UNIVERSIDADE FEDERAL DE SÃO CARLOS
CENTRO DE CIÊNCIAS BIOLÓGICAS E DA SAÚDE
PROGRAMA DE PÓS-GRADUAÇÃO EM FISIOTERAPIA

ADAPTAÇÕES SENSÓRIO-MOTORAS EM CURTO PRAZO APÓS UMA ÚNICA SESSÃO DE TERAPIA ROBÓTICA ASSOCIADA AO VIDEOGAME

MARCELA DE ABREU SILVA COUTO

SÃO CARLOS- SP
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Tese de doutorado apresentada ao Programa de Pós-graduação em Fisioterapia da Universidade Federal de São Carlos, como parte dos requisitos par aa obtenção do título de Doutora em Fisioterapia.

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Folha de Aprovação

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LISTA DE ABREVEATURAS

USP- Universidade Estadual de São Paulo – São Carlos

AVC- acidente vascular cerebral/encefálico

FAC- Functional Ambulation Categories

EMG- electromyography

HG- hemiparesis group

CG- control group

MVIC- maximum voluntary isometric contraction

SD- standard deviation

CV- coefficient of variation

RMSE- root mean square error

DST- Dynamical Systems Theory

MIT- Massachusetts Institute of Technology

DP- dorsi/plantarflexion

IE- inversion/eversion

FMA- Fugl-Meyer Assessment

MAS-Modified Ashworth Scale

ROM- range of motion

Nm/rad: newton meters per radians

i- initial

f- final;

s- second

rad/s- radians per second

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MANUSCRITO 1

plantarflexion movements, significant differences between the groups after the session only in the gastrocnemius medial muscle were identified. The control group was increased when compared to the hemiparesis group for all situations. There was no interaction between pre and post-robotic assisted sessions for both movements.

Figura Material complementar 3. Minimum EMG peak during torque peak of concentric contraction. CG: control group; HG: hemiparesis group; DF: dorsiflexion; PF: plantarflexion; * Significant differences were identified between the paretic group when compared to the control group on pre or post-robotic therapy ($p \geq 0.05$). Significant differences were identified between groups during the dorsiflexion on the tibialis anterior muscle in the pre and post-robotic assisted session. Significant differences between the groups were found only in the post-sessions for the lateral gastrocnemius and soleus muscles during dorsiflexion. The lateral gastrocnemius and soleus muscles presented significant differences between groups just in post-session during dorsiflexion. The hemiparesis group increased when compared to the control group for all situations except for the tibialis anterior muscle in the pre robotic-session, when the hemiparesis group decreased during dorsiflexion. There were no significant differences between the groups in the plantarflexion. There was no interaction between the pre and post-robotic assisted session for both movements.

MANUSCRITO 2

Figura 1. Flowchart of enrolled participants. T: total of recruited individuals, H: hemiparesis group and C: control group. FAC: Functional Ambulation Categories.

Figura 2. **Videogame Interface.**

Figura 3. Initiation without robotic assistance*.* Line 0: no robotic assistance to initiate the movement; Line 1: robot assistance to initiate the movement.

Figura 4. ***Videogame metric data.*** *Significant difference for comparison between first unassisted block 0initial (0i) with other blocks, ɸ Significant difference between groups. A) Initiation time. B) Mean Speed. Regarding impedance analysis, the control group was slower in the 50initial and 100final, the hemiparesis group was slower in the 150, 100final and 0final during dorsiflexion. In the group analysis, the hemiparesis group was slower than the control only in the 50initial block. Regarding the plantarflexion movement, the hemiparesis group was slower in the 50initial block when compared to the initial unassisted block. C) Number of speed peak. Regarding impedance analysis, the control group presented less smoothness and continuity in 50initial. The hemiparesis group presented less smoothness and continuity in the 100final and 0final blocks during the dorsiflexion movement. Significant differences between the groups only in the 50initial block during dorsiflexion movement were identified. No significant differences between groups during the plantarflexion were identified. D) Trajectory Variation. Brackets indicate the analysis between the initial and final impedance.

SUMÁRIO

RESUMO

A inclusão de dispositivos robóticos em programas de reabilitação está aumentando. Este recurso pode ser associado a videogames. Diferentes níveis de assistência podem ser aplicados durante tarefas específicas e orientadas por metas com significados a fim de evocar movimentos coordenados em pacientes com hemiparesia. No entanto, não existem diretrizes suficientes para prescrever a terapia para a reabilitação dos membros inferiores. O primeiro objetivo deste trabalho foi verificar se uma única sessão de terapia robótica promove adaptação motora, influenciando a coordenação dos movimentos do tornozelo (manutenção do torque submáximo do tornozelo - Steadiness), as variáveis de força máxima concêntrica, como torque, potência e trabalho e o desempenho funcional de indivíduos hemiparéticos crônicos; e o segundo objetivo foi descrever as análises dos dados métricos relacionados à precisão, velocidade, suavidade e movimentos iniciados sem assistência, bem como a variação da trajetória registrada durante o protocolo de terapia do tornozelo robótico com base nos critérios de ajuste de aumento e diminuição da assistência robótica. O desenho experimental de ambos os estudos foi double-arm pilot, sendo uma amostra de conveniência de participantes com AVC crônico (*n* = 14) que apresentaram déficits hemiparéticos residuais e um número igual de sujeitos controle saudáveis pareados por idade e sexo. O equilíbrio, a mobilidade e a função foram avaliados. No primeiro manuscrito, os testes concêntrico isocinético e steadiness foram avaliados utilizando a dinamometria. Os picos máximos e mínimos de ativação muscular foram registados por eletromiografia simultaneamente com os testes concêntricos. No segundo manuscrito, a pontuação do jogo, o número de movimentos iniciados sem assistência, o tempo de iniciação, a velocidade média, o número de picos de velocidade e a variação da trajetória foram variáveis registradas em sete blocos de repetições com níveis variáveis de assistência. Um questionário de motivação foi dado ao grupo hemiparético. Os principais achados foram: adaptações motoras foram identificadas preferencialmente durante a dorsiflexão. O grupo hemiparético apresentou ganhos imediatos na manutenção do torque submáximo, maior destreza, melhor reação inicial e suavidade durante a dorsiflexão após a terapia robótica. O protocolo de terapia robótica promoveu a preservação e manutenção do desempenho neuromuscular quando comparado ao grupo controle saudável. Além disso, a análise dos dados métricos obtidos durante a sessão de terapia robótica corroborou para identificar adaptação motora relacionada à velocidade, precisão e erros na posição da trajetória. Além disso, a estratégia de mudança de impedância foi eficaz para promover um ambiente terapêutico desafiador e adaptações do controle motor.

Palavras-chave: **Reabilitação neurológica, reabilitação do tornozelo, AVC crônico, Videogame, Anklebot, Tecnologia Assitiva.**

ABSTRACT

Robotic device deployment used for the recovery of people with hemiparesis is increasing. This resource can be associated to video games and different levels of assistance can be used for specific and oriented tasks. However, there are insufficient guidelines to prescribe rehabilitation therapy of the lower limbs. The first aim of study was to verify whether a single session of robotic therapy promotes short-term ankle motor adaptations, influencing the coordinate movements (sub-maximum torque maintenance of ankle – steadiness), maximal strength outcomes, such as torque, power and work and functional performance in chronic post-stroke individuals; and the second objective was to describe the analysis the metric data related to accuracy, speed, smoothness and movement initiated without assistance, as well as trajectory variation recorded during robotic ankle therapy protocol based on the criteria of increasing and decreasing impedance adjustments. Both studies had double-arm pilot design, on a convenience sample of participants with chronic stroke (*n* = 14) who had residual hemiparetic deficits and an equal number of age- and sex-matched non-disabled control subjects. In the first manuscript, balance, mobility and function were measured. Concentric isokinetic and steadiness tests were assessed using dynamometry. The maximum and minimum muscle activation peaks were recorded by electromyography simultaneously with concentric tests. For submaximal sensorimotor control analysis (Steadiness), the standard deviation, coefficient of variation and root mean standard error (RMSE) were recorded. In the second manuscript, game score, movement initiated without assistance, initiation time, mean speed, number of speed peaks and trajectory variation were variables recorded over seven blocks with variable assistance levels. A motivation questionnaire was given to the hemiparesis group. The main results were motor adaptations in sub maximum maintenance, which were identified preferentially during the dorsiflexion. The hemiparesis group showed greater dexterity, initial reaction and smoothness during dorsiflexion post-robotic assistance therapy. People with chronic hemiparesis presented short-term performance gains in submaximal torque maintenance, especially during dorsiflexion after a single robotic therapy session. The actual robotic therapy protocol promoted preservation and maintenance of neuromuscular performance when compared to the healthy control group. In addition, analyzing the metric data obtained during the robotic therapy session corroborated to identify motor adaptation related to the speed, accuracy and errors in the trajectory position. Moreover, impedance change strategy was effective to promote challenge and motor control adaptation.

Keywords: **Neurological Rehabilitation, Chronic stroke, Ankle rehabilitation, Videogame therapy, Anklebot, Assistive Technology.**

APRESENTAÇÃO

Esta tese está organizada conforme as recomendações do Programa de Pós-graduação em Fisioterapia da Universidade Federal de São Carlos. Inicialmente são apresentadas uma breve contextualização e uma revisão do problema a ser abordado. A seguir, os manuscritos intitulados "*Short-term adaptations of ankle sensorimotor control due to a single session of robot therapy in chronic post-stroke subjects*" e "*Ankle adaptive sensorimotor strategies in chronic post-stroke subjects due to variable assistance of robotic therapy and videogame"*. Estes trabalhos foram submetidos a revistas internacionais de alto impacto da área. Finalmente, uma conclusão geral do trabalho, bem como as atividades científicas desenvolvidas pela aluna durante o período.

CONTEXTUALIZAÇÃO

O presente estudo é o resultado de uma parceria estabelecida pelo Laboratório de Pesquisa em Fisioterapia Neurológica do Departamento de Fisioterapia da UFSCar (LaFiN) e do Laboratório de Reabilitação Robótica do Departamento de Engenharia Mecânica da Escola de Engenharia de São Carlos, USP. Verificou-se o efeito de uma sessão de terapia robótica (Anklebot), associada a um jogo computacional, sobre o controle sensório-motor de indivíduos com acidente vascular cerebral (AVC), na fase crônica.

Um aspecto inovador vinculado a este estudo relaciona-se ao sistema de assistência ao movimento utilizado pelo robô, baseado na impedância. Uma estratégia inédita de acréscimo e retirada gradual de assistência robótica foi utilizada para se estudar as modificações neuromusculares relacionadas à força muscular e coordenação do tornozelo (manuscrito 1), bem como os mecanismos de controle motor frente ao protocolo de treinamento (manuscrito 2).

Esta tese contribuiu para a criação de uma linha de pesquisa no laboratório e serviu como base para futuras intervenções terapêuticas em pacientes neurológicos. Além disso, auxilia no desenho de futuros protocolos de terapia robótica, trazendo informações sobre as estratégias adaptativas sensório-motoras frente ao tipo de estímulo utilizado e reflexões sobre o uso deste recurso na prática clínica.

Por fim, este estudo emprega alta tecnologia no tratamento de indivíduos hemiparéticos crônicos, que estão submetidos a um processo de reabilitação árduo e prolongado. Muitas vezes este processo é visto pelo paciente como desmotivador e monótono. A utilização de tecnologias que permitem a facilitação de movimentos, com a inclusão do indivíduo em um ambiente terapêutico inovador e motivacional são necessárias. Além disso, a propagação do conhecimento relacionado a tecnologias empregadas na reabilitação corrobora para o aumento da usualidade e acessibilidade de tecnologias existentes, como também, promove o desenvolvimento de tecnologias nacionais de custo reduzido que possibilitem ampliar o acesso desses recursos aos profissionais e pacientes.

REVISÃO DA LITERATURA

O Acidente Vascular Cerebral (AVC) é um grave problema de saúde pública em todo o mundo. Atualmente, é considerada a segunda principal causa de morte e a terceira causa de incapacidade. Afeta principalmente os indivíduos no auge de sua vida produtiva, exercendo um enorme impacto sobre o desenvolvimento socioeconômico dos países (JOHNSON *et al* ., 2016). Há uma previsão realizada pela American Heart Association que considera que se as medidas apresentadas pelos governos continuarem sendo implantadas com rigor, haverá uma redução de 20% das ocorrências de AVC em 2020 (GO *et al* ., 2013).

No Brasil, o AVC ainda está entre as principais causas de morte e internação. A estimativa é de aproximadamente dois milhões de pessoas com sequelas de AVC, dentre elas, quinhentos mil apresentam incapacidade grave. A prevalência de 1,6% ocorre em homens e 1,4% em mulheres, e a de incapacidade 29,5% em homens e de 21,5% em mulheres (BONSENHOR *et al* ., 2015).

Os pacientes que apresentam incapacidades passam por um longo e complexo programa de reabilitação. Esses indivíduos tornam-se limitados na realização das atividades de vida diária, como caminhar, subir e descer degraus, realizar cuidados pessoais e trabalhar (GILES e ROTHWELL, 2008; MAKI *et al* ., 2006). Em relação ao caminhar, a fraqueza nos músculos dorsiflexores que elevam o pé durante a caminhada, comumente referida como "pé caído" é frequentemente identificada como um problema limitante da marcha, mesmo em pacientes hemiparéticos deambuladores comunitários que apresentam um nível satisfatório de recuperação funcional. As duas principais complicações do pé caído são a falta do apoio do calcanhar e o arrastar dos dedos do pé durante a fase de balanço, além de ser um fator desencadeante de quedas e ser um dos principais fatores para a instabilidade durante a marcha (KNARR *et al* ., 2013).

O tornozelo desempenha um papel fundamental na locomoção de várias maneiras. A estabilidade desta articulação contribui para a manutenção da postura ortostática estável, absorção do impacto durante a locomoção atenuando a força de impacto com o solo (HANSEN *et al* ., 2004). Além disto, também é responsável pela manutenção da velocidade da marcha e promove uma maior flexão do joelho durante a fase de balanço (KNARR, 2013). Ainda, atua como um dos principais contribuintes para a estabilidade da marcha.

Dentre os músculos envolvidos no caminhar destacam-se o sóleo, responsável pela propulsão, o gastrocnêmio atua na estabilidade postural e o tibial anterior que é fundamental para o final do apoio na retirada do pé (toe-off) durante a marcha (KNARR *et al* . 2013). Em relação à ativação muscular de hemiparéticos, um estudo prévio do nosso grupo de pesquisa demostrou diminuição a ativação dos músculos agonistas do joelho. Clark *et al* . mostraram que a alteração da ativação agonista é a principal causa da fraqueza de torque-velocidade em sujeitos hemiparéticos crônicos. A diminuição da ativação agonista e aumento da co-ativação muscular estão presentes nos membros paréticos durante atividades funcionais. Em tarefas isométricas isoladas (indivíduo sentado), Chou *et al* . (2013) demonstraram reduções nas taxas de disparo das unidades motoras do tronozelo hemiparético.

Exoesqueleto – Anklebot

Roy e colaboradores (2009) desenvolveram um exoesqueleto para reabilitação do tornozelo, denominado Anklebot (Interactive Motion Technologies, Watertown, MA), que segue a mesma linha dos robôs para membros superiores desenvolvidos pelo mesmo grupo de pesquisa. Desenvolvido no Massachusetts Institute of Technology (MIT), ele possui baixo atrito e utiliza o controle de impedância para garantir que o sistema seja *backdrivable*, ou seja, o robô se deslocará à medida que o paciente exercer força sobre ele. Os movimentos executados foram plantiflexão e dorsiflexão no plano sagital.

O controle de impedância, proposto inicialmente por Neville Hogan, em 1985, atua diretamente na especificação da interface de contato entre o robô e o ambiente. Além disso, também modula a forma como o sistema robótico reage às perturbações geradas pelo paciente e garante um comportamento complacente. Uma baixa impedância significa que o robô se deslocará à medida que o paciente exercer força sobre ele *(backdrivability*). Portanto, um sistema robótico com controle de impedância pode ser programado para permitir que o paciente pós-AVC realize movimento no todo ou em parte, mesmo quando a tentativa for fraca ou descoordenada. Neste caso, o robô auxilia o paciente a completar a tarefa.

