in real-world performance. This suggests VR games could improve real-world motor skills in children and could increase children's confidence, which would be additionally beneficial. VR electronic games may improve these children's skills by providing gross motor practice involving a high level of visual-spatial integration, but in a context which is private, and provides strong motivation through enjoyment of the game and the challenge of self-competition. However this will only occur if the nature of the movement required is suitable.
Michelle Wang, Denise Reid. 2011[8]	Using VR as an educational and therapeutic tool allows instructors and therapists to offer both flexibility and control when administering treatments, increasing the probability of skill transfer and ensuring safety during learning.
Golomb M. R. et al. 2010[15]	Improved function appears to be reflected in functional brain changes. Use of remotely monitored virtual reality video game tele-rehabilitation appears to produce improved hand function and forearm bone health (as measured by DXA and pQCT) in adolescents with chronic disability who practice regularly.
Shira Yalon-Chamovitz, Patrice L. (Tamar) Weiss. 2008[16]	The participants demonstrated clear preferences, initiation and learning. The VR-based activities were perceived by the participants to be enjoyable and successful. They performed consistently and maintained a high level of interest throughout the intervention period. VR appears to provide varied and motivating opportunities for leisure activities among young adults with intellectual and physical disabilities. Its ease of use and adaptability make it a feasible option for this population.
H. Sveistrup et al. 2004[9]	The impact of VR exercise participation ranged from improvements in clinical measures of functional balance and mobility, time on task, as well as participant and care provider perceptions of enjoyment, independence and confidence. Although still preliminary, the data suggest that simple applications of virtual reality have significant impacts on physical and psychosocial variables. Possibilities for and benefits of home and community-based access to virtual reality-based programs are explored.
Luanda André Collange Grecco et al. 2013[17]	The combination of transcranial stimulation and physical therapy resources will provide the training for a specific task with multiple rhythmic repetitions of the phases of the gait cycle, providing rich sensory stimuli with a modified excitability threshold of the primary motor cortex, to enhance local synaptic efficacy and potentiate motor learning. The combination physical therapy resources will provide the training of a specific task with multiple repetitions of the phases of the gait cycle, promoting rich sensory proprioceptive and visual) stimuli with a modified threshold of excitability of the primary motor cortex (enhanced local synaptic efficacy), thereby potentiating motor learning.
De Mello Monteiro CB et al. 2014	With the growing accessibility of computer-assisted technology, rehabilitation programs for individuals with cerebral palsy (CP) increasingly use virtual reality environments to enhance motor practice. The results showed that individuals with CP timed less accurate than typically developing individuals, especially for the more abstract task in the virtual environment. The individuals with CP did—as did their typically developing peers—improve coincidence timing with practice on both tasks. Importantly, however, these improvements were specific to the practice environment; there was no transfer of learning.

Table 3 - PEDro scale results.

Score	Number of articles
2	3
3	1
5	1
6	2
8	1
Not applicable	2

environment. Results showed that individuals with CP scored less accurately than normal controls. However, improvements in performance were specific to the practice environment; there was no transfer of learning.

Yalon-Chamovitz et al[16] evaluated the largest number of participants, 33 people with CP including 23 males and 10 females with a diagnosis of CP and moderate or mild mental disabilities. This study had subjects in the experimental group and in the control group, but the experimental group and the control group were composed of the same population, decreasing the comparison effect. The fact that the control group did not present a number equal to or larger than the intervention group also reduces the confidence of the results. On the other hand, Howcroft et al.[13] evaluated 17 people with CP, but did not use a control group. In spite of the fact that discrepancies at baseline between the control and intervention groups were not always considered, the use of a control group always provides interesting data.

The studies of Gordon et al.[12], Golomb et al.[15] and Brien et al.[14] included much smaller numbers of participants and no control groups. Brien et al.[14] note that studies with larger samples are necessary to increase validity and trust, and that groups with differences between CP subpopulations and with more homogeneous demographic groups (gender, age), would collectively lead to better results, because the study noted limitations in performing statistical analysis and possible difficulties in generalizing the observed outcomes.

Among the reviewed studies, some important convergence points can be found relating to gross motor function and the impact on CP. Straker et al.[6], Gordon et al.[12] and Brien et al.[14] claim that virtual reality can improve motor ability in this population.

Further investigation is necessary to examine the effectiveness of different training protocols for intense VR interventions in children in younger age groups, at different levels of motor function.[14] Moreover, additional research is needed to determine the intensity, frequency, and duration of the VR intervention required to best affect functional balance and mobility in children and adolescents with CP.[14]

Brien et al.[14] hypothesized that complex balance and coordination skills in walking performance, walking speed, endurance, stair climbing and descent would be improved in these children and that these improvements would be maintained at one week and one month following the end of training with VR. Results from their study support two major findings: (i) the data suggest that functional balance and mobility in adolescents with CP can improve with an intense, short duration VR intervention and (ii) improvements in outcome measures are maintained for at least one month following VR training.[14]

It is difficult to say whether the changes observed in gross motor function were due to the training program, to a learning effect or to natural changes.[12] However, these results indicate that there may be some potential for training with a VR environment (like Nintendo Wii) to have an impact on gross motor function, and research studies should be conducted to explore this hypothesis.[12]

The VR environment provides vibrotactile, visual (e.g. by way of the on-screen avatar), auditory, and cognitive (e.g., through game scores and performance) feedback to the user.[13] Grecco et al.[17] reported that feedback provided by the image generates positive reinforcement, thereby facilitating the practice and perfection of the exercises. Gordon et al.[12] and Straker et al.[6] reported that the training of these patients with VR devices may have a positive impact, because of the high level of visual and spacial integration.