O Anklebot tem se mostrado efetivo para recuperação da função do tornozelo em posição sentada durante a terapia pós-AVC, consequentemente, possibilita o tratamento de muitos pacientes com capacidade de deambulação limitada. Também minimiza riscos de quedas e focaliza o treinamento para articulações específicas. Assim, o uso da terapia robótica, pode promover ganhos na função, considerando diferentes períodos e níveis de recuperação de acidente vascular cerebral através da melhora da coordenação do tornozelo (FORRESTER et al., 2014; ROY *et al* ., 2009).

Um melhor desempenho observado na precisão de alvos, na velocidade e na suavidade durante movimentos de plantiflexão e dorsiflexão sem assistência foi mostrado em estudos que utilizaram o Anklebot em indivíduos hemiparéticos crônicos por seis semanas (1-3 dias por semana) (FORRESTER *et al* ., 2016; FORRESTER *et al* ., 2014; ROY *et al* ., 2011). Além das melhorias relacionadas ao treino é possível observar a tranferência para tarefas funcionais. Estudos que avaliam a cinemática da marcha apontam mudanças na simetria intermembros, ganhos na velocidade e cadência durante a marcha, mesmo após o treino de repetição na posição sentada (FORRESTER *et al* ., 2016; ROY *et al* ., 2011).

Em indivíduos saudáveis, Perez *et al* . (2004) demonstraram que o tornozelo obteve o aumento da habilidade motora em curto prazo e o aumento da excitabilidade cortical referente ao músculo tibial anterior após uma sessão de repetições passivas. Este aumento da excitabilidade foi associado com a redução de erros em uma tarefa de desempenho motor do tornozelo, indicando melhora do controle motor do tornozelo. Assim, se um mecanismo semelhante é estimulado por um protótipo de tornozelo em sujeitos hemiparéticos, é possível inferir que novas estratégias motoras poderiam contribuir para melhorar a qualidade e a velocidade da marcha (FORRESTER *et al* , 2011).

Terapia robótica

O uso de dispositivos robóticos para complementar a terapia convencional ganhou atenção considerável, pois oferece recursos para o alcance de muitos objetivos relacionados à aprendizagem motora (HUANG *et al* ., 2009; MILLER *et al* ., 2010). A prática repetitiva em alta intensidade, que orienta o membro acometido por meio de biofeedback e metas que oferecem significados a tarefa, tem sido um grande foco de investigação para restabelecer a função motora em indivíduos com hemiparesia (MEHRHOLZ, 2013; MIRELMAN *et al* ., 2009).

Os efeitos da terapia robótica foram ampla e previamente estudados em membros superiores e este conhecimento tem sido utilizado para justificar os estudos em membros inferiores (MURATORI, *et al* . 2013). Em relação à terapia robótica aplicada em membros inferiores, ainda há uma abordagem estreita considerando que poucas práticas de reabilitação realmente concentram-se nas alterações do tornozelo comprometido. Ainda, poucos estudos descrevem os efeitos agudos do protocolo de terapia robótica. A descrição dos efeitos agudos da terapia robótica corrobora para futuras propostas do uso da terapia robótica em longo prazo e fornece orientação para o desenvolvimento de um protocolo desafiador, promovendo assim motivação para indivíduos hemiparéticos crônicos.

Além disso, dispositivos robóticos podem ser associados a interfaces de videogames, possibilitando o registro de dados durante a terapia. Esses dados têm sido úteis na interpretação das alterações de controle motor. Ainda, essas facilitam o processo de progressão da terapia robótica, bem como, complementam informações ao processo de avaliação clínica.

Em relação aos efeitos de aprendizagem após uma única sessão, a retenção e a transferência de habilidades foram demonstradas em um estudo prévio sobre o Anklebot (ROY A, FORRESTER e MACKO, 2011). Os pacientes melhoraram a exatidão e a precisão dos movimentos dirigidos por metas. Estas alterações observadas na análise das variáveis métricas obtidas durnate a sessão robótica foram associadas ao melhor desempenho observado na análise da cinemática da marcha. Os ganhos foram mantidos após 48h. Porém este estudo não incluiu variáveis relacionadas com o desempenho neuromuscular e a coordenação motora. Estas variáveis foram observadas no presente estudo que apresenta um protocolo de terapia robótica similar, porém com estratégias de assistência robótica e videogame diferentes.

Videogame

Videogames têm sido amplamente utilizados em intervenções somatossensoriais para idosos, pacientes neurológicos e outras populações. Profissionais que trabalham com a reabilitação de pacientes têm desenvolvido diferentes abordagens para utilização deste recurso, deixando de ser brinquedos para diversão para se tornar ferramentas terapêuticas para reabilitação e promoção da saúde. Green e Bavelier (2003) afirmaram que jogar videogames efetivamente promove o aumento de habilidades visuais e atenção dos jogadores, além da contribuição na promoção da memória de curto prazo, atenção seletiva e motivação para adultos e idosos (GAMBERINI *et al* ., 2008). Ainda, os videogames possibilitam incrementam o ambiente terapêutico pela utilização de biofeedback visual, sonoro e tátil. O biofeedback é um estímulo para reforço ou adequação de alguma função ou comportamento fisiológico, que ajuda jogadores a obter controle consciente sobre específicas funções ou tarefas (BYUN *et al* ., 2016). O uso de biofeedback em ambiente terapêutico também está baseado na literatura que investiga os princípios do controle motor (LOHSE *et al* ., 2014)

A utilização desses recursos técnológicos mostra-se promissora em relação à reabilitação neurológica, porém ainda há muitas lacunas. Por exemplo, ainda não está claro como a terapia robótica pode influenciar o controle sensório-motor durante tarefas específicas que exigem força e controle motor de membros inferiores de indívíduos hemiparéticos crônicos. A quantidade de repetições ou assistência poderia afetar o desempenho neuromuscular? Quais seriam as melhores estratégias de biofeedback? Considerando estas questões, a proposta inicial deste estudo foi verificar se o protocolo de terapia robótica utilizado promove alterações sobre níveis de força durante contrações concêntricas e a coordenação motora durante o torque submáximo. Além disso, analisar a acurácia, a velocidade, a suavidade e o erro durante a trajetória, ou seja, os dados métricos regitrados pelo videogame.

MANUSCRITO 1 – SUBMETIDO À PHYSICAL THERAPY

Title: Short-term adaptations of ankle sensorimotor control due to a single session of robot therapy in chronic post-stroke subjects

Short title: Ankle paresis and robotic therapy

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Itemized list of tables and figures: Tables 1 and 2; Figures 1, 2, 3 and 4, Supplementary material: Table 1, Figures 1, 2 and 3.

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Abstract

Background: Robotic device deployment used for the recovery of people with hemiparesis is increasing. This resource can be associated to videogames and different levels of assistance can be used for specific and oriented tasks. However, there are insufficient guidelines to prescribe rehabilitation therapy of the lower limbs. The aim of the study was to verify whether a single session of robotic therapy promotes short-term ankle adaptations, influencing the coordination of movements (sub-maximum torque maintenance of ankle – steadiness), maximal strength outcomes, such as torque, power and work and functional performance in chronic post-stroke individuals. **Methods:** This was a double-arm pilot study on a convenience sample of participants with chronic stroke (*n* = 14) who had residual hemiparesis deficits and an equal number of age- and sex-matched non-disabled control subjects. Balance, mobility and function were measured. Concentric isokinetic and steadiness tests were assessed using dynamometry. The maximum and minimum muscle activation peaks were recorded simultaneously with concentric tests. For submaximal sensorimotor control analysis (Steadiness), the standard deviation, coefficient of variation and root mean standard error (RMSE) were recorded. **Results:** A significant difference was identified only when comparing the groups ($p=0.001$) during the 10-meter walking test, however no significant differences were identified in pre and post-session analyses. Among the pre-session concentric isokinetic variables, the control group presented higher strength levels when compared to the hemiparesis group during movements of dorsiflexion ($p\leq0.03$) and plantarflexion ($p=0.01$). Among the post-session concentric isokinetic variables, the control presented higher strength levels when compared to the hemiparesis group only for the plantarflexion movement ($p\leq0.01$). There was a decrease in the maximum peak and an increase in the minimum activation peak observed mainly during dorsiflexion of the paretic group. Regarding the pre and post-robotic assistance sessions, no significant difference was observed for any comparison ($p>0.05$) except for the steadiness test. Considering the steadiness test initial values, the hemiparesis group had a low performance during dorsiflexion and plantarflexion ($p\geq0.03$) when compared to the control group. However, the hemiparesis group showed greater dexterity during dorsiflexion post-robotic assistance therapy ($p\geq0.02$). **Conclusion:** People with chronic hemiparesis presented short-term performance gains in submaximal torque maintenance, especially during dorsiflexion after a single robotic therapy session. The actual robotic therapy protocol promoted preservation and maintenance of neuromuscular performance when compared to the healthy control group.

Keywords: Neurological Rehabilitation, videogame therapy, Chronic stroke, Anklebot, Ankle rehabilitation, Assistive Technology.

Introduction

Using robotic systems to complement conventional post-stroke rehabilitation programs is a promising resource. Robotic devices can provide high-intensity, repetitive, specific and oriented task practice. They allow for varied and adjustable levels of assistance to facilitate impaired limbs.[1,2] Furthermore, videogames and biofeedback interactions can promote additional motor control adjustments and improve motivation, optimizing task performance in individuals with hemiparesis.[2,3] Using robots to treat post-stroke patients has come to the forefront over the last decade, however there is little information in the literature on how this type of therapy can affect sensorimotor performance and relearning.[4] In addition, to the best of our knowledge, there are no guidelines that describe how to design projects, prescribe and use lower limb devices in clinical practice.[5,6]

Most studies that described the effects of robotic therapy have focused on the upper limbs.[4,6,7] Moreover, there is little evidence for its effects on the recovery of the lower limbs and especially the ankle joints.[5] Many robotic devices are used for gait training, seeking to bring stability and correction to knee and hip movements.[8] However, foot drop and the ankle weakness during stance phase of gait are very common clinical problems. Whereas strength and coordination of the ankle are critical for the performance of functional tasks, such as walking.[9,10,11]

In order to improve the sensorimotor control of the ankle joint, Anklebot, which is a lower-extremity robotic module, developed at the Massachusetts Institute of Technology (MIT) has been shown to be effective.[1,2,9,12] It isolates the ankle in a seated position during post-stroke therapy, consequently, helping to treat many patients with limited ambulatory capacity, consequently, it may improves function in different stroke recovery periods.[2,13] The increase in targeting accuracy, speed and smoothness in dorsiflexion and plantar flexion variations during unassisted movements were shown in studies that used the Anklebot over six weeks (1-3 days per week).[2,9,12] Furthermore, the observed shifts toward greater interlimb symmetry, gains in gait velocity and cadence suggest improvements in the ability to coordinate and control the limbs while walking.[9,13] Ankle training in a seated position in response to visual stimuli is related to training gait function.[2,13]

The retention of performance and transfer of abilities after a single session robotic therapy was demonstrated in a previous Anklebot study.[12] Patients improved the accuracy and precision of goal-directed movements. However, it is still unclear how robotic therapy could influence sensorimotor control during specific tasks that require strength and motor control. Could the amount of repetitions or assistance affect neuromuscular performance? In order to aggregate information on sensorimotor adaptations after robotic therapy, it can be stated that the innovation of this study was to investigate the influence of the robotic therapy protocol in activities that require specific ankle control to maintain the submaximal force. This control is observed by Steadiness test, which is a sensorimotor control analysis that verifies torque fluctuations during submaximal contractions around a target torque.

Accordingly, the aim of the study was to verify whether a single session of robotic therapy promotes short-term ankle adaptations, influencing the coordination of movements (sub-maximum torque maintenance of ankle – steadiness), maximal strength outcomes, such as torque, power and work and functional performance in chronic post-stroke individuals. The hypothesis was that the single robotic-assisted session promotes short-term adjustments in motor control, including force generation and maintenance and these changes can influence walking test performance.

Material and methods

Ethical Guidelines

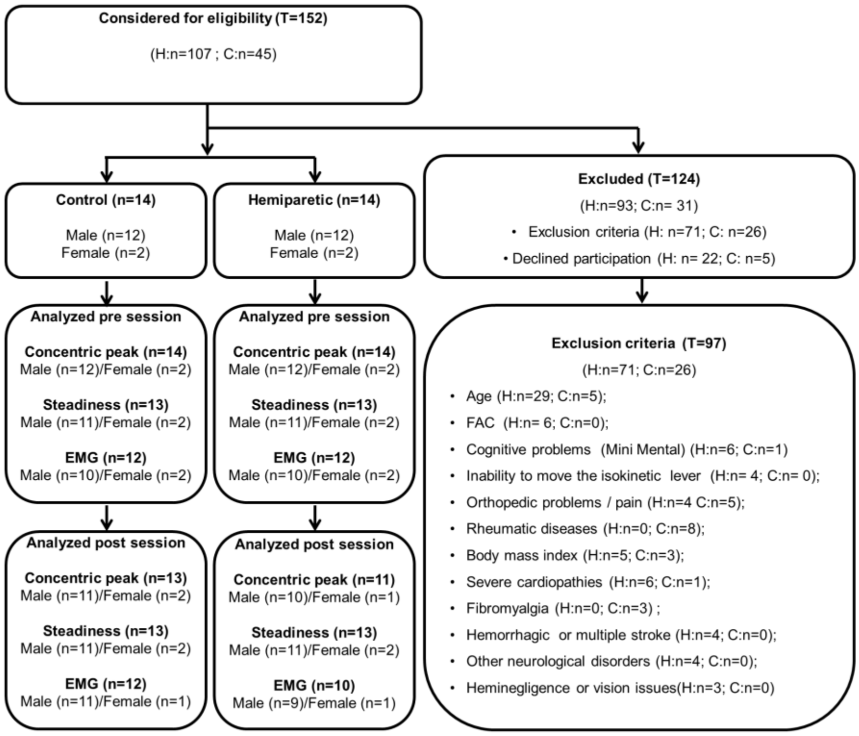
The study was conducted according to the guidelines and standards for human research (Resolution 196/1996, the National Health Council) and it was approved by the local ethics committee (report no.: 527.556/2014). This was a double-arm pilot study.

Experimental Design

The hemiparesis subjects were recruited from the *Hospital Santa Casa de Misericordia of São Carlos* and the waiting list from the local medical center. The control subjects were recruited of local community. The individuals with hemiparesis were not linked to any rehabilitation programs and this experience was the first contact with robotic therapy. The following inclusion criteria were considered: 6 or more months post-stroke; men or women aged between 50 and 75 years; low spasticity (less than level 3 on the modified Ashworth scale [14] so that the individual would be able to perform the isokinetic test); and independent overground walking (levels 2 and 5 according to the Functional Ambulation Categories). [15] The control group participants had to score greater than 8 on the Physical Activity Questionnaire Basal, which indicates they were not sedentary.[16,17] This is important because sedentary people have deleterious modifications in the neuromuscular system.[18] Furthermore, individuals from the control group performed physical activity (mainly aerobic activities) at least 3 times a week. No further criteria regarding the physical activity level were used. The exclusion criteria were: clinical signs of severe heart failure or chronic metabolic disease; severe cognitive or communication impairments; minimum score on the Mini-Mental State Examination according to the education level;[19] a history of lower limb injuries, deformity or contractures of the ankle joint; a smaller range of motion than 10^{o} for dorsiflexion and 20^{o} for plantarflexion; sensory deficits and neglect absence defined by clinical exams. *Bell*'s [20] and *Clock drawing* [21] *tests* were used to identify the neglect. Six or more errors indicate visuospatial hemi-neglect in the Bell´s test. Concerning the *Clock drawing test*, neglect patients are often found to omit numbers or to place all of the numbers on the right hand side of the clock face. The statistical power was calculated at the end of the study using the standard deviation variable of submaximal sensorimotor control during dorsiflexion (power = 0.96, effect size = 0.7, critical F = 4.2). These values were found using GPower® software.

Participants

The flowchart for participant exclusion and inclusion is presented in Figure 1. Thus, 28 individuals took part in the study. The hemiparesis group (n=14) comprised 12 men and 2 women with ischemic and unilateral stroke. The mean time after stroke was 4.2±6 years. The control group (n=14) also consisted of 12 men and 2 women who were matched to the hemiparesis group by age (± 3 years), gender and body mass index (± 4 kg/m^2). For ethical reasons, after protocol, all the hemiparesis participants were invited to attend an eight-week conventional therapy program. This program was conducted by physiotherapists. The control group received information about the importance of doing regular physical activity.