Considering motor learning, Howcroft et al.[13] report that motor learning depends on factors such as improvement (in performance), consistency (uniformity in the results of a task) and stability. The learning of a motor task includes many principles of learning. Through practice, the individual has the opportunity to experience alternatives in finding solutions to a given motor problem. Practice is fundamental to the learner for the acquisition of motor skills. The objectives can result in stable and accurate performance and the ability to overcome difficulties imposed by environmental or physical factors pre-established by the pathology already present.

Generally, children learn cognitive and motor skills by training and through reasoning.[18] Training implies acquiring habits of mind and behaviour that have been shaped by others, enabling the child to acquire the skills required to fit in.[18]

Using VR as an educational and therapeutic tool allows instructors and therapists to offer both flexibility and control when administering treatments, increasing the probability of skill transfer and ensuring safety during learning.[8] Flexibility is essential when designing therapeutic programs because children with neurodevelopmental disorders are not only heterogeneous, but also require extra learning support.[8] The treatment programs for individuals with CP increasingly use virtual environments (VR) to improve motor functioning. Yet, although these programs are successful in terms of adherence, it remains unclear if increases in motor functioning in virtual environments transfer positively to motor functioning in natural environments.[20]

Three studies included in this review, Straker et al,[6] Golomb et al[15] and Grecco et al[17] claim that motor learning can be potentiated with VR, with transfer of motor abilities and real-life integration; they observed that VR can also be an important educational and therapeutic tool. Forms of physical therapy seek to promote motor learning through the administration of functional training and multiple sensory stimuli.[17]

Although it is clear that VR systems rely on hardware and software, their use in all rehabilitation situations requires clinicians to make decisions about the appropriateness of the intervention for the patient, implementation of treatment parameters and progression through different levels of the game or task.[19]

There is evidence to confirm that VR is a promising tool in the treatment of such children.[17] The potential uses of VR are vast, yet validation of findings is necessary as the current body of research is dominated by low quality evidence. Despite the benefits, this review shows that more research is required to confirm these findings, especially considering the training transfer from VR to a real environment.

CONCLUSION

The studies showed the benefits of the use of VR in children with CP in gross motor function and improvements in motor learning with skill transfer to real-life situations. Therefore, it seems to be a promising resource and a strategic option for care of these children.

However, there are few studies about motor learning with use of VR. The long-term benefits of VR therapy are still unknown. The published studies need to be better designed with more rigorous methodology. A high quality random clinical trial with a large sample is needed to determine that the use of VR for people with CP can be better than traditional rehabilitation interventions.

AUTHORS' CONTRIBUTIONS

All authors participated in the acquisition of data and revision of the manuscript. All authors determined the design, interpreted the data and drafted the manuscript. All authors read and gave final approval for the version submitted for publication.

DECLARATION OF INTEREST

The authors report no conflict of interest. All authors were responsible for the content and writing of this paper.

RESUMO

Indivíduos com paralisia cerebral apresentam distúrbios motores complexos, o principal sendo um déficit de tônus muscular, que afeta a postura e o movimento; observam-se alterações de equilíbrio e coordenação motora, diminuição de força e perda de controle motor seletivo com problemas secundários de contratura e deformidade óssea. Esta população pode ter dificuldades na aprendizagem de habilidades motoras. O aprendizado de habilidades resulta de exposição repetida e de prática. Devido ao aumento do uso de realidade virtual no processo de reabilitação e a importância do desenvolvimento motor na aprendizagem de indivíduos com paralisia cerebral, há necessidade de estudos nesta área. O objetivo do presente estudo foi investigar os resultados mostrados em estudos anteriores de aprendizagem motora com realidade virtual em pacientes com paralisia cerebral. Inicialmente, 40 estudos foram encontrados, mas 30 artigos foram excluídos por não preencherem os critérios de inclusão. Os dados extraídos dos dez estudos elegíveis são apresentados. Os estudos mostraram benefícios da utilização da Realidade Virtual em crianças com paralisia cerebral na função motora grossa e melhorias na aprendizagem motora com a possibilidade de transferir para situações da vida real. Portanto, a realidade virtual parece ser uma alternativa promissora e uma opção estratégica para o atendimento dessas crianças. No entanto, existem poucos estudos sobre aprendizagem motora com realidade virtual. Os benefícios a longo prazo do tratamento com realidade virtual ainda são desconhecidos.

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