Procedure and Measuring Instruments

The evaluations were performed as follows: on the first day, screening was performed to apply the inclusion and exclusion criteria (clinical assessment), as well as functional tests. The second day was for becoming familiarized with the evaluation protocol of the robotic session (the protocol of robotic assisted therapy associated to videogame was defined as a session). After one week, the evaluation protocol was carried out (Suppl Mat Fig 1).

Clinical assessment

For a detailed description of the hemiparesis group, their balance and mobility were assessed using multiple scales and tests: the Berg Balance Scale[22], the

“Timed Up & Go” Test[23], and the 10-Meter walking test[24]. Furthermore, motor performance and activities of daily living were assessed using the Fugl-Meyer Assessment for lower limbs[25] and Barthel Index [26], respectively.

Assessment protocol and robotic assisted therapy familiarization

The familiarization procedures were conducted as follows: 10-meter walking test, concentric contraction, maximum voluntary contraction, steadiness and robotic assisted therapy. The 10-meter walking test was used to verify functional task (gait performance), concentric contraction to verify force levels, maximum voluntary contraction to calculate the sub-maximum torque (target torque), steadiness to verify the ankle sensorimotor control during maintenance of the sub-maximum torque (target torque). One week after familiarization procedures, the same assessment protocol was applied in pre and post robotic assisted therapy session times. In addition, the concentric, steadiness and 10-meter walking tests were redone after the robotic therapy. The sub-maximum torque value obtained during pre-therapy was used in the post-therapy steadiness test for comparison purposes.

10-meter test

Participants were instructed to perform a preferred walking speed or comfortable walk with their usual walking device. The participant time was recorded for the middle 10-m of the 12-m walkway, and the average gait velocity was calculated. Three trials were carried out and the average was recorded for data analysis. A brief rest was given in between trials. [24]

Concentric isokinetic assessment

Five maximal concentric contractions, during ankle dorsiflexion and plantarflexion, at a speed of 30°/s were performed using the Biodex System 3 dynamometer (Biodex Multi-joint System 3, Biodex Medical System Inc., New York). This speed reflects the function of the ankle during walking. [27, 28] The range of motion testing was set between 10° (dorsiflexion) and 20° (plantarflexion). Subjects performed three repetitions of dorsiflexion and plantarflexion movements with submaximal strength in order to familiarize themselves with the movement.[29] During contractions, the subjects were encouraged by visual feedback to achieve maximum strength. These tests were carried out with the paretic limb of the hemiparesis group and the dominant limb of the control group. [29,30] The variables measured were peak torque, work and power. To complement the interpretation about torque, the electromyographic methodology and data can be found in the supplementary material (Figures 2 and 3).

Steadiness test

The higher peak torque of three CIVM repetitions was used to calculate the target strength (20% of CIVM).[31] The submaximal sensorimotor control was evaluated during five repetitions and conducted by visual feedback, displayed as a horizontal line for 20 seconds, with a 60 second rest between sets. Only three repetitions were used in the analysis. The first and last sets were excluded. Considering the initial and final motor adjustments, the three first seconds and the last second were excluded. The low-pass second-order, Butterworth filter, with a cut-off frequency of 7Hz was used. The following variables were calculated: Standard deviation (SD), Coefficient of variation

(CV), and root mean square error (RMSE). Standard deviation (SD) is the absolute measurement of the amplitude fluctuation torque. Coefficient of variation (CV) is a measure of torque fluctuations expressed as a percentage of average torque (CV=SD/ average torque x 100). SD and CV values for torque fluctuation were used to probe the subject's ability to sustain a steady submaximal contraction at a constant torque level. The root mean square error (RMSE) is the square of the vertical distance between the target torque and generated torque.[32]

Ankle Robotic therapy (Anklebot) and videogame

Anklebot device: The Anklebot robotic system (Interactive Motion Technologies, Inc., Watertown, MA, USA) is a wearable and backdrivable system that can be used in a seated position or during walking. It allows actuation and sensing within the normal range of motion in dorsiflexion/ plantarflexion (DP) and inversion/ eversion (IE) movements of the ankle joint.[1] Anklebot uses an impedance controller with adjustable stiffness and damping.

Anklebot setups: The patient was positioned according to the description of Roy *et al* (2009).[1] The paretic lower limb was positioned at ~45° on a cushioned knee support, isolating the foot to move freely about the ankle (Fig 2). Subjects were then introduced to the videogame "race" that was subsequently used to assess the paretic ankle motor control. The chair was positioned at 1.5 meters from the computer screen.[33]

Figure 2: *Image of patient positioned in the anklebot during the game task.*

Videogame: The movements were visually promotes (movement initiated by visual feedback) and the objectives were presented in a videogame that reproduces an obstacle course. The ankle was free to move in the frontal plane, the patient controlled the ankle during movements of dorsiflexion and plantar flexion to achieve the targets. This interactive approach used an impedance controller. The Anklebot control functioned as a cursor showing "up" or "down". The individual was directed, along a trajectory, by target in two vertical levels corresponding to 10° dorsiflexion and 20° plantarflexion degrees. Assistance at the beginning of the movement was provided when necessary, allowing individuals to achieve the target, i.e., if the subject was not able to start moving after two seconds, the Anklebot provided torque to initiate the movement towards the target[1,13].

Repetition protocol and varying impedances: 350 ankle movements were distributed in seven blocks and there was a 3.5-second interval between each target. The protocol comprised switched robotic-assistance levels that were modified at each block of 50 movements/targets. The first and the last block were exempt from any robotic assistance. At the second to fourth blocks, there was a gradual impedance increase of 50Nm/rad. The fifth and sixth blocks presented gradual impedance decrease. Thus, the following impedance sequence was applied: 0Nm/rad ► 50Nm/rad ► 100Nm/rad ► 150Nm/rad ► 100Nm/rad ► 50Nm/rad ►0Nm/rad.

Game score: The total score recorded in each block was 1500 points. The player´s aim was to move through the gate passage and reach the target object (30 points). Bumping the cursor on game obstacles on the wall (-20 points) and on the spots on the race track (-10 points) were the error possibilities. At the end of the session, the total number of errors and correct answers were shown. During the game, according to the performance of the player, a bar remained green or red as a visual feedback. The Electromyography information and the game score values are presented in the Supplementary Material (Figure 2 and 3;Table 1; respectively). There was no difference between the groups and between the blocks ($p \geq 0.05$). A video about the game is presented in the material supplementary (Suppl Mat; Video 1).

Data Analysis

Data were tested for normality and homogeneity (Shapiro-Wilk and Levene tests, respectively). The demographic and functional data (parametric data), were applied Independent t-test (group comparison). Regarding 10 meters walking test, concentric contraction and steadiness variables (parametric data), ANOVA two-way (group x evaluation) with repeated measures (evaluation: pre and post-robotic assisted session) were used to verify the effect of the ankle robotic-assisted session. Anklebot® and Biodex data processing were performed using MatLab software (v.7.0.1) and SPSS for statistics analysis (v.17). The GraphPrism (v.7) software was used to develop the graphs.

Results

Demographic and Functional data

Groups were similar according to the demographic variables. Both groups presented mental integrity and independence during activities of daily living according to the Mini-Mental Exam and Barthel Index, respectively. The hemiparesis group presented good mobility and no risk of falls according to the Berg Balance and Timed Up and Go tests. Moreover, the hemiparesis group presented a reduced level of spasticity and slight motor impairment according to the Modified Ashworth Scale and Fugl-Meyer Assessment, respectively. Eight patients presented lesions in the dominant hemisphere. The descriptive data (e.g., demographic and functional data) are presented in Table 1.

Table 1. *Subjects´ Characteristics*

	Control Group (n= 14)	Hemiparesis Group (n=14)
Gender (Male/Female)	11/ 2	11/ 2
Age (years)	64 (74-53)	65 (74-54)
Height (meters)	1.66 (1.83-1.50	1.65 (1.75-1.52)
Body Weight (Kg)	70 (94-55)	71(93-58)
Body Mass Index (Kg/m^2)	25.4 (30.3-20.8)	25.8 (35.6-20.7)
FAC (0/1/2/3/4/5)	NA	(0/0/0/2/12)
Mini Mental	28 (29-24)	26 (29-24)
Barthel Index	20 (20-19)	19.5 (20-17)
MAS (0/1/1+/2/3/4)		
Hip	NA	10/4/0/0/0/0
Knee	NA	5/6/2/1/0/0
Ankle	NA	2/8/4/0/0/0
FMA	NA	32 (24-42)
Berg Balance Scale	56 (56-52)	51.5 (56-41)*

TUG test (sec)	**8.1(11.1-6.3)**	**12 (31.1-7.8)***

Measurements are reported as median (maximum and minimum values). FMA: Fugl-Meyer Assessment; FAC: Functional Ambulation Categories: 0=nonfunctional ambulation, 1=ambulatory, dependent for physical assistance, level 2, 2=ambulatory, dependent for physical assistance, level 1, 3=ambulatory, dependent for supervision, 4=ambulatory, independent, level surfaces only, 5=ambulatory, independent; MAS=Modified Ashworth Scale: 0=no increase in muscle tone, 1=slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end of the range of motion [ROM], 1=slight increase in muscle tone, manifested by a catch, followed by minimal resistance throughout the remainder of the ROM, 2=more marked increase in muscle tone through most of the ROM, but affected parts easily moved, 3=considerable increase in muscle tone, passive movement difficult, 4=affected parts rigid in flexion or extension; TUG test= Timed Up & Go test. *Significantly different compared to control group (p=0.001).

10-meter Walking Test

Differences were identified only in the comparison between groups (F=29.1; p=0.001). The control group presented an average gait velocity of 2.01±0.4m/s in the pre-robotic session and 1.9±0.3m/s in the post-robotic session. The Hemiparesis group presented 1.07± 0.4m/s in the pre-robotic session and 1.04±0.3 m/s in the post-robotic session.

Concentric isokinetic test

Regarding pre-session assessments, the torque peak, work and power variables presented significant differences between the control and hemiparesis groups during movements of dorsiflexion (F=4.9; p=0.03; F=7.06, p=0.01; F=6.05, p=0.01) and plantarflexion (F=7.7, p=0.01; F=10.07, p=0.01; F=10.5, p=0.01), respectively. Regarding torque peak, work and power in post-session variables, significant differences between groups were observed only for plantarflexion movements (F=8.90, p=0.01; F=10.42, p=0.01; F=12.6, p=0.01), respectively. Regarding to the comparisons between pre and post-robotic assisted sessions, no significant differences were observed (p>0.05; Fig 3).

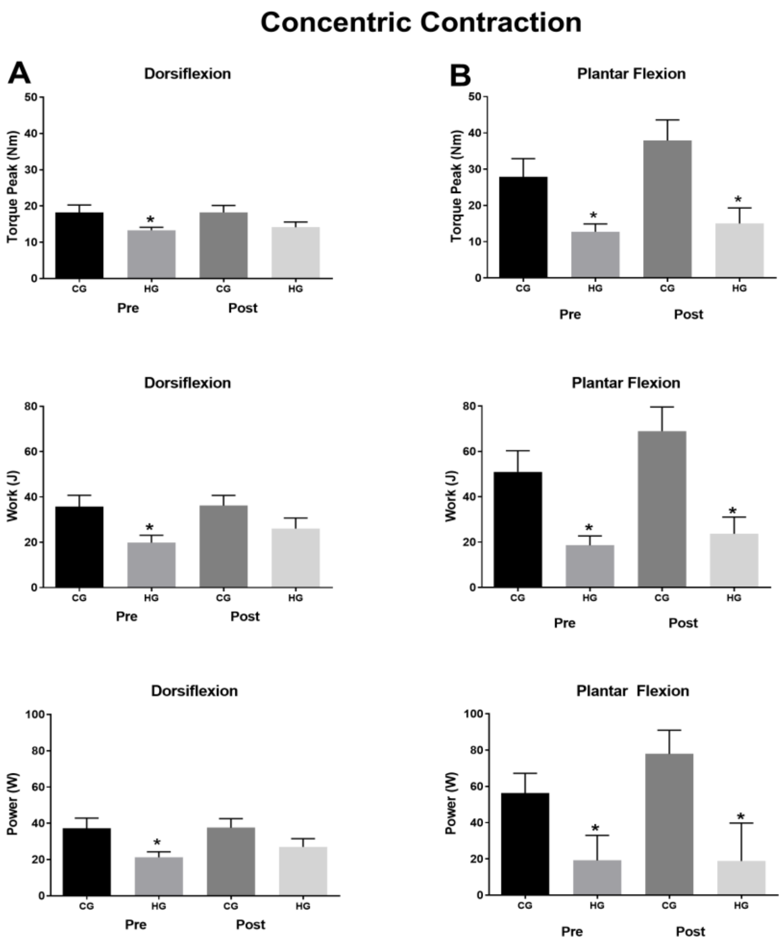


Figure 3: *Concentric isokinetic outcomes (torque peak, work and power) ankle dorsiflexors and plantiflexors muscles.* CG: control group and HG: hemiparetic group. The asterisk symbol (*) represents the paretic group difference when compared to the control group in pre or post-robotic therapy ($p<0.01$).

Steadiness

Significant differences were observed between the hemiparesis and the control group for SD ($F=6.6$; $p=0.018$), CV ($F=12.90$; $p=0.002$) and RMSE ($F=5.00$; $p=0.03$) during dorsiflexion, and SD ($F=8.40$; $p=0.008$), CV ($F=27.80$; $p=0.001$) and RMSE ($F=20.10$; $p=0.001$) during plantarflexion. Regarding to the comparison between pre and post post-robotic assisted session analyses, only the dorsiflexion movement presented significant differences for SD ($F=7.10$; $p=0.01$) and CV ($F=6.20$; $p=0.02$). See Table 2 and Figure 4.

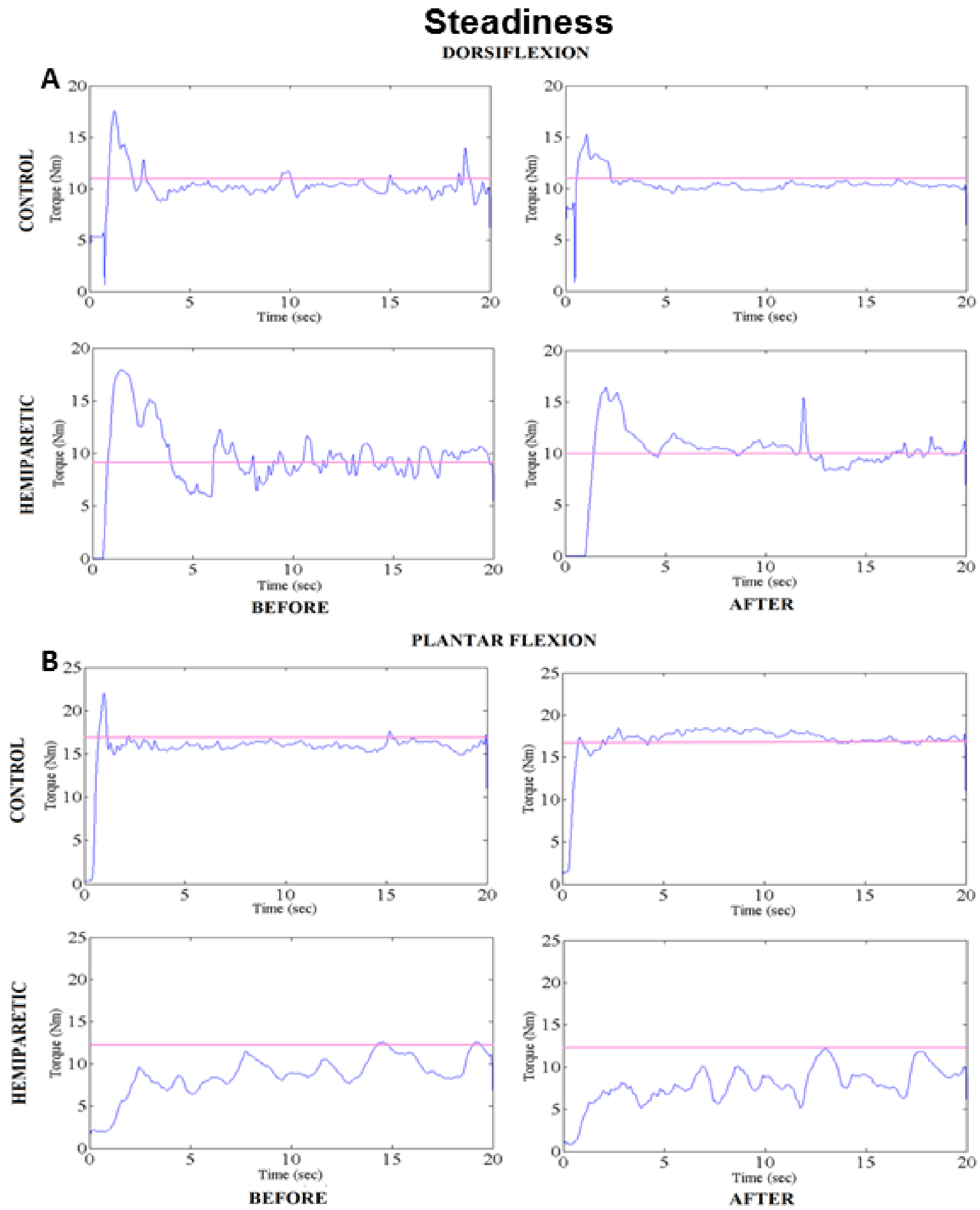


Figure 4: *Maintenance of submaximal torques during ankle dorsiflexion or plantarflexor.* Representation of generate torque data (black line) and target torque (pink line). A) control group, (B) hemiparesis group during sensorimotor control assessment. Representative data of one individual from each group.

Table 2. Steadiness variables during dorsiflexion and plantar flexion for both groups after and before robotic session.

		PRE SESSION			POST SESSION		
		SD	**CV**	**RMSE**	**SD**	**CV**	**RMSE**
DF	**HG**	2.10 (±0.93)*	23.73 (±11.90) *	3.12 (±0.80) *	1.57 (±0.73) †*	17.35 (±7.16) †*	3.20 (±0.44) *
	HG	1.27 (±0.60)	11.87 (±6.10)	2.85 (±0.32)	1.00 (±0.77) †	9.14 (±0.77) †	2.77 (±0.34)
PF	**HG**	1.59 (±1.11) *	17. 65 (±8.75) *	3.71 (±0.45) *	1.33 (±0.81) *	14.68 (±7.94) *	3.53 (±0.62) *
	CG	0.56 (±0.45)	4.65 (±4.36)	2.89 (±0.47)	0.80 (±0.58)	5.28 (±4.24)	2.80 (±0.34)

*Significant difference compared to the control group ($p<0.05$). † Significant difference compared to the pre-robotic-assistance session. CG: control group; HG: hemiparesis group; DF: dorsiflexion; PF: plantarflexion; SD: standard deviation; CV: coefficient of variation; RMSE: root mean square error

Discussion

This study presents innovations that help prescribe robotic therapy to people with chronic hemiparesis. The robotic therapy protocol associated to the videogame proved to be safe and efficient to promote adjustments of ankle sensorimotor control during dorsiflexion, ensuring the maintenance of neuromuscular performance. According to the aim of the study, this study showed short-term effects of a single robotic therapy session by observing the change in sensorimotor control during the submaximal torque maintenance and force generated capacity during concentric contraction for individuals with chronic hemiparesis. Thus, the variables observed in this study initiated a discussion about the interaction between neuromuscular system and the environment due to robotic therapy.

Variable impedance strategy used here showed an improvement in sensorimotor control during dorsiflexion after robotic therapy, observed in steadiness analysis. A lower torque variability or movement fluctuation is usually associated with a greater dexterity.[31] There was a decrease in the standard deviation and coefficient of variation variables when the hemiparesis was compared to the control group in pre and post the robotic therapy assessments. In addition, it can be observed in Figure 4 that the sensorimotor control of the hemiparesis ankle presents less variability after the robotic therapy session. This strategy of improving coordination is related to short-term sensorimotor control adaptation.[4,12]

Previous studies that used the Anklebot device associated the changes in motor control to the gait optimization of people with chronic hemiparesis.[1,33] The only variable that we have in our study related to gait is mean velocity during the 10-meter test. The gait velocity after the robotic therapy session was the same when compared to the initial value. Therefore, the functional capacity was preserved, not increased. However, a study conducted by Forrester *et al* [13] verified that patients significantly increased their walking speed in the 10-meter test (from 19.1±3.0 to 37.2±4.9 m/s) after a shorter protocol of 200 repetitions associated with computer games during one day, which was not the case in our study with chronic patients. It suggests that the earlier the robotic therapy, the more responsive people with hemiparesis are to the treatment. The 10 meter test only tells us about time and not about number/length of steps or angular joint measures, thus it is also important to recommend using kinematic analysis for future studies.

It should be mentioned that we stumbled across an important finding that cannot be ignored. We observed two patients in this study, who finished the robotic therapy, however, they showed fatigue, which made it difficult to perform the tests after the robotic session. In the functional profile analysis of the participants, no characteristic was found to justify this behavior. Therefore, when proposing a robotic therapy protocol, it is important to establish criteria to determine specific details concerning progression protocol. In addition, the difficulty of the task corresponding to the skill level while performing is an important criterion to prevent frustration, boredom and fatigue when engaging the learner in robotic therapy.

Regarding strength level after robotic therapy, subjects maintained their initial torque, work and power levels, which indicates that the capacity to generate force was not affected by the intensity, repetitions, impedance change strategy and time of therapy. This is important because the results do not indicate changes compatible to fatigue (except for two isolated cases). In fact, an increase in strength after a single robotic therapy session was not expected, however if the recruitment pattern of muscle fibers was modified, this would be important information for the discussion on the effects of long-term robotic therapy. A previous study carried out by Forrester *et al* .[33] demonstrated that strength levels of chronic hemiparetic individuals were not altered by robotic therapy. After 6 weeks (18 sessions), individuals with chronic hemiparesis presented a possible change in force exclusively during dorsiflexion movements (from 74.7 ± 15.9 N to 101.6 ± 11.0 N), but failed to reach statistical significance, similar to the present study.

Regarding the EMG analysis, alterations in the minimum and maximum muscle activation of the paretic group were observed when compared to the control group, mainly during the dorsiflexion movement. Moreover, the graphs showed no significant difference between the pre and post-robotic assisted session for both groups and all movements (Figures 2 and 3 of Supplementary Material). These results suggest that the sensoriomotor control promoted by the single robotic-assisted session applied was not enough to change the pattern of activation of the ankle muscles during maximal contractions. One positive point is that these findings confirm that muscles do not show signs of fatigue because no decrease in muscle activation was observed. [10,37]

Regarding the videogame and impedance change criterion, it is worth mentioning that it represented an equivalent level of challenge for both groups. Based on the presented results, we can infer that the strategy of impedance change between blocks of 50 movements was effective to promote sensorimotor adaptation. Both groups were challenged to complete the game, in which the difficulty level was equivalent for both groups (see Table 1; suppl material game score). The game protocol was similar to the protocol of Roy *et al* .[38], however, the author used the decreasing criterion for assistance level changes. The patient started the game with a lot of assistance and ended the game without assistance. The present protocol presented two situations, one criterion of increasing assistance and the second criterion of decreasing assistance; however, the differences between the different assistance levels in the game score analyzed were not identified. Roy *et al* .[38] were concerned with patient motivation and used the 80% accuracy criterion to increase the level of difficulty between sessions. Our patients presented levels greater than 80% accuracy during the game. The association of videogames to robotic therapy allows for suitable control of important task variables (accuracy, difficult level, smoothness) and individuals (motivation, enjoyment, adherence) during rehabilitation.[39,40,41] Resources provide meaningful feedback that encourage motor learning based on motor control principles of movement organization.[39,40]

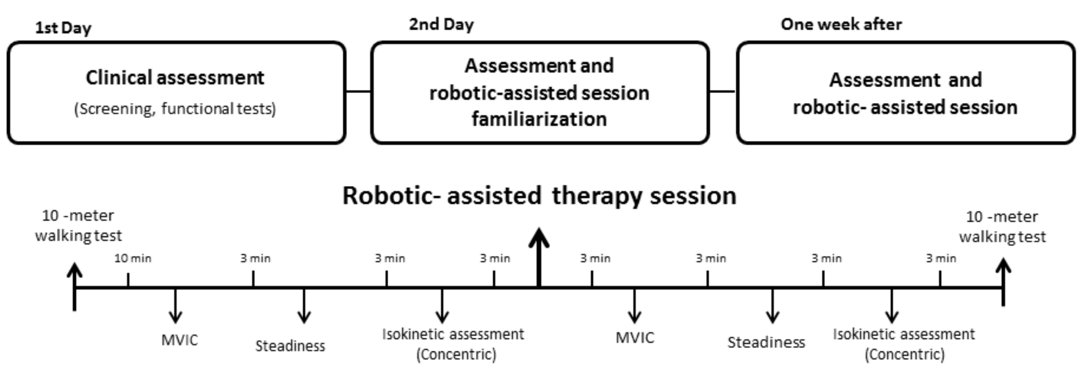
Some limitations should be reported, such as the fact that lack of resting periods after evaluations could affect neuromuscular performance. In addition, no information about retention can be presented considering the study design. Finally, the evaluations order were not randomized.

Conclusion

Individuals with chronic hemiparesis presented short-term gains in submaximal torque maintenance performance (sensorimotor control) during dorsiflexion after a single robotic therapy session. Subjects with chronic hemiparesis presented greater dexterity in the dorsiflexion movement after a single robotic assistance therapy. Thus, the actual robotic therapy protocol proved to be useful for patients who presented preservation and maintenance of neuromuscular performance when compared to the health control, considering concentric torque, muscle activation and function.

Considerations for clinical practice: It is necessary to comply with the functional capacity of the patient by screening, indicating whether or not he/she is eligible for this therapy. This study presented references for protocol design that can be used for a long-term robotic therapy program. In addition, the association with other exercises is possible, considering that the robotic treatment protocol is accomplished in 30 minutes and a conventional session in approximately 1 hour.

Supplementary Material



Suppl Mat Figure 1. *Assessment design:* MVIC: maximal voluntary isometric contraction. Individuals attended the laboratory over three days. On the second day, they carried out the familiarization protocol. After one week, the evaluation protocol was carried out. Above the line is an indication of rest time between procedures.

Suppl. Mat Table 1. Game score.

	1° block (0Nm/rad)	**2° block (50Nm/rad)**	**3° block (100Nm/rad)**	**4° block (150Nm/rad)**	**5° block (100Nm/rad)**	**6° block (50Nm/rad)**	**7° block (0Nm/rad)**
CG	**1297.5±285**	**1425.0±52**	**1422.5±93**	**1431.6±79**	**1445.8±50**	**1405±158.2**	**1312.33±380**
HG	**1068.3±425**	**1252.5±280.6**	**1250.0±271**	**1269.1±251.3**	**1304.17±233**	**1269.17±323**	**1160±433**

CG: control group; HG: hemiparesis group. Impedance or exoskeleton assistance K= Newton meters per radians (Nm/rad). The comparison between game scores during several blocks did not present significant differences (p≥0.005).

Assessment of muscle activity

Electromyography activity was simultaneously assessed during concentric isokinetic tests. Tibialis anterior (TA), peroneus longus (PL), medial gastrocnemius (GM) and lateral gastrocnemius (LG) and soleus (SL) activations were investigated. Maximum and minimum activation for each muscle were measured in millivolts (mV) [30]. The EMG signals were acquired using an 8-channel recording system. A portable system (Myomonitor IV, Delsys, Boston, USA) at a sampling rate of 2000 Hz using rectangular-shaped (19.8 mm wide and 35 mm long) bipolar surface electrodes with 1 x 10 mm 99.9% Ag conductors and an inter-conductor distance of 10 mm were also used. The system has an input impedance of >1015Ω // 0.2pF, a common mode rejection ratio of >80 dB, signal-to-noise ratio<1.2 μV and a pre-amplifier gain 1000 V/V±1%. The electrode with geometry detection on two parallel bars ($1mm^2$ x 1 cm, 99.9%) double-phase (Delsys) was used. The signals were corrected for offset and filtered at 20 to 400 Hz using a fourth-order, zero-lag Butterworth band-pass filter. The root mean square amplitude was quantified with a window duration of 20 milliseconds and a temporal overlap of 50%. The maximum and minimum muscle activation was calculated (in millivolts) for each repetition.

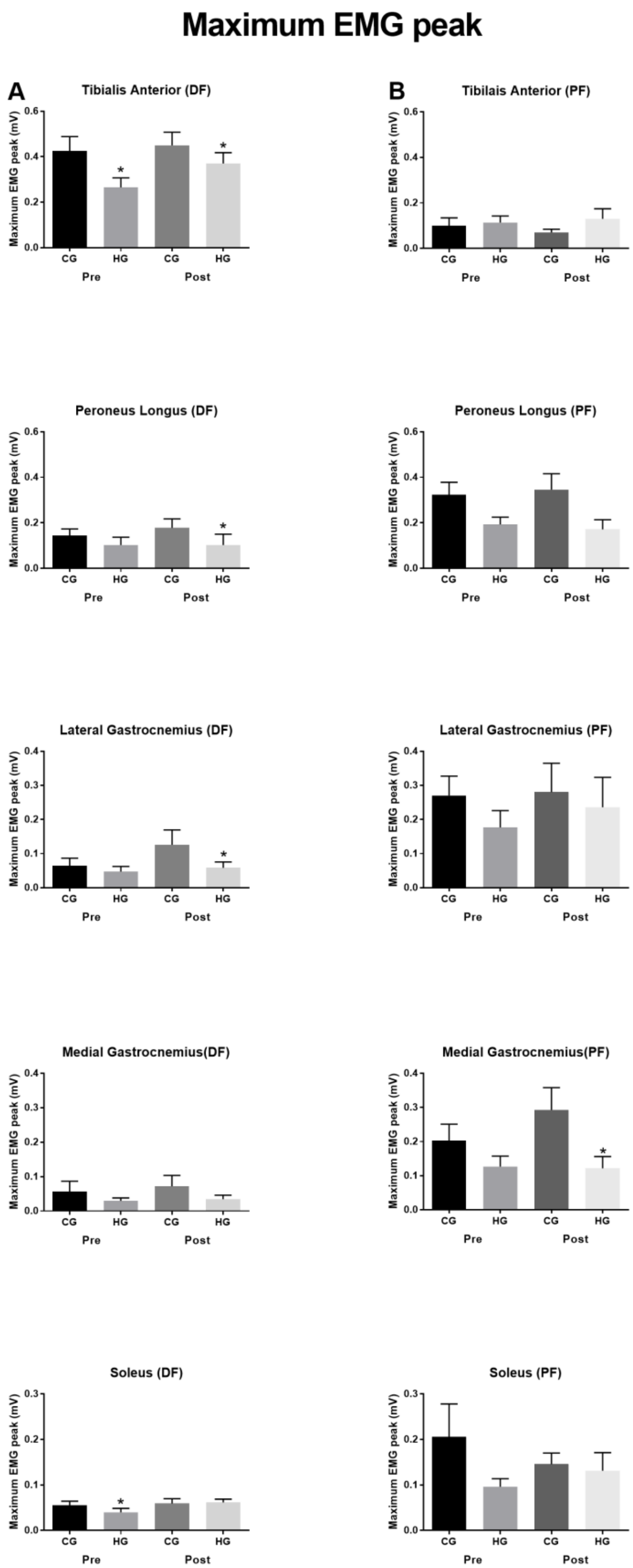
Statistical Analysis

For the maximum and minimum muscle activation (nonparametric data), a Mann- Whitney U test (hemiparetic x control group) and a Wilcoxon test (pre and post-robotic assisted session) were used. Delsys-EMG data processing was performed using MatLab software (v.7.0.1) and SPSS v.17 for statistics analysis.

Muscle activity - EMG

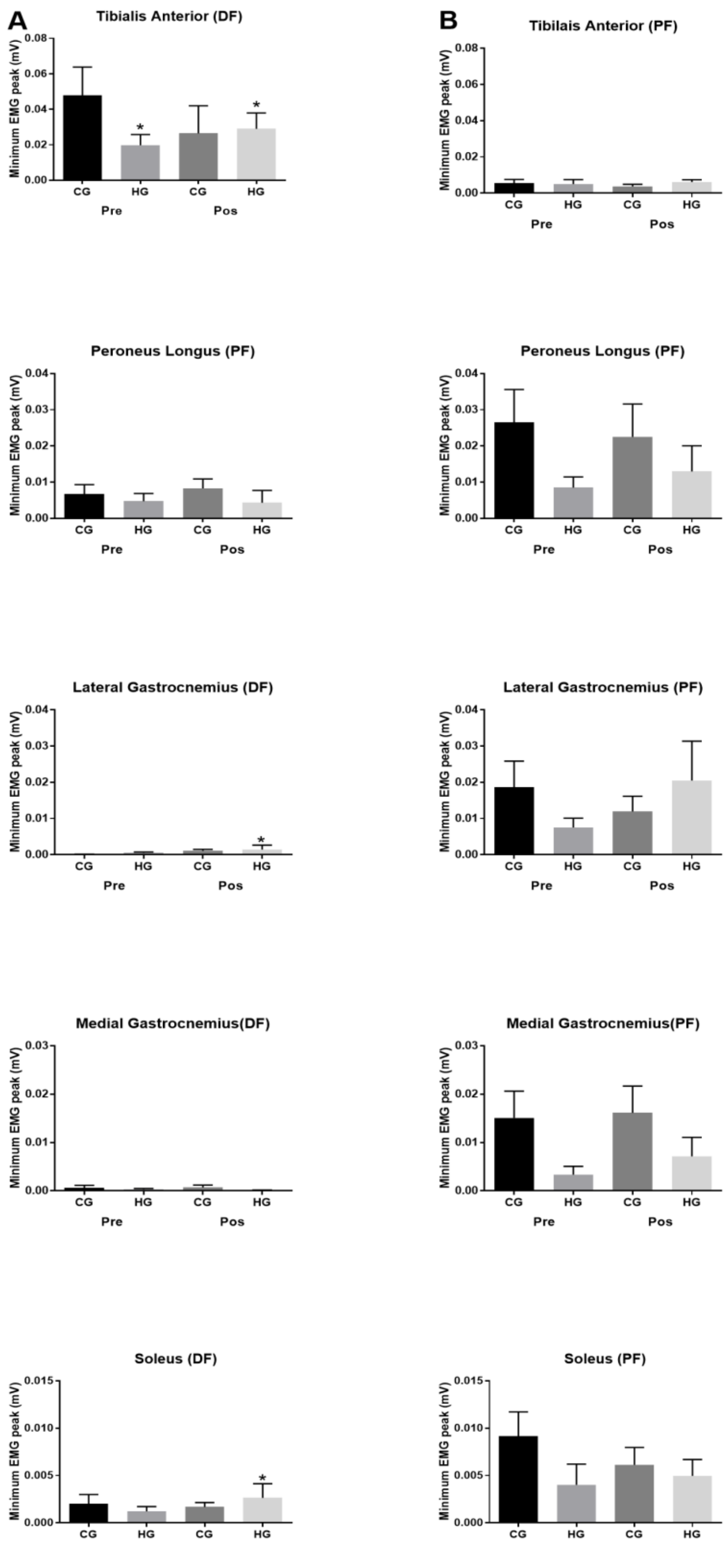
Maximum activation: The anterior tibialis muscle was lower during dorsiflexion in the hemiparesis group when compared to the control group at pre (p=0.03) and post-session (p=0.01) assisted robotic therapy assessments. Peroneus longus and gastrocnemius lateral muscles were lower during dorsiflexion in the hemiparetic group when compared to the control group at post-session (p=0.02). The soleus muscle was lower during dorsiflexion in the hemiparetic group when compared to the control group at pre-session (p=0.01). Regarding the plantarflexion, only the medial gastrocnemius muscle was lower during dorsiflexion in the paretic group when compared to the control group at post-session (p=0.01) There was no significant difference between the pre and post-robotic assisted session analyses for both movements and groups (Suppl Mat Fig 2).

Minimum activation: The anterior tibialis muscle was higher during dorsiflexion in the paretic group when compared to the control group at pre (p=0.03) and post-session (p=0.04) assisted robotic therapy assessments. The lateral gastrocnemius (p=0.01) and Soleus (p=0.02) muscles were higher during dorsiflexion in the hemiparetic when compared to the control group at the post-session. There were no significant differences between the groups during plantarflexion. There was no significant difference between pre and post-robotic assisted session for both movements and groups. (Suppl Mat Fig 3).


Maximum EMG peak
A
Tibialis Anterior (DF)
B
Tibilais Anterior (PF)
Peroneus Longus (DF)
Peroneus Longus (PF)
Lateral Gastrocnemius (DF)
Lateral Gastrocnemius (PF)
Medial Gastrocnemius(DF)
Medial Gastrocnemius(PF)
Soleus (DF)
Soleus (PF)
Maximum EMG peak (mV)
CG
HG
CG
HG
Pre
Post
*

Suppl Mat Figure 2: *Maximun EMG peak* during torque peak of concentric contraction. CG: control group; HG: hemiparesis Group; DF: dorsiflexion; PF: plantarflexion; *Significant difference between paretic group when compared to the control group in pre or post-robotic therapy ($p \leq 0.05$). Significant differences between groups during dorsiflexion movements were identified in the tibialis anterior muscle at pre and post-session. Significant differences between the groups in in post-session assisted robotic therapy assessments were identified in the peroneus longus and lateral gastrocnemius muscles. Soleus presented differences between the groups only in the pre-robotic assisted session. Regarding the plantarflexion movement, significant differences between the groups were identified after the session only in the gastrocnemius medial muscle. The control group was increased compared to the hemiparesis group for all situations. There was no significant difference between pre and post-robotic assisted sessions for both movements.

Minimum EMG peak



Suppl Mat Figure 3. *Minimum EMG peak during torque peak of concentric contraction.* CG: control group; HG: hemiparesis group; DF: dorsiflexion; PF: plantarflexion; *Significant differences were identified between the paretic group when compared to the control group on pre or post-robotic therapy (p≤0.05). Significant differences were identified between groups during the dorsiflexion on the tibialis anterior muscle in the pre and post-robotic assisted session. Significant differences between the groups were found only in the post-sessions for the lateral gastrocnemius and soleus muscles during dorsiflexion. The lateral gastrocnemius and soleus muscles presented significant differences between groups just in post-session during dorsiflexion. The hemiparesis group increased when compared to the control group for all situations, except for the tibialis anterior muscle in the pre-robotic session, which was decreased for hemiparesis group during dorsiflexion. There were no significant differences between the groups in the plantarflexion. There was no significant difference between the pre and post-robotic assisted session for both movements.

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MANUSCRITO 2 - SUBMETIDO A TRANSACTIONS ON NEURAL SYSTEMS & REHABILITATION ENGINEERING

Title: Ankle adaptive sensorimotor strategies in chronic post-stroke subjects due to variable assistance of robotic therapy and videogame

Short title: Robotic assistance therapy and motor control

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Itemized list of tables and figures: **Tables 1 and 2. Figures 1, 2, 3 and 4.**

Keywords: **Neurological Rehabilitation, Physical Therapy, Stroke, Anklebot, Ankle.**

Number of words:3.500

Abstract

Background: Using robotic devices to complement traditional therapy has gained considerable attention because this equipment offers resources to meet many of the objectives related to motor learning. Modular robotics are designed to facilitate focusing on a single impaired joint or limb, stimulating adequate movements and challenging motor control. **Objective:** This study aims to describe the changes in motor control by analyzing the metric data related to accuracy, speed, smoothness and movement initiated without assistance, as well as trajectory variation recorded during robotic ankle therapy protocol based on the criteria of increasing and decreasing impedance adjustments. **Methods:** This was a double-arm pilot study on a convenience sample of participants with chronic stroke (*n* = 14) who had residual hemiparetic deficits and an equal number of age- and sex-matched non-disabled control subjects. Balance, mobility and function were assessed. Game score, movement initiated without assistance, initiation time, mean speed, Number of speed peaks and trajectory variation were variables recorded over seven blocks with variable assistance levels. A motivation questionnaire was given to the hemiparesis group. **Results:** The motor adaptations were identified preferentially during the dorsiflexion movements and these changes were observed during the first unassisted impedance level ($0K_{initial}$ to $50K_{initial;}$ $p \leq 0.05$), during maximum impedance assistance level (150K; $p \leq 0.05$) and during the impedance removal (150K to $100K_{final}$ and $0k_{final;}$ $p \leq 0.05$). As expected, the hemiparesis group presented an initial reaction slower than the control group, receiving assistance to start the motion more frequently ($p \leq 0.002$). The hemiparesis group showed greater smoothness at the end of the protocol (100_{final} and 0_{final} blocks; $p \leq 0.04$). Regarding the variation of the error during the trajectory, the hemiparesis group presented adjustments for both movements in key moments of increment and the removal of assistance ($50_{initial}$, 150, 100_{final} and 0_{final} blocks; $p \leq 0.04$). **Conclusion:** Analyzing the metric data obtained during the robotic therapy session helped us to identify short-term motor adaptation related to the speed, accuracy and errors in the trajectory position. In addition, impedance change strategy was effective to promote challenge and control motor adaptation.

Keywords: Neurological Rehabilitation, videogame therapy, Chronic stroke, Anklebot, Ankle rehabilitation, Assistive Technology.

Introduction

Using robotic devices to complement traditional therapy has gained considerable attention because this equipment offers resources to meet many of the objectives related to motor learning.[1,2] Repetitive goal oriented practice using impaired limb and high-volume task-oriented training has been a major research focus in terms of restoring motor function in individuals with hemiparesis stroke[1,3,4]. Modular robotics are designed to facilitate focusing on a single impaired joint or limb, stimulating adequate movements and challenging motor control.[4,5]

Recent studies have shown that robotic ankle training in chronic stroke patients has the potential to transfer adaptations to locomotor performance in long-term protocols.[3,4] Previous research shows that visually-guided and evoked practice with an ankle robot (Anklebot) improves paretic ankle motor control[4,5]. In addition, metric data recorded during robotic therapy provide useful information to interpret these motor control changes. The seated training position opens up opportunities for therapy for patients who have extremely limited ambulatory capacity.[5,6,7] However, there is a narrow approach concerning the paretic ankle. Nevertheless, few studies have described the acute effects of the robotic therapy protocol. The description of acute effects and progression methods is important because it provides guidance to develop an effective protocol.

Regarding robotic therapy progression, it is important to consider the variation of task difficulty. Functional task difficulty refers to how challenging the task is in relation to the skill level of the individual performing the function and the conditions under which the task is being performed. The following variables define high or low difficulty levels: the task objective (skill level), the speed and repetition frequency. The difficulty level is important because of the learning process and it is also related to the motivation level of the patient. However, there is no consensus on how to synchronize the progression of these variables. [9,10]

In addition, the assistance, defined by the robot impedance, is also used as an instrument of difficulty progression of the robotic therapy protocol.[5] The impedance control, initially proposed by Neville Hogan in 1985 modulates the robotic system reaction regarding disturbances generated by the patient and ensures compliant behavior. Low impedance means that the robot will move as the patient exerts force on it, a characteristic called backdrivability.[11]

This study aims to describe the changes in sensorimotor control by analyzing the metric data related to accuracy, speed, smoothness, movement initiated without assistance and trajectory variation recorded during robotic ankle therapy protocol based on the criteria of increasing and decreasing impedance adjustments, i.e., different levels of assistance using the Anklebot device. The hypothesis of the study was that the metric analysis will indicate the effectiveness of the robotic assistance protocol, based mainly on the changes in the impedance levels adopted. Furthermore, the protocol used will promote important short-term adjustments in the sensorimotor control of the ankle.

Material and methods

Ethical Guidelines

The study was conducted according to the guidelines and standards for human research (Resolution 196/1996, the National Health Council) and it was approved by the local ethics committee (report no.: 527.556/2014). This was a double-arm piloty study.

Experimental Design

The hemiparesis subjects were recruited from the *Santa Casa de Misericordia hospital of São Carlos* and the waiting list of local medical centers and control volunteers were recruited from the local community. The individuals with hemiparesis were not linked to any rehabilitation programs. The following inclusion criteria were considered: six or more months post-stroke; men or women aged between 50 and 75 years; low spasticity (less than level 3 on the modified Ashworth scale [12], so that the individual would be able to perform the isokinetic test); and overground walking (levels 2 and 5 according to the Functional Ambulation Categories) [13]. The control group participants had to score greater than 8 in the Physical Activity Questionnaire Basal, which indicates they were not sedentary [14,15]. This is important because sedentary people have deleterious modifications in their neuromuscular system [16]. Furthermore, individuals from the control group performed physical activities (mainly aerobic activities) at least 3 times weekly. No further criteria regarding physical activity levels were applied. The exclusion criteria were: clinical signs of severe heart failure or chronic metabolic disease; severe cognitive or communication impairments; minimum score in the Mini-Mental State Examination [17] according to the education level; and a history of lower limb injuries, and deformity or contractures of ankle joint; smaller range of motion than 10^{o} to dorsiflexion and 20^{o} to plantarflexion; sensory deficits and neglect on clinical exams defined by *Bell*'s [18] and *Clock* *drawing* [19] *tests*. The statistical power was calculated at the end of study using the Mean Squared Error (MSE) variable (Power=0.98 and effect size 1.01). These values were performed by the GPower® software.

Participants

The flowchart showing participant exclusion and inclusion is presented in Figure 1. Twenty eight individuals took part in the study. The hemiparesis group (n=14) comprised 12 men and 2 women who had ischemic and unilateral strokes. The mean time after the stroke was 4.2±6 years. The control group (n=14) also consisted of 12 men and 2 women who were matched to the hemiparesis group by age (± 3 years), sex and body mass index (± 4 kg/m^2). For ethical reasons, all the individuals from the hemiparesis group were invited to attend an 8-week conventional therapy program after evaluations. This program was carried out by physiotherapists. The control group received information about the importance of practicing regular physical activity.

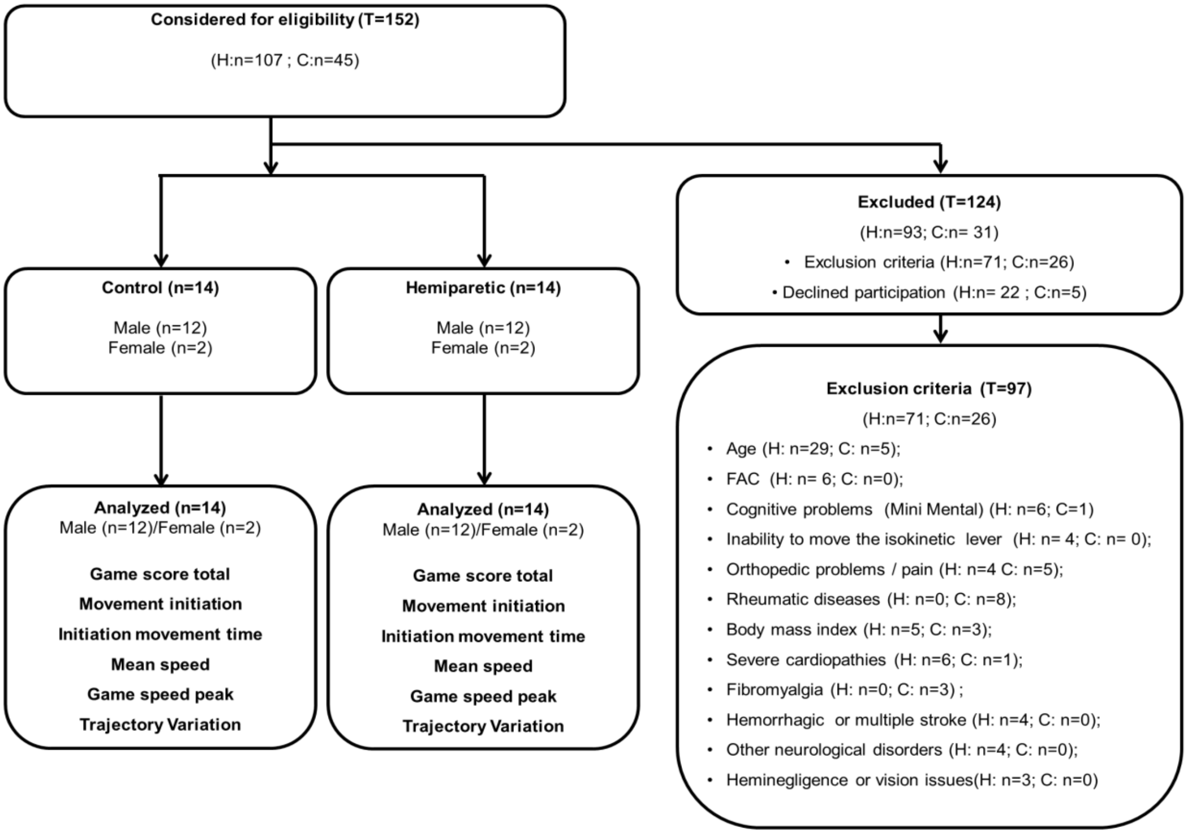

Figure 1. *Flowchart of enrolled participants*. T: total of recruited individuals, H: hemiparesis group and C: control group. FAC: Functional Ambulation Categories.

Procedure and Measuring Instruments

The evaluations were performed as follows: on the first day, screening (clinical assessment) was performed to apply inclusion, exclusion criteria and functional tests. On the second day, the individuals were familiarized with the evaluation protocol, including neuromuscular tests and a robotic rehabilitation session (the protocol of robotic assisted therapy associated to videogame was defined as a session). After one week, the evaluation protocol was effectively carried out.

Clinical assessment

For a detailed description of the hemiparesis group, their balance and mobility were assessed using multiple scales and tests: the Berg Balance Scale [20], the “Timed Up & Go” Test [21] and the 10-Meter Walk Test [22]. Furthermore, motor performance and activities of daily living were assessed using the Fugl-Meyer Assessment [23] and Barthel Index [24], respectively.

Ankle Robotic therapy (Anklebot) and videogame

Anklebot device: The Anklebot robotic system (Interactive Motion Technologies, Inc., Watertown, MA, USA) is a wearable and backdrivable system that can be used in a seated position or during walking. It allows actuation and sensing within the normal range of motion in dorsi/plantarflexion (DP) and inversion/eversion (IE) movements of the ankle joint[5.] Anklebot uses an impedance controller with adjustable stiffness and damping.

Anklebot setups: The patients were positioned according to the description of Roy *et al* 2009 [5]. The paretic lower leg was positioned at ~45° on a cushioned support, isolating the foot to move freely around the ankle. Subjects were then introduced to the videogame “race” that was subsequently used to assess the paretic ankle motor control. The chair was positioned at 1.5 meters from the computer screen.

Videogame: The movements were visually evoked (movement started as visual feedback) and the objectives were presented in a computer game that reproduces an obstacle course (Fig 2). The ankle was free to move in the frontal plane while the patient controlled the ankle while performing dorsiflexion and plantar flexion movements to reach the targets. The Anklebot control functioned as an "up" or "down" cursor on the game screen. The individual moved on two vertical levels corresponding to 10° dorsiflexion and 20° plantarflexion. If as the subject did not start moving after 2 seconds, the Anklebot provided a torque toward the target [5,7]

Repetition protocol and varying impedances: 350 ankle movements were distributed in seven blocks, at a 3.5-second interval between each target. At each block of 50 movements or targets, there was a change (increase or withdrawal) of the robotic assistance level. The first and the last block (0Nm/rad initial and final) were exempted from unassisted movements. From the second to fourth blocks, there was a gradual impedance increase in 50Nm/rad. The fifth and sixth blocks showed a gradual decrease in the impedance values. Thus, the following robotic-assistance impedance sequence was applied: 0Nm/rad (0initial) ►50Nm/rad (50initial) ►100Nm/rad (100initial) ►150Nm/rad (maximum assistance level) ►100Nm/rad (100final) ►50Nm/rad (50final) ►0Nm/rad (0final).

Videogame score: The total score recorded in each block was 1500 points. The player´s aim was to move through the gate passage and reach the target object (30 points). Bumping or hovering the cursor over the wall-shaped game obstacles (-20 points) and the race track stains (-10 points) were the possible mistakes. During the game, the bar remained green or red as a visual feedback on the player's performance.

Videogame variables: Game score, movement initiated without assistance, initiation time, mean speed during movement, number of speed peaks and trajectory variation. The game score is related to ankle targeting accuracy during therapy, which is the quantification of the wrong and correct answers during the game. Movement Initiated without assistance is the number of attempts in which the patient initiated the movement voluntarily before the two seconds determined for the movement initiative without robotic assistance. Initiation time corresponds to the total time used by the patient to initiate movement after the target is presented. This variable is related to the assistance provided to the patient by the robotic device.

A longer initiation time provides insight concerning the patient´s difficulty to start the movement. The mean speed during movements is related to the difficulty level of the patient to perform every movement. Lower speeds are associated with errors. Number of speed peaks refers to the continuity and smoothness of the movement, the smaller the number of peaks, the greater the continuity of movement and the better its execution. Trajectory variation is a sum of the squared errors related to desired trajectory. It relates to the variation of the ankle position during the patient's trajectory. A smaller trajectory variation implies greater approximation for desired trajectory to be executed.

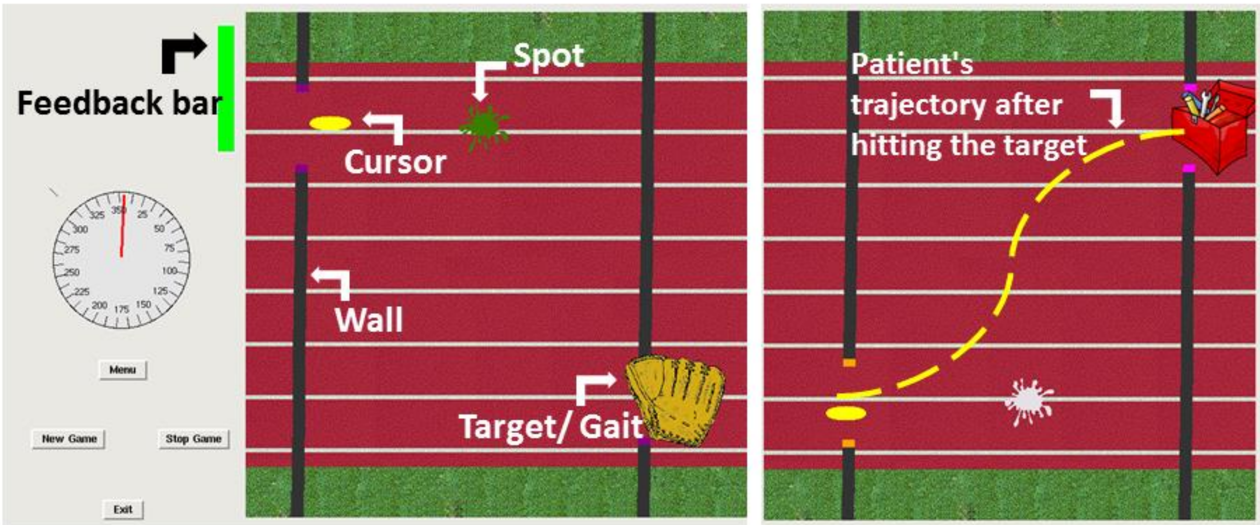

Figure 2: *Videogame Interface.*

Motivation Questionnaire

The questionnarie was given only to the hemiparesis group. Four questions were presented that evaluated the resource used for the robotic therapy session and the computer game. The questions were: 1) What did you think of the robotic therapy session? The possible responses were given: a- I really enjoyed it and I would repeat it more often; b- I liked it and would repeat it a few times; c- I liked it, but I would not like to repeat it; d- I did not like it; 2) How did you feel during the game? a- Enthusiastic/Motivated; b- Normal; c- Tired; d- Bored; 3) If you liked it, how long could you continue playing feeling the same way? a- One hour; b- Half an hour is an ideal time; c- Fifteen minutes; d- Five minutes; 4) Did you feel any muscle discomfort during the game? If yes, where? a- No discomfort; b- Mild discomfort; c- Moderate discomfort; d- Severe discomfort.

Data Analysis

The data were tested for normality and homogeneity (Shapiro-Wilk and Levene tests, respectively). The Mann-Whitney U test (group analysis) and Wilcoxon (impedance block analysis) were used for the initiation movement time, mean speed during movement, number of speed peaks and trajectory variation variables.

Results

Subject characterization

Groups were similar according to the demographic variables. Moreover, the hemiparesis group presented a reduced level of spasticity and slight motor impairment according to the Modified Ashworth Scale and Fugl-Meyer Assessment, respectively. Descriptive data (e.g. demographic and functional data) are presented in Table 1.

Table 1. *Characteristics of Subjects*

	Control Group (n= 14)	Hemiparesis Group (n=14)
Gender (Male/Female)	**(H:11/ M:2)**	**(M:11/ F:2)**
Age (year)	**64±6**	**64.4± 6**
Post-stroke time (month)	**/**	**62±36**
Hemiparesis side (Right or Left)	**/**	**R:7/ L:7**
BM I(Kg/m^2)	**25.4±3**	**26.5±5**
MAS(0/1/1+/2/3/4)		
Hip	**/**	**10/4/0/0/0/0**
Knee	**/**	**5/6/2/1/0/0**
Ankle	**/**	**2/8/4/0/0/0**
FMA	**/**	**32 (24-42)**

Measurements are reported as median (maximum and minimum values). BMI: Body Mass Index; FMA: Fugl-Meyer Assessment; MAS=Modified Ashworth Scale: 0=no increase in muscle tone, 1=slight increase in muscle tone, shown by a catch and release or by minimal resistance at the end of the range of motion [ROM], 1=slight increase in muscle tone, shown by a catch, followed by minimal resistance throughout the remainder of the ROM, 2=more marked increase in muscle tone throughout most of the ROM, but affected parts easily moved, 3=considerable increase in muscle tone, passive movement difficult, 4=affected parts rigid in flexion or extension.

Videogame and performance of patients during the game

Regarding the total game score (CG: 1422±56; HG: 1252±76; p=0.14), no significant differences between the groups were identified (Table 2). Regarding comparison between the blocks, the control group presented greater accuracy in the $100_{initial;}$ (p=0.021), 150 (p=0.025) and 100_{final} (p=0.047) when compared to the hemiparesis group.

Movement Initiated without assistance

Regarding the total values (CG:49.17±1.06; HG: 45.72±1.3; p=0.001), the control group performed more repetitions without robotic assistance than the hemiparesis group. Regarding impedance comparison, significant differences between the groups were identified (p≤0.002) for all the blocks, except for the last unassisted block (0_{final}). The control group performed more repetitions without assistance (p=0.038) compared to the hemiparesis group (Table 2; Figure 3).

Table 2. *Game score and Movement initiated without assistance*

	Game score		***Movement initiated without assistance***	
Impedance Variation (Nm/rad)	**CG**	**HG**	**CG**	**HG**
0i	**1297.5±285**	**1068.3±425**	**46.92±3.1***	**42.64±5.4**
50i	**1425.0±52**	**1252.5±280.6**	**49.17±1.6***	**45.71±4.7**
100i	**1422.5±93***	**1250.0±271**	**49.50±0.6***	**45.64±5.1**
150	**1431.6±79***	**1269.1±251.3**	**49.50±0.7***	**46.71±3.34**
100f	**1445.8±50***	**1304.17±233**	**49.42±0.9***	**47.00±3.9**
50f	**1405±158.2**	**1269.17±323**	**49.00±2.7***	**45.79±4**
0f	**1312.33±380**	**1160±433**	**47.08±6.7**	**45.14±5.4**

CG: Control group; HG: Hemiparesis group; Nm/rad: Newton meters per radians; I; initial; f; final; *Significant differences between groups.

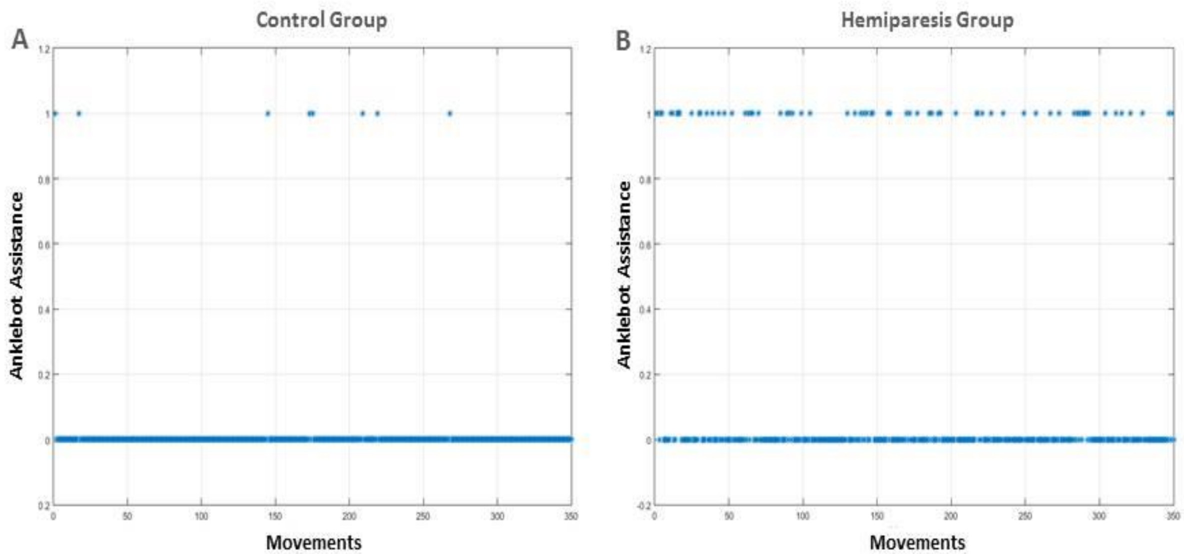

Figure 3: *Initiation without robotic assistance.* Line 0: no robotic assistance to initiate the movement; Line 1: robot assistance to initiate the movement.

Initiation time

Regarding the dorsiflexion movement, compared to the first unassisted block, the control group required a shorter time to start the movement during 50_{final} ($0_{initial;}$ p=0.01). Regarding the plantarflexion movement, the hemiparesis group presented less time to start the movement during $50_{initial}$, 100_{final} and 0_{final} (p=0.02). Significant differences between the groups considering the dorsiflexion movement were not identified. The control group required less time to start the plantarflexion movement during the 100_{final} and 50_{final} blocks (p=0.02) compared with the hemiparesis group.

Mean Speed

Regarding the dorsiflexion movement, when compared to the first unassisted block ($0_{initial}$), the control group was slower during the $50_{initial}$ and 100_{final} blocks (p=0.04). The hemiparesis group was slower during the 150, 100_{final}, 0_{final} (p≥0.04). When comparing the groups, the control was faster than the hemiparesis group only during the $50_{initial}$ (p=0.04). Regarding the plantarflexion movement, the hemiparesis group was slower in the $50_{initial}$ (p=0.03) block. When comparing the groups, no changes in the mean speed during the plantarflexion movement were identified (p≥0.05).

Number of speed peaks

Regarding the dorsiflexion movement, when compared to the first unassisted block ($0_{initial}$), the control group presented greater smoothness and continuity in the second block ($50_{initial}$; p=0.04). The paretic group showed greater smoothness and continuity of movement in the 100_{final} and 0_{final} (p=0.04) blocks. The control group presented greater smoothness and continuity only in the $50_{initial}$ block when compared to the hemiparesis group (p=0.03). No change of smoothness and continuity during plantar flexion were identified (p≥0.05).

Trajectory variation

Regarding the dorsiflexion movement, when compared to the first unassisted block ($0_{initial}$), the control group presented a greater variation in the $50_{initial}$ and 100_{final}) blocks (p=0.04). The hemiparesis group presented a greater variation in the $50_{initial}$, 150, 100_{final}, 50_{final} and 0_{final}) blocks (p=0.04). During plantarflexion, the control group presented a greater variation in the $50_{initial}$, 100_{final} and 0_{final} blocks (p=0.04). The hemiparesis group presented a greater variation in the $50_{initial}$, 100_{final} and 0_{final} blocks (p=0.01). Regarding initial and final impedance analyses (pre and post maximum impedance level =150, represented by brackets). The second block ($50_{initial}$) presented a greater variation compared to the sixth (50_{final}) block (p=0.01). The third block ($100_{initial}$) presented a greater variation compared to the fifth (100_{final}) block (p=0.01). No significant differences between the groups during both movements were identified.

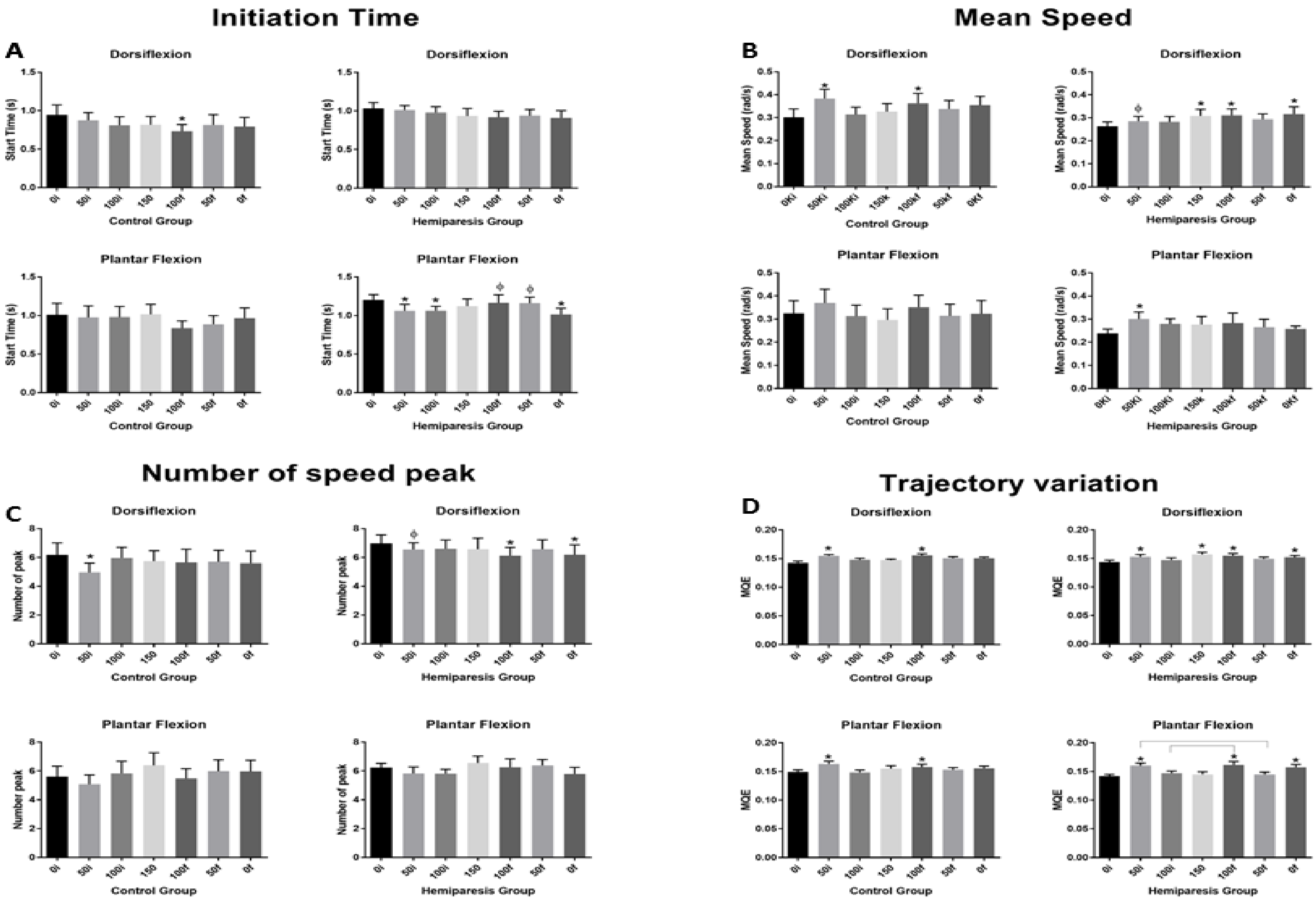
Initiation Time
A
Dorsiflexion
Start Time (s)
Control Group
Hemiparesis Group
Plantar Flexion
Mean Speed
B
Mean Speed (rad/s)
Number of speed peak
C
Number of peak
Number peak
Trajectory variation
D
MQE

Figure 4. *Videogame metric data.* * Significant difference for comparison between first unassisted block $0_{initial}$ (0i) with other blocks, ɸ Significant difference between groups. A) *Initiation time.* B) *Mean Speed.* Regarding impedance analysis, the control group was slower in the $50_{initial}$ and 100_{final}, the hemiparesis group was slower in the 150, 100_{final} and 0_{final} during dorsiflexion. In the group analysis, the hemiparesis group was slower than the control only in the $50_{initial}$ block. Regarding the plantarflexion movement, the hemiparesis group was slower in the $50_{initial}$ block when compared to the initial unassisted block. C) *Number of speed peak.* Regarding impedance analysis, the control group presented less smoothness and continuity in $50_{initial}$. The hemiparesis group presented less smoothness and continuity in the 100_{final} and 0_{final} blocks during the dorsiflexion movement. Significant differences between the groups only in the $50_{initial}$ block during dorsiflexion movement were identified. No significant differences between groups during the plantarflexion were identified. D) Trajectory Variation. Brackets indicate the analysis between the initial and final impedance.

Motivation questionnaire

The questionnaire was given only to the hemiparesis group. The questions and the number of answers in parentheses are as follows. 1) What did you think of the robotic therapy session? The possible responses were given: a- I really enjoyed it and I would repeat it more often (n=11); b- I liked it and would repeat it a few times (n= 0); c- I liked it, but I would not like to repeat it (n=0); d- I did not like it (n=0); 2) How did you feel during the game? a- Enthusiastic/Motivated (n=7); b- Normal (n=4); c- Tired(n=0); d- Bored (n=0); 3) If you liked it, how long could you continue playing feeling the same way? a- One hour (n=2); b- Half an hour is an ideal time (n=9); c- Fifteen minutes (n=0); d- Five minutes (n=0); 4) Did you feel any muscle discomfort during the game? If yes, where? a- No discomfort (n=9); b- Mild discomfort (n=2); c- Moderate discomfort; d- Severe discomfort. Two patients reported mild discomfort in the region of the plantarflexor muscles.

Discussion

The description of changes in motor control by analyzing the metric variables recorded during the robotic ankle therapy protocol was based on the criteria of increasing and decreasing impedance adjustments. Important insights about motor adaptation were identified in this study. The metric analysis and the therapy protocol design used provided us with new information to interpret short-term adjustments in ankle motor control. Moreover, this is an important tool to help maintain or develop the training protocol.

The presented protocol which considers impedance changes was based on a study carried out by Roy *et al* . 2009, [5] which used a similar protocol in which changes in impedance levels consisted of the progression from higher to lower levels of robotic assistance. The treatment lasted 6 weeks and the metric data at the end of this period were correlated using kinematic gait data. Data from a submitted manuscript reveals that although the protocol did not influence levels of concentric force and the gait speed of these individuals, the protocol used promoted an adjustment in the fine motor coordination of the ankle during dorsiflexion, which was observed in a specific test to maintain the submaximal force (steadiness).

In the present study, both groups presented similar metrics, except for specific situations. The motor adaptations were identified preferentially during the dorsiflexion movements and these changes were observed during the first unassisted impedance level ($0_{initial}$ to $50_{initial}$), during the maximum impedance assistance level (150) and during the impedance removal (150 to 100_{final} and 0_{final}). The groups were similar in accuracy, observed in the game score table, however the hemiparesis group presented an initial reaction slower than the control group, receiving assistance to start the motion more frequently. This slowness to initiate movements (time for reaction) is a typical characteristic of this population. It occurs by altering the connections with basal ganglia.[25,26]

This delay is demonstrated in studies of the kinematics of this population.[27] The hemiparesis group also presented a reduced mean speed at different levels of assistance. This reduction in speed may have occurred due to the improvement of movement quality, considering the smoothness and position of the trajectory. However, the speed reduction indicates that the patient is more conductive to error. [8,28] The study performed by Roy *et al* ., showed that there was an increase in the mean speed, after six weeks in a protocol of gradual assistance decrease. This speed increase was associated to changes observed in gait kinematics variables.

The hemiparesis group showed greater smoothness during the protocol ending (100_{final} and 0final block). This is an indication of improved motor control. Regarding the variation of the error during the trajectory, the hemiparesis group presented adjustments for both movements in key moments of increment and the removal of assistance ($50_{initial}$, 150, 100_{final} and 0_{final} blocks). These adjustments suggest that the strategy of gradually adding and removing robotic assistance served as a type of disturbance, generating motor adaptations to a refinement strategy of motor control that resulted in improved task quality.

Regarding the number of repetitions, the protocol presented 350 repetitive movements, distributed in blocks of 50 movements, impedance level changes and the time used for each goal. [5] The total therapy time was performed according to the protocols used in the recent literature. [6,8,29,30,31] Recent studies on animals present relevant data regarding the repetition protocols. In most rodent stroke studies that use reaching tasks as part of the rehabilitation protocol, there is often no limit imposed on the amount of reaching allowed. Rats will typically reach 300 times in a training session. In another study, a smaller number of repetitions were used and recovery did not occur. [32] Changes in synaptic density in primary motor cortex occur after 400 reaches. [33] However, there is a consensus that adverse effects can occur for approximately 1000 repetitions. [34]

Our subjects had similar adjustments compared to the protocol used. Scheidt and Stoeckmann (2007)[9] used the MIT-Manus to compare force field adaptation in post-stroke and healthy subjects. They found that the compensatory strategy utilized by the post-stroke group was the same as the healthy group, but paretic patients may need more practice trials. In relation to the difficulty level of the game, the used protocol can be classified as a low difficulty level because it presented a comfortable speed of 3.5 seconds for each goal, with a simple and predictable goal variation. This criterion of difficulty is in agreement with the systematic approach of classification that would establish criteria to appoint optimal levels of task difficulty to promote the motor. [35] The difficulty level of the game was low, however the patients showed interest and were motivated according to the motivation questionnaire. Patients reported motivation to play and return for future sessions (supplementary material).

Another important concept is that the feedback influences the learning process. The high frequency of feedback can hinder the acquisition process. In this study, visuo-acoustic feedback was used; the error and success rate was represented by a green bar at the top right of the screen that was red if the patient performed a sequence with many errors, and consequently, the bar turned red. However, when committing an error, the patient was warned with an audible/acoustic alert. Considering a protocol to be used in long-term robotic rehabilitation protocol, Byun *et al* . (2016)[36] shows which visuo-acoustic biofeedback is predicted to be advantageous in early stages of treatment, but this advantage may be attenuated or eliminated as the goal of treatment shifts from acquisition to generalization of an accurate motor plan.

The fact that the control group presented motor adaptation in different blocks assures us that our protocol was effective. However, the construction of concepts related to robotic therapy need to be improved, and thus acquire support for designing more effective and appropriate protocols for each stage of the recovery process and to support patients according to the impairment level.

Future studies could suggest what the slightest change would be in motor control that the patient should present in a single session to be classified as eligible for robotic therapy. Furthermore, the description of criteria for ideal speed variation and biofeedback contribution should be considered.

Conclusion

The analysis of metric data obtained during the robotic therapy session enabled us to identify short-term motor adaptation related to the speed, accuracy and errors in the trajectory position. In addition, impedance change strategy was effective to promote challenges and control motor adaptation.

Conflict of interests: None of the authors have any competing interests in the manuscript.

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CONCLUSÃO GERAL

Indivíduos com hemiparesia crônica apresentaram ganhos em curto prazo no desempenho durante a manutenção de torque submáximo, especialmente durante a dorsiflexão após uma única sessão de terapia robótica. Os indivíduos com hemiparesia crônica apresentaram maior destreza no movimento de dorsiflexão. Além disso, a análise dos dados métricos obtidos durante a sessão de terapia robótica permitiu identificar a adaptação motora de curto prazo relacionada à velocidade, precisão e erros na posição da trajetória. Ainda, a estratégia baseada na mudança do nível de assistência foi eficaz para promover desafios e promover a adaptação motora.

PRODUÇÃO NO PERÍODO

Manuscritos submetidos e produzidos diretamente ao projeto do doutorado

Manuscrito 1

SILVA-COUTO MA[1], MS, SIQUEIRA AGS, PHD, SANTOS GL, MS, RUSSO TL[1], PHD. *Short-term adaptations of ankle sensorimotor control due to a single session of robot therapy in chronic post-stroke subjects*.
Submetido ao Jornal Physical Therapy

Manuscrito 2

SILVA-COUTO MA1, SIQUEIRA AS2, PEREZ BARRA JL2, GUEDES R1, ROSANGELA M1, RUSSO TL1. *Ankle adaptive sensorimotor strategies in chronic post-stroke subjects due to variable assistance of game robotic therapy*.
Submetido ao Jornal Transactions on Neural Systems & Rehabilitation Engineering

Manuscrito 3

SILVA-COUTO MA, RUSSO TL[1], PATTEN C, PHD SIQUEIRA AGS, PHD. Análise eletromiográfica durante contração máxima, onset e sinergia dos músculos do tornozelo de indivíduos hemiparéticos comparados ao controle. Uma abordagem sobre fadiga.
Manuscrito em fase de elaboração. Este artigo contará com a participação da professora do exterior Dra Carolyn Patten integrante do Brain Rehabilitation Research Center e Neural Control of Movement Laboratory da University of Florida.

Manuscrito 4

Manuscrito em fase de elaboração: Manuscrito relacionado ao projeto vinculado ao estágio no exterior. Este trabalho teve o objetivo avaliar a biomecânica da marcha, por meio de cinemática (Sistema Vicon) de indivíduos hemiparéticos e controles saudáveis durante a assistência da perna mecânica TIBION. Dados coletados no Neural Control of Movement Laboratory, no Brain Rehabilitation Research Center da Universidade da Florida.

Manuscritos submetidos relacionados a outros projetos

Manuscrito 5

JUAN CARLOS PÉREZ-IBARRA1, ADRIANO A. G. SIQUEIRA1, MARCELA A. DE **SILVA-COUTO**2, THIAGO L. DE RUSSO2, AND HERMANO I. KREBS. *Adaptive Impedance Control Applied to Robot-Aided Neurorehabilitation of the Ankle.*

Manuscrito enviado ao Jornal Transactions on Neural System and Rehabilitation Engineering. Este artigo foi o resultado da participação de um projeto no laboratório de Mecatrônica na USP, projeto desenvolvido durante o mestrado do aluno Juan Carlos Perez com a participação do pesquisador Hermano Krebs do Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA, USA.

Manuscrito 6

SILVA-COUTO MA[1], MS, PAIVA FP[2], ALCÂNTARA CC[1], MS, THAIANNE M.[1] PRADO-MEDEIROS CL[1], PHD, SALVINI TF[1], PHD, RUSSO TL[1], PHD. Midfemoral Bone Volumes Is Correlated To Knee Isometric Muscle Performance And IGFBP-3 Serum Concentration Of Post-Stroke Chronic People.

Manuscrito em fase de submissão. Sendo configurado para ser enviado ao Brazilian Journal of Physical Therapy. Este trabalho está relacionado ao projeto de mestrado desenvolvido em parceria com a doutoranda Carolina Alcântara e Christiane L. Medeiros juntamente ao laboratório de Plasticidade Muscular com participação da Dra Tania Salvini.

Manuscrito 7

C.C. ALCÂNTARA[1], MSC, L.F. GARCÍA-SALAZAR[1,2], MSC, M.A. **SILVA-COUTO[1]**, MSC, G.L. SANTOS[1], MSC, D. REISMAN[3], PHD, T.L. RUSSO[1], PHD. Post-stroke BDNF concentrations changes following physical exercises: A SYSTEMATIC REVIEW

Manuscrito em fase de submissão. Este trabalho foi resultado da reunião da equipe de trabalho do laboratório LaFin. Conta com parceria com integrante internacional, a professora Darcy Reisman do Department of Physical Therapy, University of Delaware. Newark, Delaware, USA.

Manuscrito 8

C. ALCÂNTARA, MS[1], F. PAIVA, MS, PHD[2], A. OLIVEIRA, PHD[3], M. **SILVA-COUTO**, MS[1], A. OLIVEIRA[1], C. PRADO-MEDEIROS, PHD[4], T. SATO, MS, PHD[5], T. SALVINI, PHD[4], T. MATA[1],

T. RUSSO, PHD[1] Chronic post-stroke hemiparesis does not change non-contractile tissue and passive torque in the paretic limb".

Manuscrito submetido ao Journal of Neurologic Physical Therapy. Este trabalho está relacionado ao projeto de mestrado desenvolvido em parceria com a doutoranda Carolina Alcântara e Christiane L. Medeiros juntamente ao laboratório de Plasticidade Muscular com participação da Dra Tania Salvini.

Manuscritos publicados

Manuscrito 9

SANTOS GL, ALCÂNTARA CC, **SILVA-COUTO MA**, GARCÍA-SALAZAR LF, RUSSO TL. *Decreased Brain-Derived Neurotrophic Factor Serum Concentrations in Chronic Post-Stroke Subjects.* J Stroke Cerebrovasc Dis. 2016 Sep 1. pii: S1052-3057(16)30286-5. doi: 10.1016/j.jstrokecerebrovasdis.2016.08.014.

Resumo estendido

ALCÂNTARA C.C., **SILVA-COUTO M.A**., PRADO-MEDEIROS C.L., SALVINI T.F., *RUSSO T.L. Evaluation of knee flexors and extensors isokinetic torque and IGF-1/IGFBP-3 concentrations after eccentric training in chronic hemiparetic subjects*. December 2015 Volume 42, Supplement 3, Pages S58–S59. doi.org/10.1016/j.gaitpost.2015.03.103

Apresentação trabalho internacional

ALCÂNTARA C.C., **SILVA-COUTO** M.A., PRADO-MEDEIROS C.L., SALVINI T.F., *RUSSO T.L. Evaluation of knee flexors and extensors isokinetic torque and IGF-1/IGFBP-3 concentrations after eccentric training in chronic hemiparetic subjects*. December 2015 Volume 42, Supplement 3, Pages S58–S59. doi.org/10.1016/j.gaitpost.2015.03.103

Apresentação trabalho nacional

SANTOS RM, RUSSO TL, SIQUEIRA AG, **SILVA-COUTO** MA. *O desempenho funcional de pacientes hemiparéticos crônicos após uma sessão de terapia robótica. Simpósio Especialização Geriatria.* V Curso de Especialização em Fisioterapia Geriátrica da Universidade Federal de São Carlos, apresentação do Trabalho de Conclusão de Curso. 2014

RUSSO TL, **SILVA-COUTO** MA, SANTOS L, ALCÂNTARA CA, SANTOS GS, SALAZAR LG, TURI A. Semana Nacional de Ciência e Tecnologia - Realizado pela Universidade Federal de São Carlos. Apresentação do pôster intitulado: "O papel do exercício físico na prevenção do AVC". 2013

Participação em congresso Internacional

5th IEEE RAS/EMBS International Conference on Biomedical Robotcs and Biomechatronics – *BioRob*. 12 a 15 de Agosto de 2014

Participação em Simpósio internacional

10th Annual Neuromuscular Plasticity Symposium; March 13, 2015. Neuromuscular Plasticity Training Program. University of Florida.

Participação Simpósio Nacional

2014- Simpósio AVC Campinas – Realizado pela faculdade de ciências médicas. Carga Horária: 8 horas

2014- IV jornada de Estudos em Gerontologia – Estratégias de promoção do envelhecimento ativo e saudável. Carga Horária: 4 horas

Atividades Acadêmico-Didáticas

Orientação de alunos

2014- Orientação da aluna Rosangela Monteiro dos Santos, que realizou o Curso de Especialização em Fisioterapia Geriátrica da Universidade Federal de São Carlos, o trabalho de Conclusão de Curso foi intitulado de **"**O desempenho funcional de pacientes hemiparéticos crônicos após Uma sessão de terapia robótica".

2014- Co-orientação do aluno Ramon Guedes Camargo em seu Trabalho de Conclusão de Curso intitulado "A correlação da escala FM com dados métricos do videogame após uma sessão de terapia robótica"

Projeto de extensão

2013- Projeto PROEXT intitulado **"***Cuidado aos usuários com afecções neurológicas no município de São Carlos: uma perspectiva de linha de cuidado vinculada ao SUS"***,** (aprovado em 2012, desenvolvido em 2013 e 2014). Co-Autora e participante como membro do corpo clínico do projeto que tinha como objetivo incluir pacientes hemiparéticos crônicos em ambiente terapêutico. Uma proposta de exercícios aeróbicos e o estímulo do auto-cuidado.

Preceptora voluntária

2014 - Programa de Educação pelo Trabalho para Saúde/Saúde da Família (PET-Saúde/SF). Participei como tutora voluntária do Programa de Educação Tutorial no estágio de Fisioterapia em saúde Pública que ocorre nas Unidades Municipais de Saúde de São Carlos. Esse trabalho foi realizado em posto de saúde da Rede SUS, com atendimentos semanais, na qual acompanhei alunos de estágio em fisioterapia em atendimentos prestados à Comunidade. Carga Horária: 100 horas

Supervisão de Estágio

2014 - Trabalhei como tutora voluntária na Unidade de Saúde Escoça (USE) supervisionando alunos estagiários da área de Fisioterapia em Neurologia do Adulto. Carga Horária: 90 horas

Participação da banca examinadora

2013 - Participação da banca examinadora de trabalho de conclusão de especialização em Neuropediatria da aluna Luisa Fernanda G Salazar, intitulada "Alterações morfofuncionais no músculo espástico decorrente da aplicação da toxina botulínica em crianças com paralisia cerebral: uma revisão sistemática".

2013 - Participação da banca examinadora do trabalho de conclusão de curso de graduação da aluna Carolina Akemi Maeda intitulado "Efeitos do fortalecimento excêntrico na correlação entre o volume muscular e o torque dos extensores e flexores do joelho de hemiparéticos crônicos".

2013 - Participação da banca examinadora do trabalho de conclusão de curso de graduação da aluna Erica Zavaglia Kabbach intitulado "Comparação das estratégias do tronco durante o movimento de alcance em indivíduos hemiparéticos crônicos, respectivamente".

Estágio no exterior

2015 - Durante o estágio no exterior (Janeiro a outubro de 2015) participei de atividades acadêmicas (seminários, palestras e disciplinas) como aluna especial.

Seminários e palestras

NeuroTalk - Este projeto consistia em palestras de pesquisadores que trabalham com técnicas de diagnóstico.
Os assuntos abordados foram: Electrocorticography (ECoG), TMS, Brain imaging and cognition markers entre outros. Carga horária: 20 horas

NeuroNoons Seminars - Este projeto tem o objetivo de reunir pesquisadores de diferentes áreas e laboratórios da Universidade da Florida para discutir resultados inéditos de trabalhos vinculados a programas de pós-graduação da área. Foram 18 aulas ministradas relacionadas a diversos temas como: AVC, Lesão Espinhal, Marcadores biológicos relacionados ao câncer e caquexia, Doença de Parkinson, Distrofia Muscular de Duchenne, Neuroproteção e estratégias de reparo do SNC; Dor e comportamento motor entre outros. Carga horária: 40 horas

Spring 2015 Rehabilitation Science Seminars - Este projeto tem o objetivo de reunir pesquisadores de diferentes áreas e laboratórios de diversas Universidades. Foram 18 aulas ministradas relacionadas a diversos temas como: Hipóxia intermitente nas desordens neuromusculares, Evidence Based Virtual Reality Design, Lesões crônicas córtico-espinhais em modelos humanos e ratos. Carga horária 20 horas.

As principais atividades práticas realizadas foram:

Experiência de Observação dos experimentos executados pelo grupo neste período:

Membros inferiores: Experimentos Relacionados com a marcha incluem: a análise da Marcha Assimétrica guiada (experimento 1) e o Marcha unilateral (experimento 2)
(Lower limb: Gait Analysis Asymmetrical Robotic Guidance (Experiment 1) and Unilateral Stepping (Experiment 2))

Estes experimentos incluíram a análise da cinemática da marcha, considerando as variáveis: Parâmetros Espaço-Temporais; Marcha com orientação assimétrica e Marcha unilateral com membro não-parético. Além da análise de respostas motoras evocadas, Eletromiografia e ondas-M e reflexos-H.

Membros superiores: Observei as coletas do projeto sobre inibição intra-cortical durante tarefas com membros inferiores. A resposta motora evocada durante a estimulação magnética transcraniana foi observada durante a execução do teste Box and Block.
(Upper limbs: “Task differences effect on intra cortical inhibition”.

Trabalhei no pré-processamento da cinemática da marcha. Este trabalho teve o objetivo caracterizar o fenômeno neuromotor durante a estimulação Magnética Transcraniana.

Analisei os dados do projeto TIBION. Este trabalho também tem como objetivo avaliar a biomecânica da marcha, por meio de cinemática (Sistema Vicon) de indivíduos hemiparéticos e controles saudáveis durante a assistência da perna mecânica TIBION. Um artigo relacionado a este tema está em processo de elaboração.

Cursos

2017 - Educação terapêutica sobre dor baseada na neurociência: explicando a dor aos pacientes. Carga horária: 20 horas

2016 - I curso de Capacitação em Terapia por Contensão Induzida: Infantil e Adulto oferecido pela Universidade Federal de São Carlos, Departamento de Fisioterapia. Carga horária: 20 horas

2013 - Curso Básico do Método Therapy Taping – Conceito de Estimulação Tegumentar. Carga Horária: 20 horas

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ANEXOS

Physical Therapy

OXFORD UNIVERSITY PRESS | Physical Therapy
Journal of the American Physical Therapy Association

Short-term adaptations of ankle sensorimotor control due to a single session of robot therapy in chronic post-stroke subjects

Journal:	*Physical Therapy*
Manuscript ID	Draft
Manuscript Category:	Case Report - Intervention
Keywords:	Neurology, Rehabilitation, Ankle Joint, Robotic therapy, Videogame, Chronic Stroke

Note: The following files were submitted by the author for peer review, but cannot be converted to PDF. You must view these files (e.g. movies) online.

VÍDEO-JOGO_02.avi

Transactions on Neural Systems and Rehabilitation Engineering

Ankle adaptive sensorimotor strategies in chronic post-stroke subjects due to variable assistance of robotic and game therapy

Journal:	*Transactions on Neural Systems & Rehabilitation Engineering*
Manuscript ID	TNSRE-2017-00035
Manuscript Type:	Paper
Date Submitted by the Author:	13-Feb-2017
Complete List of Authors:	Silva-Couto, Marcela; Federal University of Sao Carlos, Physical Therapy; University of Sao Paulo, Mechanical Engineering Siqueira, Adriano; University of Sao Paulo, Mechanical Engineering Ibarra, Juan; Universidade de Sao Paulo, Mechanical Engeneering Camargo, Ramon ; Universidade Federal de Sao Carlos, Physical Therapy dos Santos, Rosangela; Universidade Federal de Sao Carlos, Physical Therapy Russo, Thiago; Universidade Federal de Sao Carlos

UNIVERSIDADE FEDERAL DE
SÃO CARLOS/UFSCAR

Plataforma Brasil

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: O uso da terapia robótica para a reabilitação do tornozelo de indivíduos hemiparéticos crônicos: análise do desempenho neuromuscular

Pesquisador: Marcela de Abreu Silva Couto

Área Temática:

Versão: 2

CAAE: 26917314.6.0000.5504

Instituição Proponente: Centro de Ciências Biológicas e da Saúde

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 527.556

Data da Relatoria: 11/02/2014

Apresentação do Projeto:

O uso da terapia robótica para a reabilitação do tornozelo de indivíduos hemiparéticos crônicos: análise do desempenho neuromuscular RESUMOSegundo a Organização Mundial da Saúde (OMS), o Acidente Vascular Cerebral (AVC) é a principal causa de incapacidade. A reabilitação dos indivíduos pós-AVC geralmente é longa e complexa. A terapia robótica vem sendo recomendada para complementar a terapia convencional com algumas vantagens, como por exemplo, assistência controlável durante os movimentos, boa dinâmica na terapia (repetitividade de tarefas), maior motivação durante o treinamento através do uso de jogos interativos e a redução de custos no cuidados de saúde. Estudos com dispositivo robótico de tornozelo (exoesqueleto Anklebot®) têm sido realizados com o propósito de facilitar os movimentos do tornozelo em indivíduos hemiparéticos e, assim, reduzir as limitações pós-AVC. Ensaios clínicos tem mostrado que a terapia robótica é uma importante ferramenta para auxiliar o processo de reabilitação em indivíduos hemiparéticos. Nesse contexto, o objetivo deste estudo é investigar o efeito de uma sessão de terapia robótica com o exoesqueleto Anklebot® sobre o desempenho neuromuscular e funcional do tornozelo de indivíduos hemiparéticos crônicos. Para tal, será desenvolvido um estudo transversal, com 34 sujeitos (40 a 70 anos), de ambos os sexos, divididos em dois grupos: 1) Controle, indivíduos saudáveis; e 2) Hemiparéticos. O desempenho dos músculos dorsiflexores

e flexores plantares serão avaliados e uma sessão de terapia robótica será motivada por um jogo virtual. O controle do jogo serão realizadas pelo exoesqueleto Anklebot®. O desempenho neuromuscular será avaliado por dinamômetria e por eletromiografia. As variáveis do desempenho muscular investigadas serão pico de torque, trabalho e potência concêntricos, excêntricos e isométricos e manutenção do torque submáximo alvo. As variáveis eletromiográficas serão: pico de ativação e frequência mediana dos músculos tibial anterior, sóleo, porções medial e lateral do gastrocnêmio e fibulares; onset muscular, ordem de recrutamento muscular e índice de coativação. O índice de fadiga eletromiografico também será calculado. Todos os indivíduos passarão por avaliação da função motora com a Escala Fugl Meyer, Teste de caminhada de 10 metros e Escala de Berg para caracterização dos níveis funcionais. Para a estatística, serão aplicados os
testes de normalidade e homogeneidade. Caso os dados sejam paramétricos, será aplicada Anova-two-way seguido por Tukey. Será considerado o nível de significância de 0.05, com um intervalo de confiança (IC) de 95% para todos os testes estatísticos. O programa SPSS (versão 10.0) será utilizado.

Objetivo da Pesquisa:

Objetivo Primário:

Investigar o efeito de uma sessão de terapia robótica com o exoesqueleto Anklebot® sobre o desempenho neuromuscular e funcional do tornozelo indivíduos hemiparéticos crônicos. Objetivos específicos: Identificar o efeito de uma sessão de terapia robótica com Anklebot® sobre o pico de torque, torque médio, trabalho e potência em contração voluntária isométrica máxima e também durante contrações isocinéticas concêntricas e
excêntricas dos músculos flexores e extensores do tornozelo, em indivíduos hemiparéticos crônicos; Avaliar o efeito da terapia robótica sobre a manutenção do torque submáximo alvo em indivíduos hemiparéticos crônicos. Avaliar o efeito da terapia robótica sobre as variáveis as seguintes variáveis eletromiográficas: pico de ativação e frequência mediana dos músculos tibial anterior, sóleo, gastrocnêmico porções medial e lateral,
fibulares; onset muscular, ordem de recrutamento muscular e índice de coativação; Avaliar o padrão eletromiográfico entre músculos agonistas e antagonistas durante a terapia robótica em indivíduos hemiparéticos crônicos; Comparar os achados com indivíduos controle saudáveis; Correlacionar as variáveis entre si.

Objetivo Secundário:

Identificar o efeito de uma sessão de terapia robótica com Anklebot® sobre o pico de torque,

torque médio, trabalho e potência em contração voluntária isométrica máxima e também durante contrações isocinéticas concêntricas e excêntricas dos músculos flexores e extensores do tornozelo, em indivíduos hemiparéticos crônicos; Avaliar o efeito da terapia robótica sobre a manutenção do torque submáximo alvo em indivíduos
hemiparéticos crônicos.Avaliar o efeito da terapia robótica sobre as variáveis as seguintes variáveis eletromiográficas: pico de ativação e frequência mediana dos músculos tibial anterior, sóleo, gastrocnêmico porções medial e lateral, fibulares; onset
muscular, ordem de recrutamento muscular e índice de coativação;Avaliar o padrão eletromiográfico entre músculos agonistas e antagonistas durante a terapia robótica em indivíduos hemiparéticos crônicos;Comparar os achados com indivíduos controle saudáveis; Correlacionar as variáveis entre si.

Avaliação dos Riscos e Benefícios:
Adequado.

Comentários e Considerações sobre a Pesquisa:
Trata-se de pesquisa de relevância na área.

Considerações sobre os Termos de apresentação obrigatória:
O orientador declara que os participantes não serão recrutados na USE e que será contactado pessoas da comunidade que participaram de outras pesquisas.

Recomendações:
Vide conclusões.

Conclusões ou Pendências e Lista de Inadequações:
Projeto aprovado.

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

Considerações Finais a critério do CEP: