UNIVERSIDADE ESTADUAL DE CAMPINAS

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Ajustes Posturais em Indivíduos Neurologicamente Normais e em Portadores da Síndrome de Down na gangorra: efeito do treino

Tese apresentada ao Instituto de Biologia da **Universidade Estadual de Campinas,** para a obtenção do título de Mestre em Biologia Funcional e Molecular, área Fisiologia.

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DEDICO

Especialmente aos meus pais Fausta e Dirceu que sempre estiveram ao meu lado.

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RESUMO

O objetivo deste estudo foi investigar as estratégias de ajustes posturais utilizadas durante o balanço em gangorra, assim como o efeito do treino. **Sujeitos**. Seis indivíduos neurologicamente normais (NN) e seis portadores da síndrome de Down (SD) participaram deste estudo. **Métodos**. Os indivíduos foram treinados a balançar em uma gangorra e foram testados antes e após o treino em gangorras com nove índices de dificuldade diferentes. Os ângulos das articulações do quadril, joelho e tornozelo, a atividade eletromiográfica de alguns músculos da perna e do tronco, e o deslocamento do centro de pressão foram registrados. **Resultados**. Os indivíduos NN mantiveram o equilíbrio na gangorra devido principalmente a movimentos da articulação do tornozelo, sendo estes movimentos correlacionados com o deslocamento do centro de pressão. Eles utilizaram um padrão alternado de atividade dos músculos gastrocnêmio medial e tibial anterior e foram capazes de modular a quantidade de oscilação postural baseado na demanda mecânica da tarefa. A ordem desta alternância muscular foi em direção oposta ao estiramento. Por exemplo, quando o tornozelo moveu em flexão dorsal, o músculo gastrocnêmio foi estirado, mas o tibial anterior foi o músculo ativado. O treino não afetou o balanço na gangorra. Os Indivíduos portadores da síndrome de Down demostraram uma dificuldade em correlacionar os movimentos das três articulações estudadas com o deslocamento do centro de pressão. Ao contrário dos NN, os indivíduos SD não alternaram a atividade dos músculos agonistas e antagonistas responsáveis pelo movimento do tornozelo. Eles apresentaram um padrão de co-ativação generalizada mesmo para as condições mais estáveis, e foram incapazes de modular as respostas de acordo com a demanda mecânica da tarefa. O treino aumentou as possibilidades destes indivíduos balançarem na gangorra, mas não alterou a estratégia de manutenção do equilíbrio. **Conclusão e Discussão**. Este estudo confirma a idéia de que o balanço na gangorra é possível principalmente devido a movimentos do tornozelo (Ivanenko et al., 1997) e mostra o uso de uma estratégia semelhante a do pêndulo invertido. Primeiro, observamos que os indivíduos NN inibiram o músculo estirado devido talvez a uma projeção supra-segmentar. Segundo, o treino não afetou a estratégia de manutenção do equilíbrio. Terceiro, os indivíduos portadores da síndrome de Down utilizaram um estratégia diferente da utilizada pelos NN, mas esta estratégia foi suficiente para garantir o balanço. Ao contrário do que tem sido mostrado na literatura (Almeida, et al., 1994), eles não alcançaram um nível de performance motora semelhante ao nível dos indivíduos NN após o treino. Esta estratégia adotada pelos indivíduos portadores da síndrome de Down parece ser uma resposta adaptativa a possíveis déficits no sistema de controle postural. Sendo esta resposta uma adaptação deveria o fisioterapeuta intervir na tentativa de mudar esta estratégia? Nossos dados suportam a idéia de que a reabilitação deve enfatizar a função e não o modelo de movimento. No entanto, antes de embarcarmos em um novo tratamento, novos estudos são necessários para mostrar se estas respostas adaptativas podem ou não ser mudadas sem detrimento da função.

ABSTRACT

The purpose of this study was to investigate the postural adjustments and the effects of practice during balance on seesaw. **Subjects.** Six individuals with Down syndrome and six neurological normal individuals (NN) took part of this study. **Methods.** The individuals were trained to balance on one seesaw and were tested before and after practice on nine different seesaws. We recorded the LED marks that were placed on the center of hip, knee and ankle joints and the EMG activities of the some leg and trunk muscles. **Results.** Neurological Normal individuals maintained balance mainly using ankle movements, and these movements were correlated with the displacement of the center of pressure. They demonstrated an alternated pattern of ankle agonist and antagonist muscles activities and were able to modulate the amount of balance based on the mechanical demand of each seesaw in terms of degree of stability. The order of this alternation was in the opposite direction of the stretched muscle. For cxample, when the ankle was movcd into dorsal flexion the gastrocnemium was stretched but the anterior tibialis was activated. Training did not affect the balance on seesaw. Individuals with Down syndrome demonstrated a difficulty to correlate the joints movements with center of pressure displacement. Contrary to NN, the Down syndrome individuals did not alternated the EMG activities. They co-activated the agonist and antagonist ankle muscles even for easy conditions and were unable to modulated the answer with mechanical demand of the task. Training increased the possibilities of these individuals balance on seesaw, but did not change their postural strategy. **Conclusion and Discussion**. This study confirm the idea that the balance on seesaw is achieved mainly by changing the ankle joint (Ivanenko et al.,

1997) and show that the NN individuals use a strategy similar to the inverted pendulum. First, we observed that these individuals inhibited the stretching muscle using perhaps a supra-segmental projection. Second, the training did not affect the balance strategy for both groups. Third, the Down syndrome used a different strategy compared with normal individuals and their strategy was enough to assure balance. Contrary to the others studies (Almeida, et al., 1994) they did not change their muscle and cinematic strategy of balance after training. It's seems that the strategy that they use is an adaptive response to deficits on postural control. If this is an adaptive response the Physical Therapist should try changing these strategy? Our study supports the idea that the rehabilitation should emphasize the motor function and not the movement pattern. However, before embarking in a new therapeutic treatment, new studies are need to show if the adaptive response used by the individuals with Down syndrome balance on seesaw can be changed without any detriment of their ability to balance on seesaw.

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I. INTRODUÇÃO

Apresentaremos uma breve revisão da literatura na qual discutiremos os mecanismos neurais e músculo-esqueléticos envolvidos no controle postural. Descreveremos algumas estratégias de manutenção do equilíbrio utilizadas pelo sistema nervoso central. Abordaremos algumas características do controle motor dos indivíduos portadores da síndrome de Down, enfatizando o controle postural.

Postura é a relação da posição do corpo e dos membros entre si e com o espaço. Em uma visão global, duas funções principais são atribuídas a postura (Massion, 1997). A primeira é a função antigravitacional, responsável pela reação às forças da gravidade e manutenção do equilíbrio. A segunda é a interpretação sensorial para a orientação espacial e alinhamento corporal.

O equilíbrio postural é obtido pela manutenção do centro de massa corporal sobre a base de suporte (Horak, 1987; Gurfinkel, et al., 1995; Massion, 1992). Nesta condição de equilíbrio, todas as forças agindo no corpo estão balanceadas de forma que o centro de massa é controlado em relação a base de suporte, tanto em uma posição estática como durante o movimento (Pedotti, et al., 1989).

O controle postural eficiente depende de uma complexa interação do sistema neural e músculo-esquelético com as forças internas e externas que atuam deslocando o centro de massa corporal (Figura 1). Os componentes neurais englobam o processamento motor, incluindo as sinergias musculares, os sistemas sensoriais (visual, vestibular, e somatosensorial), a representação interna e um alto nível de processamento, o que é essencial para os aspectos adaptativos e antecipatórios do controle postural.

No sistema músculo-esquelético consideramos a configuração anatômica dos ossos, músculos, articulações e a maquinaria contrátil, incluindo a viscosidade, rigidez, e elasticidade dos músculos.

O sistema nervoso considera tanto os componentes neurais quanto músculo-esqueléticos para o controle postural. Por exemplo, na posição bípede em uma superfície rígida observa-se uma atividade muito pequena dos músculos posturais (antigravitacionais). Nesta condição, o equilíbrio é mantido pelas propriedades mecânicas dos músculos sem interferência dos reflexos (Gurfinkel et al., 1974). Estes autores sugerem que a rigidez intrínseca dos músculos do tornozelo é suficiente para evitar a queda durante a oscilação normal que ocorre na postura bípede.

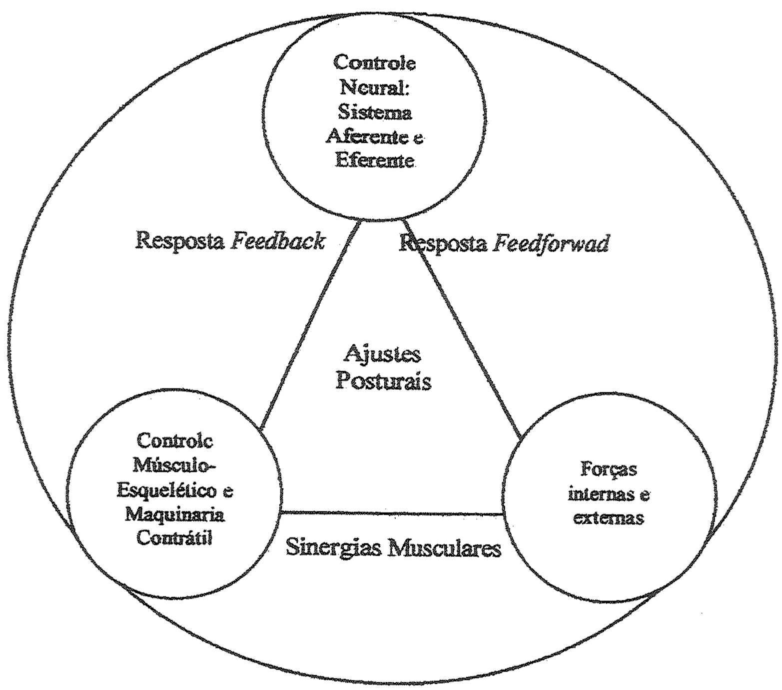

Figura1. Representação dos sistemas que contribuem para o Controle Postural.

O controle postural emerge portanto, da interação de vários sistemas. Os sistemas sensoriais (visual, vestibular, e somatosensorial) tem um papel fundamental nesta interação. O sistema nervoso utiliza as informações aferentes na elaboração dos comandos que são enviados aos neurônios motores de forma a gerar uma resposta que recupere o equilíbrio ou previna o desequilíbrio.

Informações visuais

Detectam os movimentos no campo visual. Quando a cabeça se move para frente, os objetos se movem para trás. A percepção visual ocorre em dois estágios. A luz é projetada para o olho onde é convertida em sinais elétricos por um órgão sensorial especial, a retina. Estes sinais serão transmitidos pelo nervo óptico para centros superiores no encéfalo onde serão processados (Kandel et al., 1991).

Informações somatosensoriais

Fornecem ao SNC informações sobre a posição e movimento dos segmentos corporais. Entre os receptores somatosensoriais temos os proprioceptores musculares e articulares, os receptores cutâneos e de pressão.

As informações proprioceptivas são fundamentais para a manutenção do equilíbrio e controle dos movimentos.

Informações vestibulares

O sistema vestibular fornece informações sobre a posição e movimento da cabeça em relação a gravidade e às forças inerciais. O sistema vestibular tem dois tipos de receptores que percebem diferentes aspectos da posição e movimentos da cabeça, os canais semicirculares e o sáculo e utrículo. Os canais semicirculares são sensíveis a aceleração angular da cabeça, principalmente a movimentos rápidos que ocorrem durante a marcha ou em situações instáveis (Horak & Shupert, 1994).

O sáculo e o utrículo sinalizam a aceleração e a posição da cabeça em relação a gravidade. Respondem a movimentos lentos da cabeça como os que ocorrem durante a oscilação postural.

Um dos métodos clássicos para o estudo da interação entre os três sistemas sensoriais é a manipulação das informações aferentes durante a aplicação de um distúrbio postural. As informações visuais podem ser manipuladas pela movimentação do cenário em relação ao sujeito ou pela oclusão da visão (Lee & Lishman, 1975; Kuo et al., 1998). Movimentos angulares ou lineares do campo de visão geram uma oscilação corporal na mesma direção do estímulo visual.

As informações somatosensoriais podem ser estudadas pela vibração dos tendões musculares (Wierzbicka, et al., 1998; Ivanenko et al., 1999). A vibração do músculo ativa predominantemente as fibras aferentes Ia dos fusos musculares que são sensíveis ao estiramento, produzindo uma situação de ilusão sobre a posição do membro. A ativação destes proprioceptores musculares excita os neurônios motores gerando uma contração muscular.

As informações vestibulares são manipuladas pela aplicação de estimulação galvânica (Hlavacka et al.,1999). Tem sido mostrado que a aplicação de corrente galvânica nos processos mastóideos pode despolarizar o nervo vestibular e aumentar a freqüência de disparo dos aferentes vestibulares do lado do cátodo e diminuir do lado do ânodo (Goldeberg et al., 1982). Esta aplicação resulta em uma oscilação corporal para o lado do ânodo.

Estas informações são organizadas seguindo uma ordem hierárquica, assegurando a seleção da informação apropriada para manter o equilíbrio postural (Shummway-Cook &

Woollacott, 1995). Lee & Lishman, (1975) mostraram que durante a infância, na fase inicial de aquisição da postura bípede, ocorre o predomínio das informações visuais na compensação de pertubações transitórias. Em adultos, estudos de latência muscular (tempo decorrente entre um estímulo e a contração muscular) durante a manipulação das informações visuais, vestibulares e proprioceptivas (Dietz, et al., 1991) mostraram que as respostas elicitadas por receptores musculares tem uma pequena latência 80-100ms. Respostas baseadas exclusivamente em informações visuais e vestibulares são aproximadamente duas vezes mais lentas. Estes dados levaram estes pesquisadores a sugerirem que durante ajustes posturais, o sistema nervoso preferencialmente usa as informações proprioceptivas para manter o equilíbrio. No entanto, o sistema nervoso pode adaptar o uso das informações sensoriais frente a mudanças na tarefa e condições ambientais (Shumway-Cook & Woollacott, 1995).

As informações sensoriais vão desencadear respostas posturais. Estas respostas podem ser antecipatórias, desencadeadas por forças internas que deslocam o centro de massa, ou compensatórias desencadeadas por forças externas que deslocam o centro de massa.

As forças internas com as quais os sistemas neural e músculo-esquelético reagem são representadas pelo desequilíbrio postural gerado pelo movimento focal (articulação que se deseja mover) nas articulações não focais (Aruin & Almeida, 1997). Para corrigir este desequilíbrio postural, o sistema nervoso deve ser capaz de prever o distúrbio e enviar uma resposta antecipada (reações antecipatórias). Esta resposta é caracterizada pela ativação da musculatura não focal, que gera uma força que previne o desequilíbrio. O fato das reações antecipatórias serem observadas também em indivíduos deaferentados mostra que elas são elicitadas por um mecanismo antecipatório ou *feedforward* (Forget & Lamarre, 1990). Esta resposta *feedforward* é enviada para a musculatura não focal, antes mesmo do início da atividade muscular focal e tem como principal objetivo gerar ajustes posturais antes que o movimento voluntário ocorra. Durante a prática do ato motor, através da observação das conseqüências do movimento focal nas articulações posturais (não focais) o sistema nervoso central desenvolve e elabora repostas antecipatórias ou *feedforward*.

As forças externas são representadas pelos distúrbios posturais gerados pela interação com o meio ambiente (força de gravidade, choques mecânicos). Para o desequilíbrio postural gerado pelas forças externas, o sistema de controle motor utiliza reações compensatórias ou "feedback" (Crenna, et al., 1987; Oddsson, 1990). Estas reações compensatórias são disparadas pelas informações aferentes (visuais, vestibulares ou somatosensoriais) em um mecanismo de retroalimentação.

Os ajustes posturais são modificados pela experiência e sua efetividade melhora frente a perturbações repetidas (Horak et al., 1986). Com a prática, ocorre uma diminuição na variabilidade das reações antecipatórias e redução das reações compensatórias (Nashner, 1980; Nashner & Cordo, 1981). Este aprendizado passa inicialmente pelo funcionamento acurado dos sistemas sensoriais. Estas informações aferentes são enviadas a vários níveis do sistema nervoso central e comparadas com informações anteriores. Desta forma, vai se criando um modelo de representação interna dos distúrbios gerados pelas forças internas e externas.

Sinergias e estratégias relacionadas ao controle postural.

Como vimos anteriormente, o sistema nervoso utiliza as informações aferentes na elaboração de comandos que são enviados aos neurônios motores de forma a gerar uma resposta que previna ou recupere o equilíbrio. Estas respostas são moduladas pelas características sensoriais e também pelos mecanismos relacionados a atenção, experiência, contexto, bem como a modelos pré programados de atividade muscular, denominados de sinergias (Horak et al., 1997; Macpherson, 1991). O sistema nervoso central organiza estas respostas posturais automáticas em estratégias. Dependendo da circunstância, superfície sólida (Gurfinkel, et al., 1995), estreita (Krizkova, et al., 1993), móvel (Dietz, et al., 1993), o sistema nervoso opta pela utilização de uma determinada estratégia postural.

Superfície sólida

Existem dois pontos de vista sobre a estratégia postural adotada em uma superfície sólida. A primeira visão defende que o deslocamento do centro de gravidade do corpo ocorre em relação aos pés que estão imóveis. Neste caso, o corpo pode ser considerado como um único segmento com mobilidade apenas na articulação do tornozelo (Figura 2). O corpo se assemelha a um pêndulo invertido oscilando ao redor de uma referência fixa (Winter et al., 1998). De acordo com o segundo ponto de vista a postura é baseada em vários segmentos (cabeça, tronco e pernas). Estes segmentos estariam sobre um controle automático central e periférico específico, preservando a orientação de cada segmento em relação ao espaço e/ou a outros segmentos adjacentes (Berthoz, 1991).

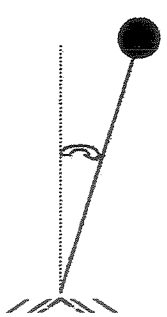

Figura 2. Desenho esquemático: Pêndulo Invertido. Deslocamento do corpo ocorre em relação aos pés que estão imóveis.

Plataforma de Translação

Em uma plataforma com pequenas pertubações de translação (deslocamento anterior e posterior em uma superfície horizontal) as respostas posturais acontecem principalmente no tornozelo, é a chamada estratégia do tornozelo. Esta estratégia é caracterizada por uma ativação esteriotipada da musculatura dos membros inferiores no sentido de distal para proximal (Nashner, 1977). Se o corpo for lançado para frente temos uma ativação do gastrocnêmio, seguido pelos isquiotibiais e paravertebrais. A atividade destes músculos puxa o corpo para trás, trazendo o centro de massa para dentro da base de suporte evitando queda. Se o corpo for lançado para trás temos ativação do tibial, seguido pelo quadríceps e reto abdominal que tendem a puxar o corpo para frente (Figura 3.1).

Plataforma de Translação Estreita

Em plataforma de translação, com a base de suporte menor do que o tamanho total dos pés e oscilações mais intensas, o que se observa é a estratégia do quadril. No caso de uma oscilação para frente (causado por oscilação para trás da plataforma) o indivíduo contrai o músculo abdominal e o quadríceps, o que causa a flexão do quadril. O tronco é levado para frente e as pernas para trás, estabilizando o centro de gravidade sem a utilização do tornozelo (Figura3.2).

Plataforma de rotação

Em uma plataforma de rotação, que gera a rotação dos artelhos para cima, temos um reflexo de estiramento com a contração dos músculos gastrocnêmio e sóleo a uma latência aproximada de 50ms. Esta contração tende a puxar o corpo para trás, prejudicando ainda mais o equilíbrio. Para corrigir este distúrbio ocorre a contração do tibial anterior (que se encontra em posição de encurtamento) a uma latência de 120ms. Esta contração puxa o corpo para frente e restaura a posição do centro de gravidade.

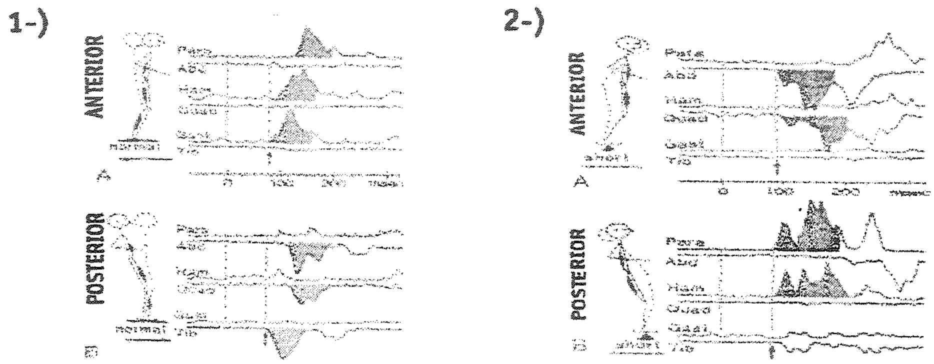

Figura 3 Atividade elétrica de seis músculos (Paravertebral; Reto abdominal, Isquiotibiais, Quadríceps, Gastrocnêmio e Tibial anterior), durante o deslocamento de plataformas de translação. 3.1) Estratégia do Tornozelo. 3.2) Estratégia do Quadril, note que a base de suporte é pequena. A) Deslocamento posterior da plataforma gerando uma oscilação postural anterior. B) Deslocamento anterior da plataforma gerando um oscilação postural posterior. Shummay Cook & Woollacott, (1995).

<u>Gangorra</u>

Na gangorra os pés não estão fixos e a estratégia do tornozelo não pode ser usada. Neste caso a manutenção do equilíbrio ocorre devido a projeção do centro de gravidade no ponto de contato da gangorra com o solo (Ivanenko, et al., 1997). A gangorra gera uma situação de instabilidade complicando a manutenção do equilíbrio e facilitando o estudo das oscilações posturais.

Como vimos anteriormente, o sistema de controle motor utiliza determinada estratégia motora dependendo da circunstância. Quando o contexto muda, o sistema de respostas também muda. Ao passarmos do chão para uma superfície estreita adotamos a estratégia do quadril aproximadamente após 15 tentativas. Ao trocarmos esta superfície estreita por uma plataforma maior, o indivíduo adota a estratégia do tornozelo após 6 deslocamentos da plataforma (Shummway-Cook & Woollacott, 1995).

Em plataforma de translação, quando o músculo gastrocnêmio medial é estirado ele apresenta uma grande resposta para retornar o corpo a posição original. Já em plataforma de rotação temos um reflexo de estiramento com contração do músculo gastrocnêmio a uma latência aproximada de 50ms. Esta contração é rapidamente inibida dando lugar a contração do tibial anterior (que se encontra em posição de encurtamento) a uma latência de 120ms. Nesta condição, o sistema de controle muda a estratégia inibindo a ação do gastrocnêmio (Chong et al., 1999).

Controle motor em indivíduos portadores da síndrome de Down.

Tem sido sugerido que os indivíduos portadores da síndrome de Down (SD) podem usar estratégias diferentes da população em geral para executar a mesma tarefa motora (Aruin & Almeida, 1997; Haley, 1986; Parker, et al., 1986). Lentidão, desajeito (Anson, 1992; Latash, 1992) e grande variabilidade na performance motora (Elliott & Weeks, 1990; Henderson et al., 1981) são algumas características dos movimentos destes indivíduos. Eles apresentam uma defasagem cronológica na aquisição das etapas do desenvolvimento motor o que é consistente com o atraso na aquisição dos componentes voluntários e posturais do controle motor. Por exemplo, sentam e levantam sem apoio cerca de 10 meses mais tarde do que as crianças neurologicamente normais (NN) (Carr, 1970).

Há duas opiniões que fundamentam as causas dos déficits motores nos indivíduos SD. A primeira diz que estes déficits se devem a disfunções orgânicas que ocorrem no sistema de controle motor (Davis & Sinning, 1987) tais como diminuição do volume do cerebelo (Bellugi et al., 1990; Crome, et al., 1966). Estas disfunções gerariam a hipotonia, predominância de reflexos primitivos e o atraso nas reações posturais.

A segunda opinião sugere que o comportamento motor dos indivíduos SD é intacto e que a falta de oportunidade de praticar os movimentos no dia a dia que leva a um padrão desengonçado (Almeida et al., 1994). Vários estudos demostram que os indivíduos SD melhoram a performance de movimentos uniarticulares com a prática, tornando-os semelhantes aos dos indivíduos NN (Almeida et al. 1994; Kanode & Payne, 1989; Kerr & Blais, 1988).

Poucos estudos falam sobre os ajustes posturais nos indivíduos SD. Durante a marcha, eles adotam uma postura mais flexionada ao nível das articulações do quadril e joelho (Parker, et al., 1986). Apresentam um atraso na aquisição das reações de equilíbrio e utilizam respostas de proteção para substituir a falta destas reações (Haley, 1986).

Shumway-Cook & Woollacott, (1985) observaram que crianças portadoras da SD usam uma estratégia de manutenção do equilíbrio em plataforma móvel semelhante a utilizada pelos indivíduos NN. No entanto, a latência da resposta muscular é maior, levando a reações posturais mais lentas. Apesar deste atraso nas respostas posturais, a latência miotática e a excitabilidade do motonêuronio são normais, e as respostas reflexas monossinápticas estão intactas (Shummay Cook & Woollacott 1985). Os indivíduos portadores da SD também são capazes de modular reações pré programadas de acordo com

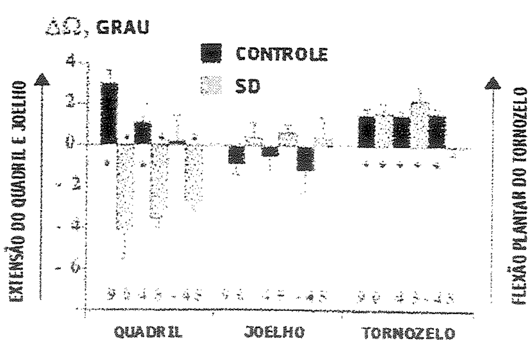

Figura 4. Movimentos do quadril, joelho e tornozelo durante movimentos bilaterais dos ombros a 90 e 45 graus de extensão e 45 graus de flexão. Note que os SD fletem o quadril enquanto os NN extendem. (Aruin & Almeida 1997).

a instrução e com a magnitude da pertubação (Latash, et al., 1993).

Estes indivíduos utilizam uma estratégia diferente para reagir a pertubações geradas por movimentos rápidos de flexão e extensão bilateral dos ombros (Aruin & Almeida, 1997). Os indivíduos NN mantém o equilíbrio movendo a pelve para frente, estendendo a articulação do quadril e fletindo o joelho, já os indivíduos SD reagem a este distúrbio movendo a pelve para trás com flexão do quadril e extensão do joelho (Figura 4). Estas duas maneiras de reagir foram capazes de manter o centro de massa dentro da base de suporte. No entanto, a estratégia utilizada pelos indivíduos SD é menos universal e requer um maior gasto energético.

Visando colaborar com o melhor entendimento das respostas posturais em indivíduos neurologicamente normais e em indivíduos portadores da síndrome de Down investigamos as estratégias de reajustes posturais durante a manutenção do equilíbrio na gangorra, assim como o efeito do treino.

II.

Os dados obtidos durante esta investigação foram organizados em um artigo a ser submetido à publicação. A metodologia adotada no estudo, a análise dos dados e a discussão serão descritas detalhadamente no artigo.

Postural Adjustment in neurological normal and Down syndrome individuals on seesaw: the effect of training

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ABSTRACT

The purpose of this study was to investigate the postural adjustments and the effects of practice during balance on seesaw. **Subjects.** Six individuals with Down syndrome (DS) and six Neurological Normal (NN) individuals took part of this study. **Methods.** The individuals were trained to balance on one seesaw and were tested before and after practice on nine different seesaws. **Results.** NN individuals maintained balance mainly using ankle movements. They demonstrated an alternated pattern of ankle agonist and antagonist muscles activities and were able to modulate the amount of balance based on the mechanical demand of seesaw. The order of this alternation was in the opposite direction of the stretched muscle. Training did not affect the balance on seesaw. Individuals DS demonstrated a difficulty to correlate the joints movements with center of pressure displacement and did not alternated the EMG activities. They co-activated the agonist and antagonist ankle muscles even for easy conditions and were unable to modulated the answer with mechanical demand of the task. Training increased the possibilities of these individuals balance on seesaw, but did not change their postural strategy. **Conclusion and Discussion.** The NN individuals used a strategy similar to the inverted pendulum and inhibited the stretching muscle using perhaps a supra-segmental projection. Second, the training did not affect the balance strategy for both groups. Third, the DS used a different strategy compared with NN individuals and their strategy was enough to assure balance. Contrary to the others studies (Almeida et al., 1994) they did not change their muscle and cinematic strategy of balance after training. It's seems that the strategy that they use is an adaptive response to deficits on postural control the Physical Therapist should try changing these strategy? Our study supports the idea that the rehabilitation should emphasize the motor function and not the movement pattern. However, before embarking in a new therapeutic treatment, new studies are need to show that the adaptive response used by the individuals with Down syndrome balance on seesaw can be changed without any detriment of their ability to balance on seesaw.

Key words: Balance, seesaw, Down syndrome, training.

INTRODUCTION

Postural control is the ability to maintain equilibrium in a gravitational field by keeping or returning the body center of mass over its base of support (Gurfinkel et al., 1995; Massion, 1992; Nashner et al, 1985). Both external and/or internal forces can disturb this center of mass disrupting the postural equilibrium. External forces result from the interaction with the environment (Horak et al., 1997). The internal forces are originated by the interaction forces applied at the non-focal joints (postural joints) due to movements generated at the focal joint, e.g., the joint wished to be moved (Almeida & Latash, 1995).

An experimental approach used to study how the Nervous System reacts to external forces to regain equilibrium is by disrupting the stable equilibrium of a stand individual on a force platform and record the muscle responses (For review see Dietz, Horak, Shummway-Cook, Woollacott, Macpherson, Massion). These studies point out that postural responses to external perturbation are characterized by preprogrammed muscle activation patterns identified as muscle synergies (Horak et al., 1997) as well as movement strategies (Macpherson, 1991). In a sense, strategy is a functional organization that allows the CNS to control the muscle activities as an unit, simplifying the control of posture (Bernstein, 1967).

Many types of postural strategies have been well characterized in the literature (Nashner, 1977; Horak & Nashner, 1986; McIlroy & Maki, 1995). The CNS choose the best strategy according to the mechanical demand to maintain equilibrium. This mechanical demand varies with the type of perturbation, such as standing in a rigid floor (Gurfinkel, et al., 1995), on a narrow base of support (Krizkova, et al., 1993), on a movable base of support (Dietz, et al., 1993), or on a seesaw (Dietz, et al., 1980; Ivanenko, et al., 1997).

During quiet stance on a flat and stable platform, neurological normal individuals sway slightly, and the body axis oscillates around the ankle joint axis like an inverted pendulum (Winter et al., 1998). On the other hand, when standing on seesaw, humans project the center of gravity in the point of contact of the seesaw with the floor (Ivanenko, et al., 1997; Ivanenko, et al., 1999).

We did not identify any study about the postural strategy used by the individuals with Down syndrome to maintain balance on seesaw. However, several other studies reported adaptation and modification on the postural control of these individuals (Shumway Cook & Woollacott, 1985; Aruin & Almeida, 1997). For example, when walking on a rigid floor the individuals with Down syndrome adopted a more flexed posture of hip and knee joints, compared with the normal population (Parker et al., 1986).

Both Down syndrome and normal children used similar strategy to keep balance on a movable platform, under different types of the sensory information - vision, vestibular and somatosensorial (Shumway Cook & Woollacott, 1985). However, the onset latencies of the muscle responses under these conditions were slower for the Down syndrome children. The individuals with Down syndrome used different postural strategy to deal with self-inflicted perturbation on the body, generated by the upper-limb movements (Aruin & Almeida, 1997). Normal individuals kept balance extending the hip and flexing the knee, whereas the individuals with Down syndrome flex the hip and extend the knee. However, both groups of individuals were able to use anticipatory reactions of the postural muscles (Aruin et al., 1997), even though the individuals with Down syndrome co-activated simultaneously the "agonist-antagonist" postural muscles. Several other studies reported a great variability and different motor strategies used by the individuals with Down syndrome to perform voluntary movements (Elliott & Weeks, 1990) and to deal with postural reactions (Shumway Cook & Woollacott, 1985; Haley, 1986; Aruin & Almeida, 1997).

Here we first showed how both normal and Down syndrome individuals couple the movements at the ankle, knee and hip to keep balance on the seesaw. Second, we showed how these individuals activate their muscle to generate the movements at these joints. Third, we explored how practicing balance on seesaw affects joint kinematics and muscles activities of both individuals group.

METHODS

We tested one group of Neurological normal (NN) individuals (3 male, 3 female, averaged age 24.5 years) and one of Down syndrome (DS) individuals (3 male, 3 female, averaged age 21.83 years). The DS individuals did not have hearing problems and could standing and walking independently. All individuals and the legal guardians of the DS individuals signed an institutionally approved informed consent according to the Universidade Estadual de Campinas.

Apparatus

Individuals balanced on movable seesaw made of metal and wood, capable of producing rotational movement (rolling). There were a total of nine seesaws with different combinations of radius and heights as showed in Table 1. These combinations were obtained in the following way: initially we made three seesaws curved in the shape of circular sector of 30, 60 and 120 cm of radius each one. The length (height) from the floor to the top of each seesaw was 7 centimeters. We added on the top of each of these seesaws one or two blocks (5x 30x 45cm respectively of height, width and length) made of polystyrene (Figure 1).

The instability of seesaw increased with the decreasing of its radius and with increasing of its height. The bigger the radius of the seesaw, the less curved and more stable it was. The higher the height of the seesaw the less stable it was. That's why we decide to order the seesaw first based on its radius and then based on its height. We arbitrarily called this ordering as the seesaw difficulty index (ID, Table 1).

Kinematics data

We recorded the X, Y and Z coordinates of the LED marks using a tridimensional motion analyses system (OPTOTRAK3020). These coordinates were used to calculate the ankle, knee, and hip angular displacement. The LED marks were attached on the left side of the shoulder (lateral aspect of the humerus), hip (between greater trochanter and superior iliac crist), knee (lateral condyle), ankle (external malleolus), foot (head of the 5th metatarsal), and on the anterior part of the seesaw. The LED coordinates were recorded at 100 frames per second.

The EMG activities

The muscle activities of the gastrocnemius medialis (GM), anterior tibialis (AT), biceps femoris (BF), rectus femoris (RF), erector spinae at L4 level (ES) and rectus abdominis (RA) were recorded using a bipolar surface EMG electrodes (DeLSys). The

EMG signals were recorded at 1000Hz, amplified (X 2000) and band pass filtered (45-450Hz). Before data analyses the EMG signal was rectified and low-pass filtered.

Platform of force

Using the force platform (AMTI OR-6) we recorded the reaction force (Fx, Fy and Fz) and moments of force (Mx, My, Mz) in the three orthogonal directions. The force platform data were collecting at 1000Hz, amplified (X4000) and band pass filtered (10-1050 Hz). Horizontal displacements of the center of pressure (CP) in anterior-posterior direction were calculated using the following formula: Center of Pressure =My/Fz ,where My is the moment of force in antero posterior direction and Fz is the force measured along the gravitational direction.

Insert here figure 1

Procedure

The seesaw was put on the center of force platform and this position was marked with a pen. After wards, the researcher helped the individuals to stand on it keeping the feet at the center of the seesaw. So, the ankle initially was maintained at the neutral position with the top of seesaw parallel to the floor. The individuals could see the seesaw while stepping on it. Once on the seesaw his/her eyes were covered by special mask (occluding any vision). Two researchers stood all time close to the individuals (one in front and other in the back) to hold him/her in case of complete loss of equilibrium. This procedure was enough to avoid any accident during the experiment.

All individuals were tested before and after training in all seesaws, in the difficulty increased order, from the 1 to 9 (Table 1). After two trials of balance without falling in one seesaw the individuals was tested on subsequent one. However, if the individual lost equilibrium completely at one seesaw, the test was interrupted and not performed for seesaws with greater index of difficulty. For each seesaw we recorded two trials during 10 seconds each one.

Instruction

All individuals were instructed to try to keep balance on the seesaw with the head kept on the upright position. No instruction about how to balance was given and each individual was free to choose any strategy to keep the balance.

Training

All individuals practiced to balance on seesaw of index of difficult 7 (Table 1). This training was done 20 minutes per day during 5 days, distributed along 1,5 weeks. The individuals was trained with vision covered by the mask. The procedures including instructions used during the practice on the seesaw were identical to the ones described for the pre and post tests. This training protocol was made on the individual's home and we did not record any trial.

Quantification of data

All kinematics (ankle, knee, and hip angles), kinetic (center of pressure) and EMG data (muscle activities of gastrocnemius medialis, anterior tibialis, biceps femoris, rectus femoris, erector spinae, rectus abdominis) were plot on the computer monitor. Using the computer cursor we identified on line the maximum and minimum value of the center of pressure for each trial. At these two instants of time (maximum and minimum displacement of center of pressure) we calculated the correspondent values of the angles (hip, knee and ankle) and the EMG activities of the six muscles.

Before data analysis we normalized the value of the EMG muscle activity using the following procedure: first, we collected the EMG activities of the six muscles studied when individuals stood without perturbation on the rigid floor before and after training. The average value of the muscle activities for each of these recorded muscle were calculated. Second, we divided the value of the EMG activity obtained for each muscle, during the minimum and maximum displacement of the center of pressure, by its correspondent average value, measured during the time that the individuals stood on the rigid platform.

Statistic analysis

We run a two ways analyses of variance ANOVA's ($p<0,05$) to test the effect of training (before and after) and the effect of the seesaws difficulty index (1 to 9) for each variable studied. These variables were the displacement of center of pressure, of the hip, the knee, the ankle and the EMG activity of the gastrocnemius medialis (GM), anterior tibialis (AT), biceps femoris (BF), rectus femoris (RF), erector spinae (ES), rectus abdominis (RA) at the time that the center of pressure of the individuals were maximally displaced in anterior (Table 2) and posterior (Table 3) direction.

We also run the two ways analyses of variance ANOVA's ($p<0,05$) to test the effect of group (Neurological normal and Down syndrome individuals) and training (before and after) for the linear correlation between the displacement of center of pressure with the hip, knee and ankle displacement (r) at the time that the center of pressure of the individuals were maximally displaced in anterior and posterior direction (Table 4).

RESULTS

Figure 2 depicts the balance of one normal (A) and one individual with Down syndrome (B) on a seesaw. Note that both individuals kept balance by moving mainly the ankle joint, and this movement were correlated with the displacement of the center of pressure. Nevertheless, the NN individual showed a smaller frequency of oscillation of the center of pressure during one trial compared with DS individual. Note also, that amount of hip excursion was larger for DS individual, and he moved the hip into flexion, whereas the NN individual moved the hip into extension.

The pattern of muscle activities differed between groups. The NN individual alternated the activation of the agonist with the antagonist ankle muscles. The order of this alternation was in the opposite direction of the stretched muscle. For example, when the NN individual was moving the ankle into dorsal flexion, the gastrocnemius was stretching and anterior tibialis shortening. However, the gastrocmenius was kept inactive and the anterior tibialis was activated (see detail on the squared box in figure 3). The opposite was true when the ankle moved into plantar flexion.

On the other hand, the DS individual co-contract the agonist and antagonist ankle muscles despite of the movement direction. The anterior tibialis was kept activated during the dorsal and plantar flexion of the ankle, even though, there was a decrease in the amount of activity of the gastrocnemius during the ankle dorsal flexion. Apparently, the muscle activities of the biceps femoris, rectus femoris, erector spinae, and rectus abdominis were not correlated with the movements of knee and hip joints.

Insert here figure 2

Kinematics and EMG activities during anterior displacement of the center of pressure: the effect of seesaw instability and training.

The seesaws were not perfect in imposing a linear crescent disturbance in the balance with difficulty index (Table 1). Nevertheless, the NN individuals increasing the anterior displacement of the center of pressure with the seesaw difficulty index (Figure 3a). Observe that the movements of the NN individuals at the ankle joint and at the center of pressure were coupled. Note that the displacement of the center of pressure at the seesaw with the smallest difficulty index was similar to the one observed at the rigid platform (broken line). Training did not affect the amount of ankle excursion neither the linear displacement of the center of pressure, even though on average it decreased after practice for NN individuals (Table 2). On the contrary of what was observed for the NN individuals, the DS individuals did not change the amount of movements of the ankle joint and the displacement of the center of pressure with the seesaw difficulty index (Figure 3b). Also, training did not affect the ankle excursion and the center of pressure displacement (Table 2).

The NN individuals kept balance at the anterior direction mainly due to activation of the gastrocnemius[1] muscles. At this direction, the ankle moved into plantar flexion

[1] The muscle activity of the gastrocnemius was larger than the one of the anterior tibialis when the subject stood still on the rigid platform. The averaged muscle activities across all six subjects, during the pretest, of the gastrocnemius was 0.019 V, and of the anterior tibialis was 0.011 V. These values did not change duirng the postest In other worlds, the absolute values of the muscle activity of the gastrocnemius was 73% larger than the on the of the anterior tibialis. Because of this, the normalized values of the gastrocnemium muscle activity seems similar to amount of tibialis anterior activity.

stretching the anterior tibialis and shortening the gastrocmenius. However, the amount of muscle activity of the gastrocnemius increased with difficulty index (Figure 3a and Table 2). The activation of the gastrocnemius generated a muscle force bringing the center of pressure into the posterior direction, avoiding the complete loss of balance. Under this condition, one would expect an inactivity or a decrease of the muscle activity of the anterior tibialis. However, there was a main effect of the difficulty index on the activity of the anterior tibialis (see Table 2). A further analysis showed that this effect was due to mainly an abrupt increasing of the muscle activity of the anterior tibialis for the seesaw with the greater difficulty index (9). Observe in figure 3a that, on average, the amount of muscle activity of the anterior tibialis did not differ from the first eight seesaws.

The strategy used by the DS individuals to activated their ankle muscles differed from the one used for the NN individuals. Although the ankle moved into plantar flexion stretching the anterior tibialis and shortening the gastrocmenius, the DS individuals co-activated both muscles at all nine seesaws (Figure 3b and Table 2). On contrary of what was observed for the NN individuals, the DS individuals used larger amount of muscle activity for the gastrocnemium and anterior tibilais for the most stable seesaws (compare Figure 3a and b).

Insert here figure 3

In general, there was a small amount of knee angular excursion during anterior displacement of the center of pressure, that did not change with seesaw difficulty index. This amount of knee excursion was smaller than 1° for both the NN (Figure 4a) and DS individuals (Figure 4b). The ANOVA test showed that this amount of knee excursion was similar across different seesaws for both subject groups. Training did not change the amount of knee excursion and the muscle activity of the rectus femoris (Table 2). The biceps femoris and rectus femoris muscle activities did not increase with seesaw difficulty index for both NN (Figure 4a) and DS (Figure 4b) individuals.

Insert here figure 4

Compared with the NN, the DS individuals moved more the hip joint during the anterior displacement of the center of pressure. There was no effect of the seesaw difficulty index on the amount of hip excursion. The hip excursion did not change with training for the NN (Figure 5a) and for the DS (Figure 5b) individuals. The amount of muscle activity of the erector spinae and rectus abdominis did not change with the increased seesaw difficulty index and was not affect by training for both individuals groups (Figure 5 and Table 2).

Insert here figure 5

Kinematics and EMG activities during posterior displacement of the center of pressure: the effect of seesaw instability and training.

We present only the statistical analyses for the kinematics and the EMG data during the maximum posterior displacement of the center of pressure (Table 3). These data had the similar comportment of the data during the anterior displacement, except for the ankle muscle. In posterior displacement the gastrocnemium was the muscle stretched and the anterior tibialis was the muscle activated. The seesaw difficulty index affects the anterior tibialis muscle.

Coupling among the displacement of the center of pressure with ankle, knee and hip angular excursion.

We calculated the linear correlation among the ankle, knee and hip angular excursions at the time that the displacement of the center of pressure were maximum at the anterior or at the posterior direction. The coefficient of the linear correlation |r| calculated for each individual and averaged among all six individuals is showed in figure 6. These analysis showed similarity and differences between groups. The first similarity observed is that both groups of individuals kept balance by moving mainly the ankle joint. Second, the ankle movements was linear correlated with the displacement of the center of pressure (Figure 6).

The NN individuals were able to better couple the movement of the ankle with the linear displacement of the center of pressure. The coefficient of linear correlation between ankle movement and center of pressure displacement was bigger for the NN (|r|=0,86) compared with the DS individuals (|r|=0,683). Training did not affect these linear correlation, and there was no interaction between groups of individuals and training (Table 4)

On the other hand, the ANOVA test did not show group and training effect for the linear correlation of knee and hip movements with the linear displacement of the center of pressure (Figure 6, Table 4). All linear correlation presented above for the ankle and knee movements with the linear displacement of the center of pressure were positive for both groups of individuals. That is, the knee and the ankle moved in phase with the displacement of the center of pressure. When the center of pressure moved forward the ankle moved into plantar flexion and the knee into extension. However, the linear correlation between hip movements and center of pressure displacement varied among individuals of both groups. For three out of six NN individuals and for four out of six DS these coefficients of correlation were positive.

Insert here figure 6

The effect of training on the number of individuals that were able to keep balance on seesaw.

Before and after training, all NN individuals were able to balance in all nine seesaws, but not all DS individuals had the same success (Figure 7). Before training three out of 6 DS individuals fail to balance in at least one seesaw, and after training just one individual of these group was unable to keep balance on the most unstable seesaw. These data are showing a great qualitative improvement in ability of the DS individuals to keep balance on the seesaw due to practice.

Insert here figure 7

DISCUSSION

Neurological normal individuals maintained balance on the seesaw mainly by changing the ankle muscle torque (Ivanenko et al., 1997) and our findings support this observation. First, the individuals maintained balance on the seesaw by moving mainly the ankle joint and these movements were in phase and linearly correlated with the displacement of the center of pressure.

The angular displacements of the knee and hip were less than one degree and closed in magnitude to the values observed when the individuals were standing on a rigid platform. So, this strategy used by the neurological normal individuals resemble an inverted pendulum, where the body is considered a rigid segment with angular displacement of the ankle joint (Winter et al., 1998). This inverted pendulum strategy would allow the CNS to freeze the proximal joints (knee and hip), reducing the number of degree of freedom to be controlled, and facilitating the task of the postural control (Berstein, 1967).

On the other hand, our findings do not support the idea that to maintain posture the CNS has to control the superimposed segments (head, trunk, legs), that are linked to each other by a set of muscles. According to this strategy, called "Segmental Theory of Postural Organization" (Berthoz, 1991), we would expect to observe a coupling between the movements of the two adjacent joints. However, this was not what we observed.

Neurological normal individuals were able to modulate the amount of balance based on the mechanical demand of each seesaw in terms of seesaw difficulty index. In order to discriminate different index of difficult of the seesaw the individuals must have an intact perceptual system. We do not know at this point what are the relevant information used by the CNS to modulate the balance with the index of difficult. The individuals had visual information just before they stood on the seesaw. So, they could visually realize which seesaw was more difficult to keep balance just by observing its height and radius. However, this would require a very sophisticated performer with good knowledge of mechanics, and that was not the case of our subjects.

The alternative explanation is that the individuals could have perceived the amount of postural disturbance using somatosensorial and/or vestibular informations. Some evidences support mainly the idea that the individuals use preferentially the somatosensorial information to keep balance on the seesaw. For example, after partial ischaemic bloking of group Ia afferents the body balance are more unstable on the seesaw and the muscle activity become longer and stronger (Dietz et al 1980). Based in this study we would expect more balance on the seesaw if the individuals have deficit in their somatosensorial system.

In our study, the individuals did not use the ankle strategy as defined by Nashner & MacCollum (1985) and Horak & Nashner (1986), but they used mainly the ankle joint to keep balance on the seesaw and on the moving platform. Study using the platform pertubation showed that patients with impaired somatosensory information (i.e., peripheral neuropathy) are unable to use the ankle strategy. On the other hand, deprivation of the vestibular information affects the hip and not the ankle strategy (Horak et al 1990). These findings also may indicate that the individuals are using mainly the somatosensorial information to perceive the amount of postural disturbance.

What was the muscle response used by the CNS to maintain balance on different seesaws?

The displacement of the center of pressure at the seesaw with the smallest difficulty index (ID=1) was similar to the one observed at the rigid platform. Nevertheless, the ankle muscles tend to be more activated at this seesaw. These results may suggest that in contradiction to what was found in investigations using rigid platform (Gurfinkel et al., 1974), on stable seesaws the normal individuals do not relay just on the visco-elastic properties of the muscles to keep balance. The increasing in both agonist and antagonist muscle activities would increase the muscle stiffness, allowing more joint stability.

With the increasing of the instability of the seesaw the neurological normal individuals demonstrated an alternated pattern of agonist and antagonist muscles activities at the ankle joint. Usually when the muscle is lengthened the spindle is activated generating a monosynaptic and polysynaptic reflex (Matthews, 1964). These responses activate the lengthening muscle that opposes the changing in length. However, on the seesaw we observed the opposite behavior. That is, the shortened muscle tended to be activated and the lengthened muscle to be silent (Figure 3).

At unstable postural conditions, such as when human was walking on a narrow beam, the H reflex gain was found to be partially suppressed, even though the muscle spindles were activated (Llewellyn et al., 1990). In our study we could assume that the spindles were activated during the muscle lengthening. So, we can speculate that a supra-segmental projection generated a pre and/or pos-synaptic inhibition of the alfa motoneuron innervating the lengthening muscles. However, at this point we do not know the neuronal pathway used by the CNS to suppress the muscle activity of the lengthening muscle and at the same time to activate the shorting muscle.

Same studies on the rotation platform showed that the stretched muscle respond between 50-70 ms and the shortened muscle are activated at 140-160 ms (Chong et al., 1999). We can not make any direct comparison of these reflex responses with our data on the seesaw. First, on the seesaw the individuals were free to choose any kind of strategy to keep balance. So, the perturbation generated by different seesaws varied between individuals. Second, the speed of the balance also varied across individuals and trials. Because the spindles are sensitive to the speed of stretching (Brown et al., 1965) the amount of the reflex response also varied across individuals and trials. Third, we measured the muscle activity at the instant of the time in which the body was maximally displaced forward or backward. For one side, we lost in terms of experiment control, for the other we gained by having a more natural task.

Effect of training on neurological normal individuals

Training did not affect the movement and the muscle strategy used by the neurological normal individuals to keep balance on the seesaw. The amount of displacement of the center of pressure, and the angular excursion at the three joints (ankle, knee and hip) did not change with practice for the trained and non-trained seesaws. Perhaps this fact was due to quickly adaptation that occurs on postural responses (Nashner, 1976). At the pre test the individuals could have performed at high level and because of that there was no room for additional improvement (ceiling effect). Rotational platform movements have been used to study the adaptation of postural response (Nashner, 1976)

These studies indicate that the individuals adapt the responses by attenuating the response amplitude over a series of approximately 10 trials.

Strategy used by individuals with Down syndrome to keep balance on the seesaw.

The Down syndrome individuals also kept balance on the seesaw by moving mainly the ankle joint (Figure 3). In a sense, we could argue that they also used the inverted pendulum strategy. However, the coupling between the angular displacement of the ankle with the center of pressure was decreased for the Down syndrome compared with the normal individuals (Figure 6). The decreasing in the coupling between the movements on the three joints show their difficulty in modulating the amount of balance based on the mechanical demand of the task.

This difficult in discriminate the mechanical demand of the seesaw could be also observed in their inability to modulate the pattern of muscle activity at different seesaw conditions. Indeed, their patterns of muscle activities were characterized by a co-activation of the agonist and antagonist muscles. The co-activation increase the joint stiffness at the expenses of increased energy consumption. Contrary to NN, the individuals with Down syndrome did not activated the shorting muscles (Figure 2).

Our data are in accordance with several studies showing that Down syndrome individuals use different strategy to execute the same motor task (Haley, 1986; Parker, et al., 1986). They also use a pattern of agonist and antagonist co-activation to react to a self-inflicted perturbation generated at the trunk due to the upper-limb movements (Aruin & Almeida 1997). Why they adopt the co-activation strategy to keep balance? Perhaps they are playing save and because of that, they co-activate their agonist and antagonist muscles to gain joint stiffness and stability (Latash, 1992). However, in several uni-articular

(Almeida, et al., 1994) and multi-articular movemets (Aruin et al., 1996) these individuals do not always used the pattern of agonist and antagonist co-activation.

Nevertheless, one could argue that the co-activation represent a deficits at central or at periferical level. At central level, the cerebellum has been assumed to play a central role in the formation of coordinated commands to several muscles to assure an option coupling between the movements (Houk et al., 1990). The cerebellum weight has been reported to be lower in persons with Down syndrome compared to the general population (Bellugi et al., 1990). The decreasing in the weight of the cerebellum has also being associated to a decreasing in muscle tonus (Davis & Sinning, 1987). Because of that one could associate the co-activation to a decreased of the cerebellum function. However, we should be very careful in making such causal correlation between the change of cerebellum weight and function.

At the periferical level one could speculate that a proprioceptive deficit (Cole et al., 1988) would impair their ability to discriminate the different mechanical demand of the seesaws. For example, Cole et al., 1988 showed that individuals with Down syndrome could fail to modulate the grip force when they were asked to lift one object with different surfaces. On the other hand, they have a normal level of neuron pool excitability and intact stretch reflex (Shumway-Cook & Woollacott, 1985). When asked to perform voluntary planar reversal movements with arm (Almeida, et al., 1994) they did not present any deficit as observed for individuals with periferal neuropathies (Sainburg, et al., 1995) So, we do not have any reason to believe that a proprioceptive deficit could account for the muscle co-activation pattern used by these individuals.

We argued that the normal individuals on the seesaw probably used supra-segmental projection to generate pre and/or pos-synaptic inhibition of the alfa motoneuron innervating the lengthening muscles. As a result they could activate the shorting muscles and keep lengthening muscles salient. The individuals with Down syndrome could have deficit in these supra-segmental projections and because of that, they would be unable to deactivate the lengthening muscles on the seesaw. The spinocerebellar projections could be a good candidate, but we do not have data to validate this hypothesis.

Effect of training in the Down syndrome individuals

Training did not change the strategy used by the DS individuals to maintain equilibrium on the seesaw. Studies showed that practice of a single-joint elbow flexion movements, improved their motor performance to the level observed for the normal individuals (Almeida et al., 1994). Here we showed their inability to change the pattern of muscle activity on seesaw with training. So, even after extensive training they failed to used a more efficient strategy to activate their muscles based on the mechanical demand of the task. Nevertheless, their strategy was enough to keep balance and the training help those individuals that lost equilibrium to stand on the seesaw and maintain balance.

These data showed that individuals with Down syndrome may have a deficit in the mechanism responsible to elicit an appropriate postural response. The training protocol used did impose to these individuals any pattern of normality in terms of strategy. They were free to choose any strategy to keep balance. Because with training, they did not shift to a more efficient strategy, we can assume that the co-activation pattern of muscle activity represent an example of postural adaptation.

If the strategy used by DS individuals are an adaptation, should the Physical Therapist try to change these strategy using a specific therapeutic intervention? By trying to change their strategy to a more "normal pattern" they could end up with the impairment in their ability to maintain equilibrium. We are favor to the idea that the rehabilitation should emphasize the function and not the movement pattern. On the other hand, we cannot be so conservative, perhaps a training protocol using EMG feedback for these individuals could help them to shift from the co-activation pattern of muscle activity to the one observed for the normal individuals. This change in the muscle strategy could improve their ability to react a postural disturbance improving their motor function. However, before embarking in a new therapeutic treatment new studies are need to show that these adaptive responses can be changed without any detriment of their motor function. New studies are also needed to show if the seesaw training can improve the postural control on more ecological situation, such as disturbance during walking.

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FIGURE LEGENDS

Figure 1

Experimental setup for study of postural adjustment on seesaw. 1 is the fixed platform of Force, 2 is the seesaw, 3 is the block of polystyrene, 4 is the LED marks, h is the height of block, h' is the height of seesaw and H = h+h' is the total height of the seesaw and r is the radius of the seesaw.

Figure 2

Balance before training on seesaw of difficulty index 7. The data are for one trial of one neurological normal individual A) and one individual with Down syndrome B). In the first panel are showed the ankle (thick line) and the linear displacement of the center of pressure (thin line), positive values are for plantar flexion (P.F.) and negative values for dorsal flexion (D.F.). In the next to upper panel are showed the knee and hip angular excursion, positive values is for extension (Ext) and negative values for flexion (Flex). In the lower panels are showed the EMG activities of muscles gastrocnemium medialis (GM), anterior tibialis (AT), biceps femoris (BF), rectus femoris (RF), erector spinae at L4 level (ES) and rectus abdominis (RA). The angular excursion is given in degree, the displacement of the center of pressure in centimeter, the muscle activity in volts and time in seconds.

Figure 3

The displacement of the center of pressure, ankle excursion and EMG activities of gastrocnemium medialis and anterior tibialis. The data are the average values obtained for the six neurological normal individuals (right panel) and the six individuals with Down syndrome (left panel). These data were collected before (open circle) and after (closed circle) training for each of the nine seesaws with increased difficulty index (ID). The center of pressure is given in centimeter (cm), the ankle excursion in degree. The muscle activity is without unit because of the normalization. Horizontal broken line represent the values obtained for each variable when the subjects was standing on a rigid platform. The vertical lines represent the standard error.

Figure 4

Same as in figure 3, except that the data are for the knee angular excursion and for the normalized EMG muscle activities of the biceps femoris and rectus femoris.

Figure 5

Same as in figure 3, except that the data are for hip angular displacement and for the normalized EMG muscle activities of the erector spinae and rectus femoris.

Figure 6

Averaged coefficient of linear correlation between ankle, knee and hip angular displacement with the linear displacement of the center of pressure. A) Neurological Normal individuals, B) individuals with Down syndrome. These data were obtained at the time that the center of pressure was maximally displaced at the posterior and anterior direction, and were collected before (open circle) and after training (closed circle).

Figure 7

A) Number of neurological normal individuals B) Number of individuals with Down syndrome that were able to keep balance on each of the nine seesaw tested with different index of difficult (ID). The data were collected before (open circle) and after (closed circle).

Table I

Seesaw difficulty index. Nine seesaws with different combinations of radius and height. We used three seesaws curved in the shape of circular sector of 30, 60 and 120 cm of radius each one. The length (height) from the floor to the top of each seesaw was 7 centimeters. We added on the top of each of these seesaws one or two blocks (5x 30x 45cm respectively of height, width and length) made of polystyrene.

Table II

ANOVA results (p<0,05) for the EMG activities, displacement of center of pressure (C.P), and kinematics variables at the time that the center of pressure of the individuals were maximally displaced in anterior direction. EMG variables: gastrocnemius medialis (GM), anterior tibialis (AT), biceps femoris (BF), rectus femoris (RF), erector spinae (ES), rectus abdominis (RA). kinematics variables: hip, knee, ankle. We tested the effect of ID; difficulty index of the seesaw, and training; before and after.

Table III

ANOVA results (p<0,05) for the EMG activities, displacement of center of pressure (C.P), and kinematics variables at the time that the center of pressure of the individuals were maximally displaced in posterior direction.. EMG variables: gastrocnemius medialis (GM), anterior tibialis (AT), biceps femoris (BF), rectus femoris (RF), erector spinae (ES), rectus abdominis (RA). kinematics variables: hip, knee, ankle. We tested the effect of ID; difficulty index of the seesaw, and training; before and after.

Table IV

ANOVA results ($p<0,05$) for the linear coefficient between the displacement of the center of pressure with the hip, knee and ankle displacement $|r|$ at the time that the center of pressure of the individuals were maximally displaced in anterior and posterior direction.

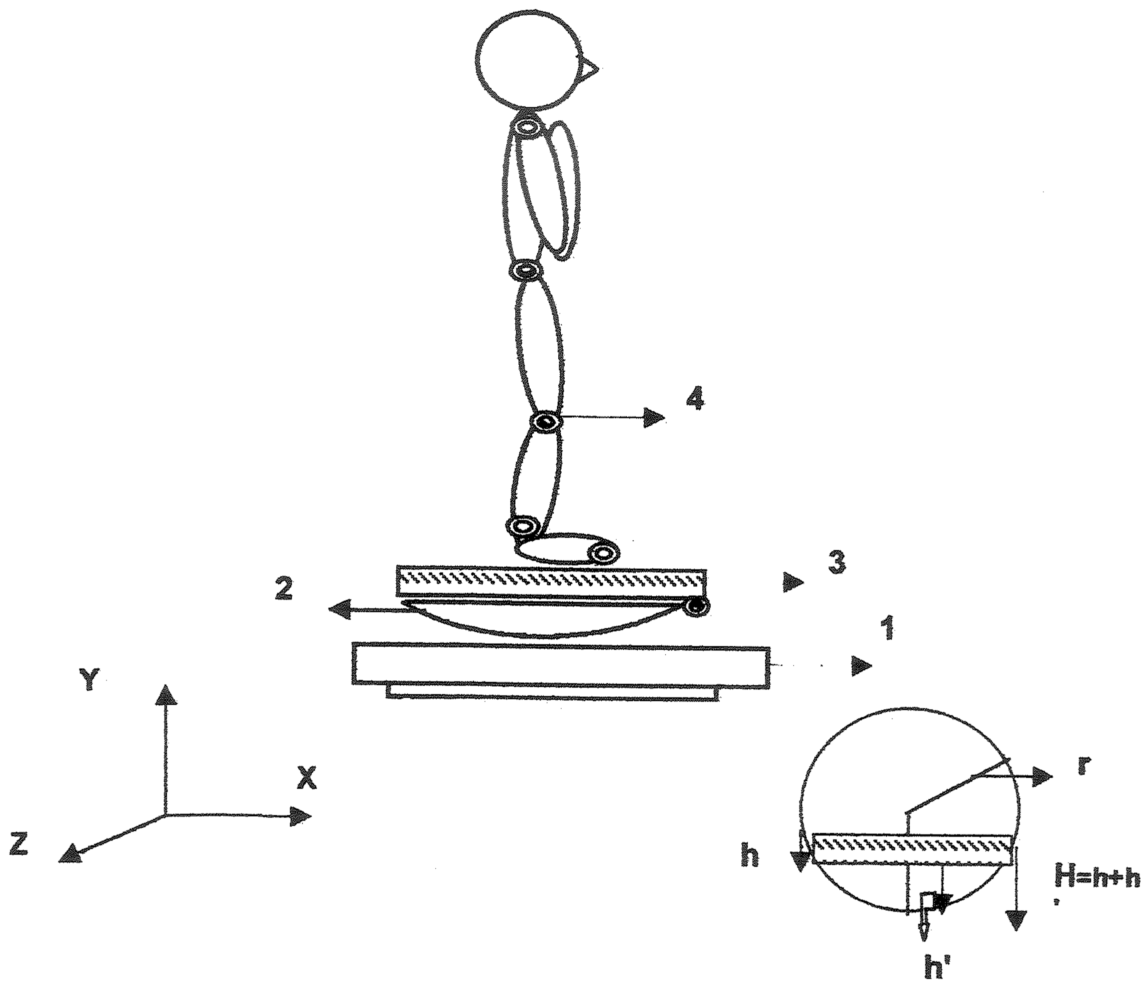

FIGURE 1

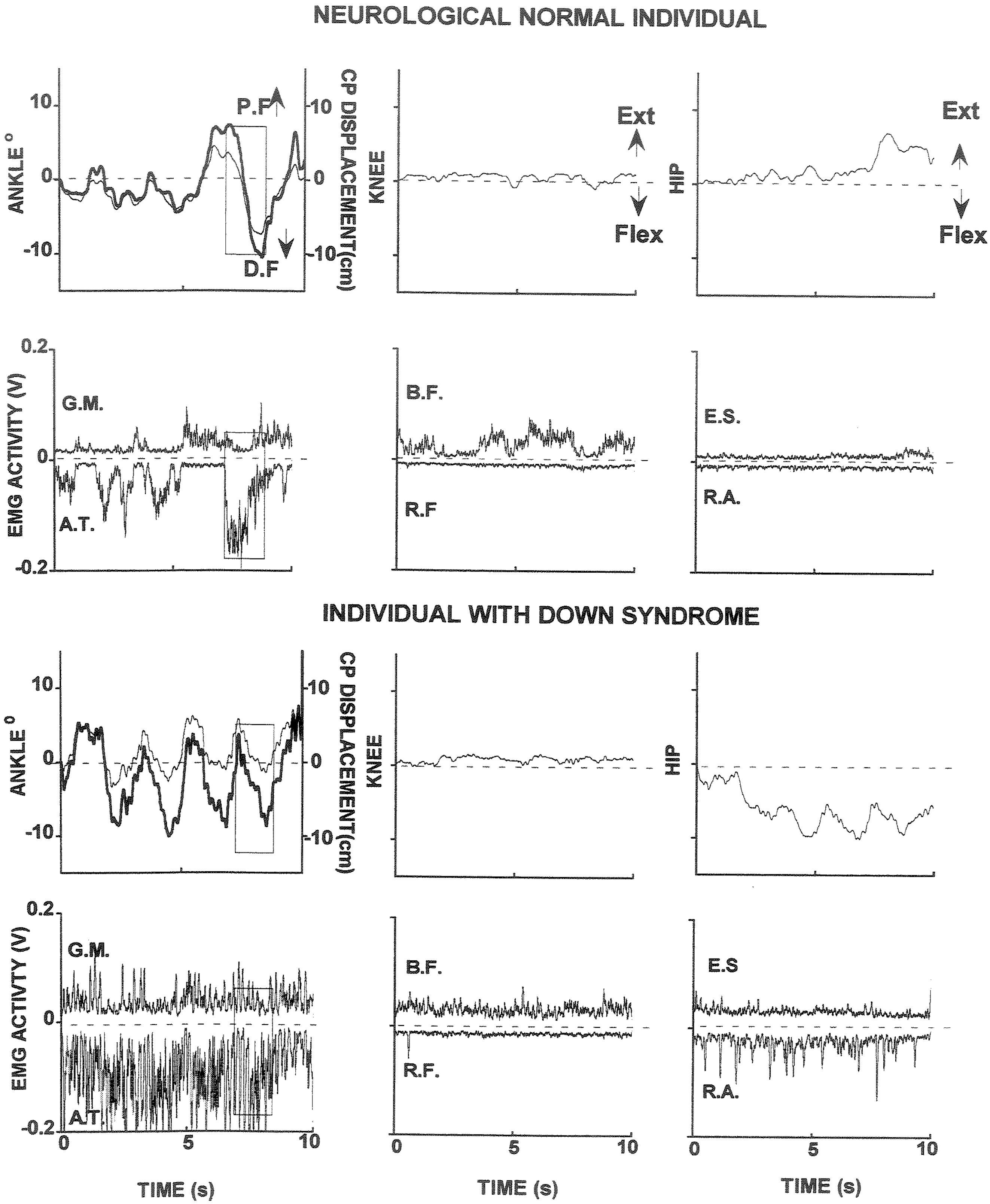
NEUROLOGICAL NORMAL INDIVIDUAL
ANKLE °
10
0
-10
P.F
D.F
CP DISPLACEMENT(cm)
KNEE
Ext
Flex
HIP
Ext
Flex
0.2
EMG ACTIVITY (V)
G.M.
A.T.
-0.2
B.F.
R.F
E.S.
R.A.
INDIVIDUAL WITH DOWN SYNDROME
ANKLE °
CP DISPLACEMENT(cm)
KNEE
HIP
EMG ACTIVITY (V)
G.M.
A.T.
B.F.
R.F.
E.S
R.A.
0
5
10
TIME (s)

FIGURE 2

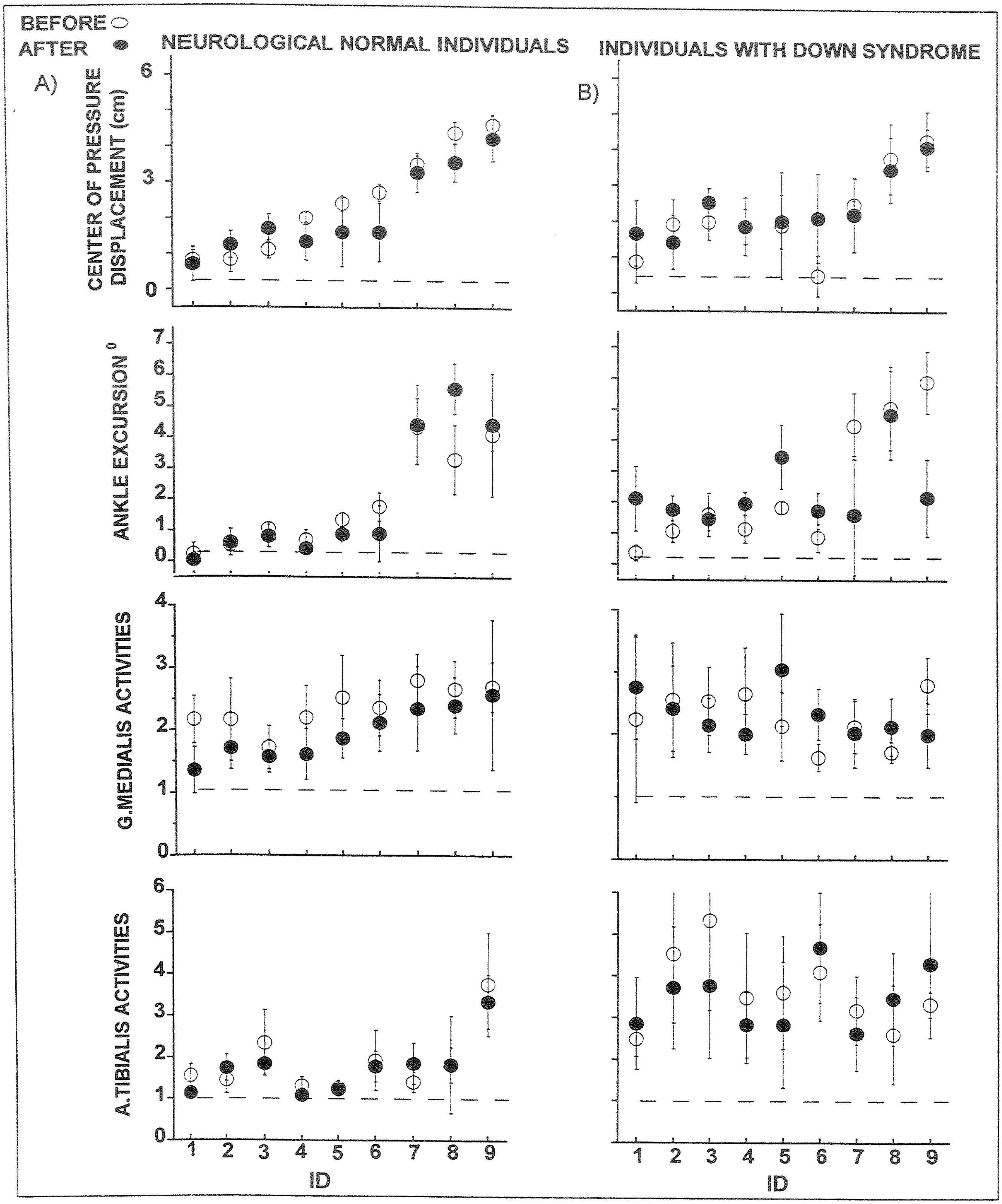
BEFORE
AFTER
NEUROLOGICAL NORMAL INDIVIDUALS
INDIVIDUALS WITH DOWN SYNDROME
A)
B)
CENTER OF PRESSURE DISPLACEMENT (cm)
ANKLE EXCURSION °
G.MEDIALIS ACTIVITIES
A.TIBIALIS ACTIVITIES
ID
ID

FIGURE 3

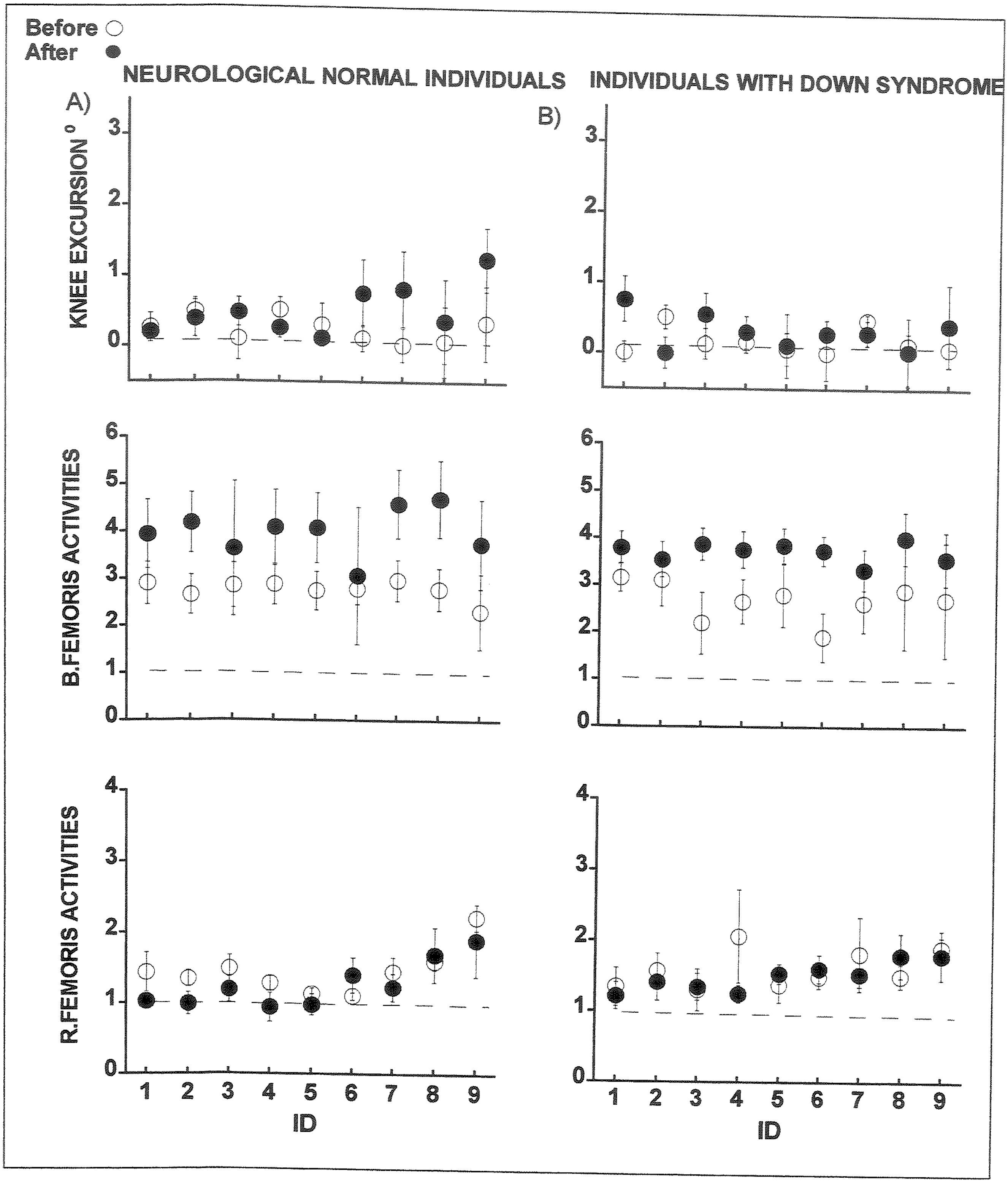
Before
After
NEUROLOGICAL NORMAL INDIVIDUALS
INDIVIDUALS WITH DOWN SYNDROME
A)
B)
KNEE EXCURSION °
B.FEMORIS ACTIVITIES
R.FEMORIS ACTIVITIES
1
2
3
4
5
6
7
8
9
ID

FIGURE 4

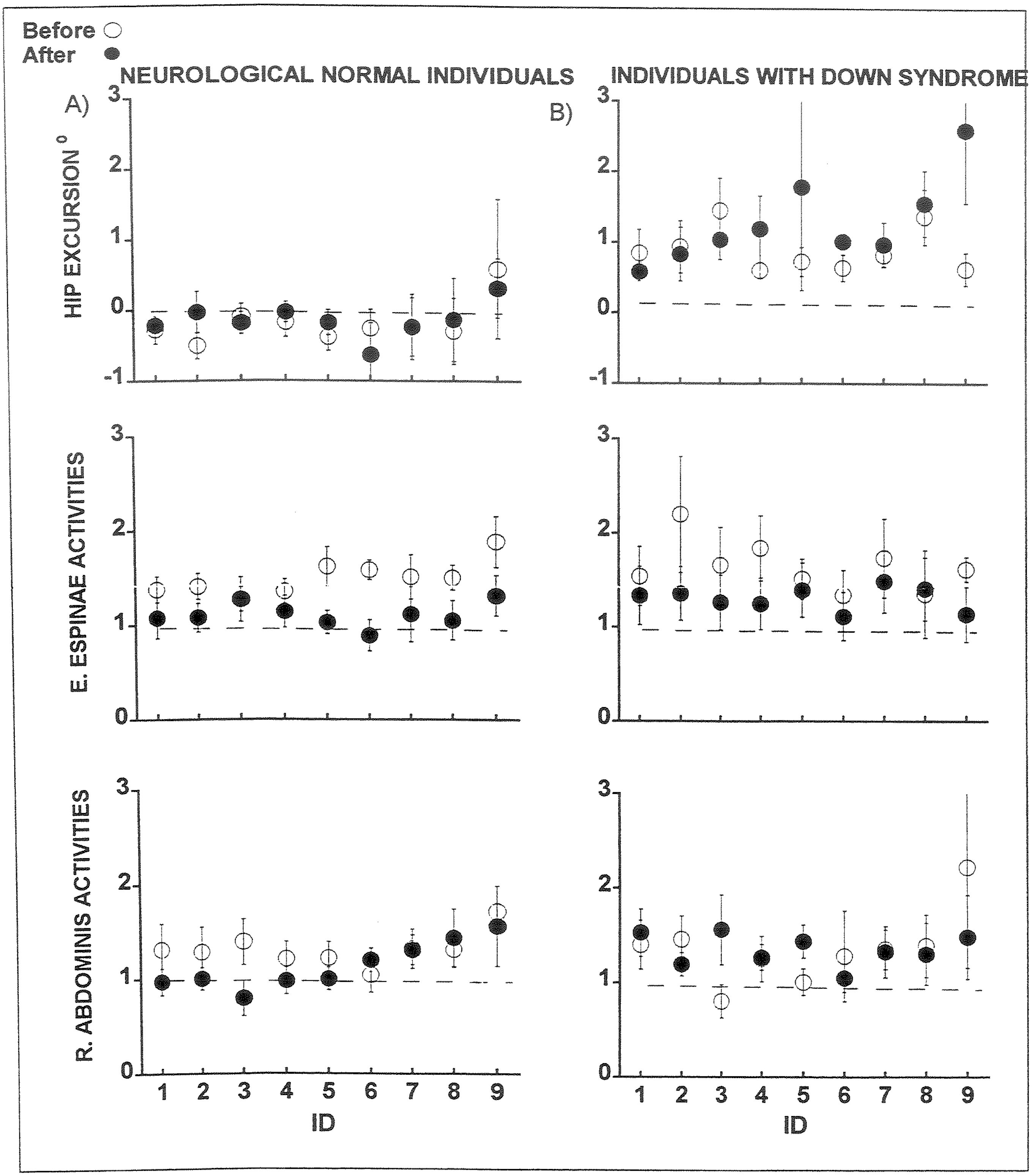
Before ○
After ●
NEUROLOGICAL NORMAL INDIVIDUALS
INDIVIDUALS WITH DOWN SYNDROME
A)
B)
HIP EXCURSION °
E. ESPINAE ACTIVITIES
R. ABDOMINIS ACTIVITIES
ID
ID

FIGURE 5

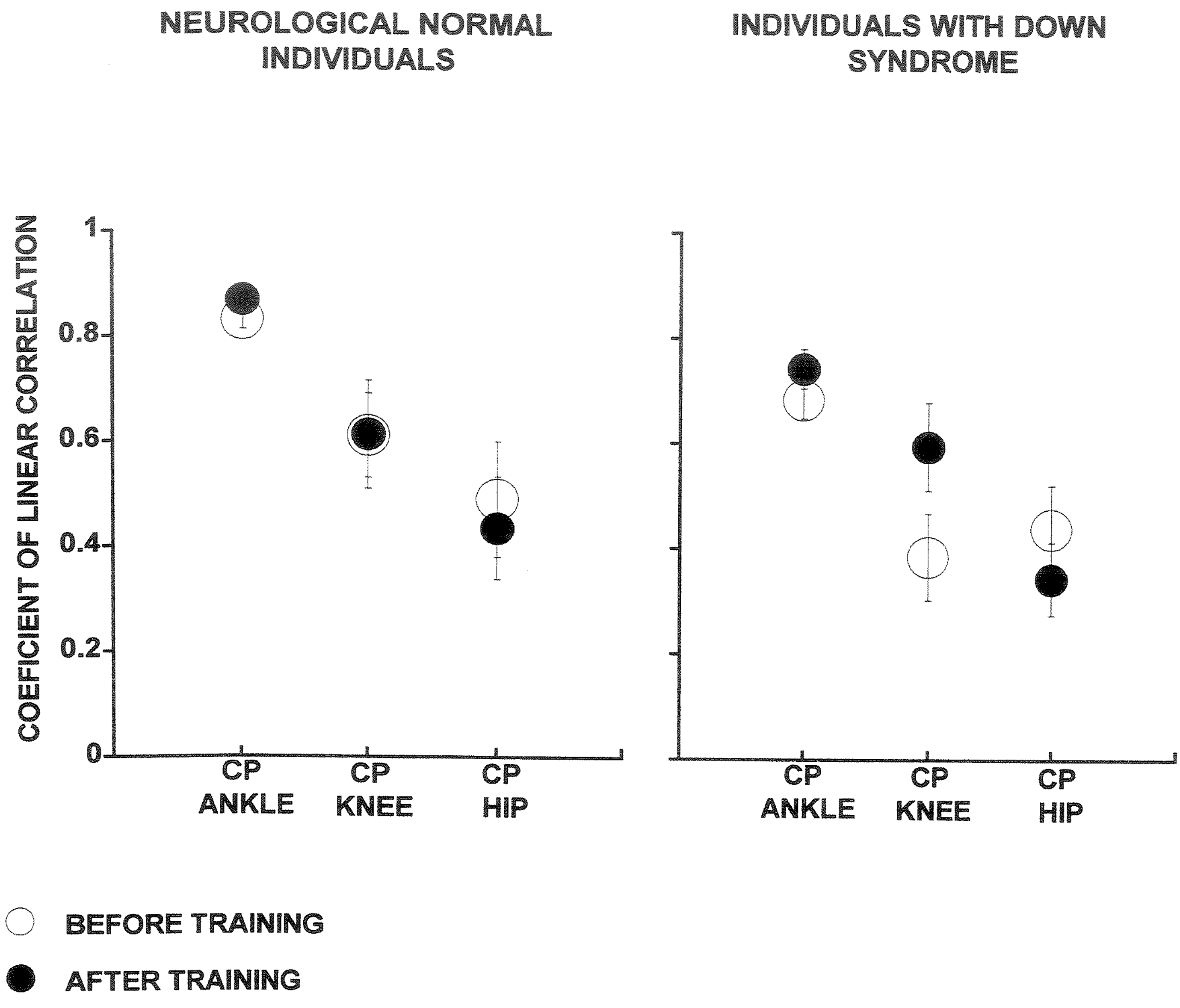
NEUROLOGICAL NORMAL INDIVIDUALS
INDIVIDUALS WITH DOWN SYNDROME
COEFICIENT OF LINEAR CORRELATION
1
0.8
0.6
0.4
0.2
0
CP ANKLE
CP KNEE
CP HIP
CP ANKLE
CP KNEE
CP HIP
BEFORE TRAINING
AFTER TRAINING

FIGURE 6

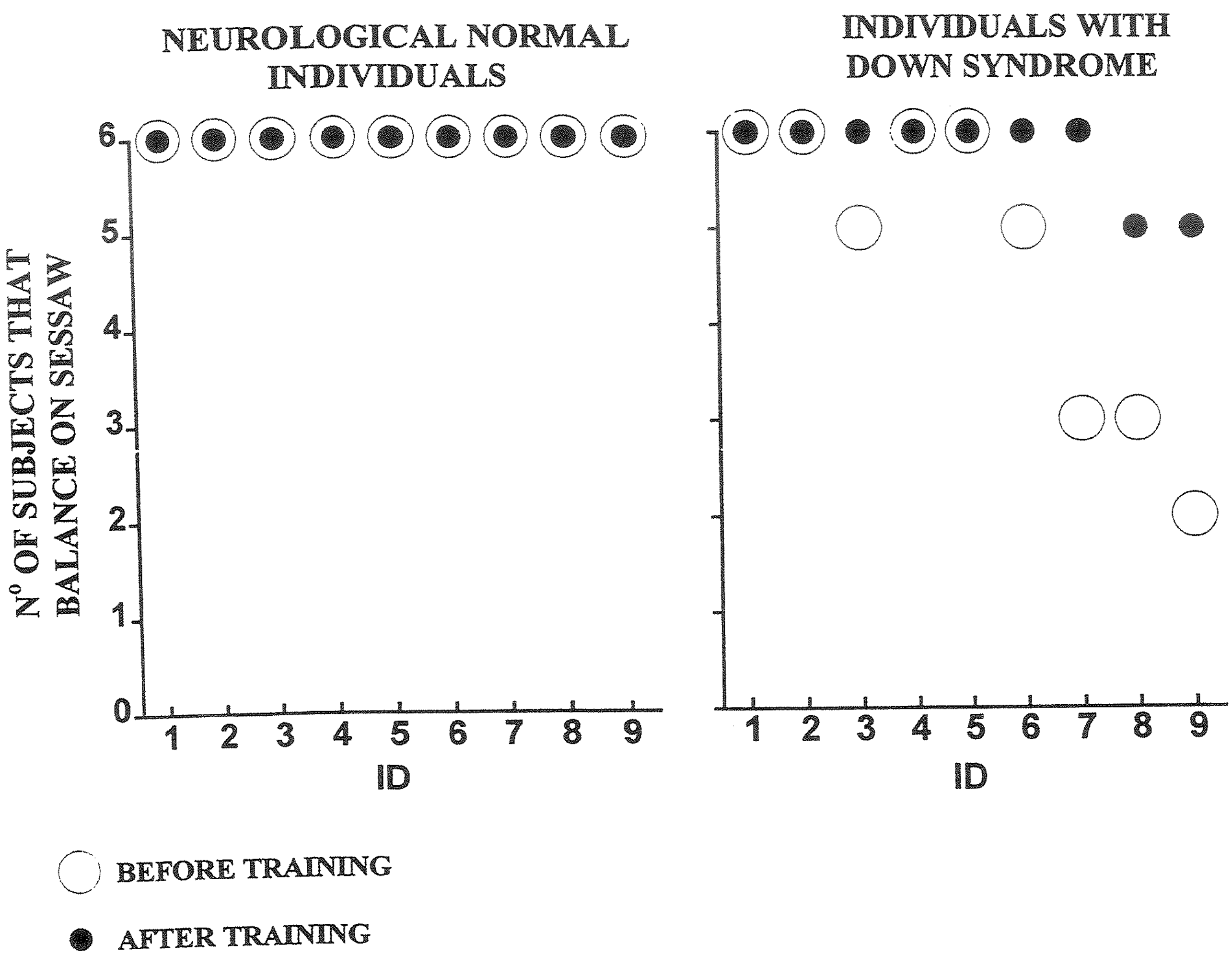
NEUROLOGICAL NORMAL INDIVIDUALS
INDIVIDUALS WITH DOWN SYNDROME
N° OF SUBJECTS THAT BALANCE ON SESSAW
0
1
2
3
4
5
6
1 2 3 4 5 6 7 8 9
ID
BEFORE TRAINING
AFTER TRAINING

FIGURE 7

TABLE I

Difficulty Index of Seesaw	1	2	3	4	5	6	7	8	9
Radius	120cm	120cm	120cm	60cm	60cm	60cm	30cm	30cm	30cm
Height	7cm	12cm	17cm	7cm	12cm	17cm	7cm	12cm	17cm

TABLE II

	NEUROLOGICAL NORMAL INDIVIDUALS						INDIVIDUALS WITH DOWN SYNDROME					
	TRAINING		**ID**		**TRAIN X ID**		**TRAINING**		**ID**		**TRAIN X ID**	
	F (1,3)	p	F(8, 24)	p	F (8,24)	p	F(1,3)	p	F(8, 24)	p	F(8,24)	p
G.M	0.115	0.757	3.46	*0.008*	0.36	0.92	0.140	0.778	0.511	0.819	0.955	0.525
T.A	0.882	0.417	5.567	*0.025*	0.609	0.761	1.56	0.428	0.681	0.700	0.587	0.525
B.F	0.423	*.008*	0.982	0.473	0.959	0.484	4.253	0.175	0.471	0.859	1.109	0.407
R.F	0.914	0.409	1,962	0.0964	1.483	0.215	0.451	0.623	1.276	0.369	0.703	0.685
P.V	2.753	0.172	0.614	0.759	0.536	0.820	2.024	0.390	1.39	0.326	0.947	0.529
R.A	0.218	0.664	2.212	0.0531	1.691	0.139	3.064	0.330	1.019	0.490	0.968	0.517
C.P.	4.666	.0970	5.491	*0.002*	1.235	0.311	0.135	0.775	0.280	0.954	2.254	0.135
Hip	1.953	0.256	0.382	0.918	0.680	0.704	0.715	0.486	0.995	0.475	0.857	0.569
Knee	1.52	0.284	0.997	0.457	1.713	0.133	0.335	0.665	0.347	0.922	0.325	0.933
Ankle	0.725	0.457	4.461	*0.002*	0.455	0.875	0.367	0.653	2.328	0.126	4.001	0.33

TABLE III

	NEUROLOGICAL NORMAL INDIVIDUALS						INDIVIDUALS WITH DOWN SYNDROME					
	TRAINING		**ID**		**TRAIN X ID**		**TRAINING**		**ID**		**TRAIN X ID**	
	F (1,3)	p	F(8, 24)	p	F (8,24)	p	F(1,3)	p	F(8, 24)	p	F(8,24)	p
G.M	7.909	0.053	1.86	0.100	1.011	0.447	2.582	0.354	1.013	0.493	0.651	0.721
T.A	0.250	0.643	6.89	*0.001*	0.743	0.653	21.52	0.053	2.354	0.123	1.136	0.430
B.F	3.352	0.142	1.763	0.1218	0.756	0.642	4.899	0.270	0.423	0.877	0.308	0.942
R.F	0.022	0.890	2.044	0.072	0.747	0.650	2.287	0.372	0.283	0.953	0.605	0.753
P.V	3.270	0.144	1.571	0.1728	0.853	0.564	0.137	0.774	0.745	0.656	0.498	0.828
R.A	1.769	0.254	1.574	0.1718	0.795	0.610	0.480	0.614	2.188	0.144	1.172	0.413
C.P.	0.848	0.425	2.348	*0.048*	0.464	0.869	0.327	0.669	1.384	0.328	0.475	0.843
Hip	3.530	0.133	1.094	0.052	3.394	0.069	67.55	0.077	1.036	0.480	3.627	0.053
Knee	0.010	0.927	1.800	0.1139	0.417	0.902	0.035	0.881	0.685	0.697	0.283	0.953
Ankle	7.870	0.067	43.79	*0.001*	1.773	0.132	0.121	0.786	2.29	0.130	0.631	0.735

TABLE IV

	SUBJECTS		**TRAINING**		**TRAINING X SUBJECTS**	
	F(1,10)	p	F(1,10)	p	F(1,10)	p
|r| ANKLE/C.P.	22.563	*0.0008*	2.419	0.150	0.124	0.7323
|r| KNEE/C.P.	1.281	0.282	2.813	0.1244	2.726	0.129
|r| HIP/C.P.	0.505	0.4934	0.825	0.3851	0.061	0.8100

III. CONSIDERAÇÕES FINAIS

Nosso estudo replica alguns conhecimentos já descritos na literatura, assim como é inovador em vários pontos. Replicamos os achados de que a manutenção do equilíbrio na gangorra é possível principalmente devido a movimentos da articulação do tornozelo (Ivanenko et al., 1997; Dietz, et al., 1980). Propomos que a estratégia de manutenção do equilíbrio adotada pelos dois grupos de sujeitos se assemelha a do pêndulo invertido. No entanto, os indivíduos NN acoplam o deslocamento do centro de pressão com o deslocamento das articulações do tornozelo, quadril e joelho de maneira mais eficiente do que os indivíduos portadores da síndrome de Down.

Observamos primeiro que os indivíduos NN apresentam um padrão alternado de atividade dos músculos agonistas e antagonistas da articulação do tornozelo (Gastrocnêmio Medial e Tibial Anterior). Segundo, esta alternância esta acoplada inversamente ao estiramento muscular, ou seja, o músculo encurtado é o ativado. Normalmente os reflexos monossinápticos são responsáveis pela ativação da musculatura quando esta é estirada (Matthews, 1964). Assumimos que na gangorra, os fusos são ativados pelo estiramento muscular, e que o músculo permanece inativo devido a uma inibição supra segmentar. Terceiro, ao contrário do padrão alternado de atividade muscular observado para os NN, os SD utilizam um padrão de co-ativação.

Quarto, o treino não afeta a estratégia de manutenção do equilíbrio para os dois grupos de sujeitos, embora aumente as possibilidades dos indivíduos SD balançarem na gangorra. Com o treino os indivíduos SD não atingem um nível de performance motora semelhante ao nível dos indivíduos NN. De um modo geral, os estudos de treinamento nesta população (Almeida, et al., 1994) mostram uma melhora no desempenho de movimentos voluntários. A análise destes estudos nos leva a sugerir que a estratégia de manutenção do equilíbrio adotada pelos indivíduos SD é uma adaptação a possíveis déficits nos mecanismos de controle postural. Estes déficits podem estar localizados a nível central ou periférico. Ao nível central, o cerebelo seria um bom candidato devido a seu papel na formação e coordenação de comandos para vários músculos (Houk et al., 1996) e ao fato de seu peso ser menor em indivíduos SD (Bellugi et al., 1990). Ao nível periférico, o candidato seria o mecanismo proprioceptivo. Devemos entretanto tomar cuidado ao relacionar problemas proprioceptivos e o menor peso do cerebelo com os possíveis déficits posturais, visto que, os reflexos de estiramento e o tônus muscular estão intactos nesta população (Shumway-Cook, & Woollacott, 1985).

Assumindo a estratégia utilizada pelos SD como uma resposta adaptativa, deveria o fisioterapeuta tentar incorporar a estratégia utilizada pelos NN na realidade dos SD? Muitas vezes, os terapeutas optam por treinar os seus pacientes a adotarem um modelo motor o mais próximo possível do observado na população em geral. No entanto, tentativas de corrigir ajustes compensatórios sem entender as causas primárias destes ajustes podem prejudicar os movimentos. Winter et al., (1990) apresentou uma análise biomecânica da marcha e concluiu que muitas características atípicas foram resultados de adaptações e não podem ser consideradas patológicas. Pela análise dos nossos dados e a par dos dados disponíveis na literatura somos favoráveis a idéia de que a intervenção deve melhorar a função e não mudar o padrão de movimento. Entretanto antes de embarcarmos em um novo tratamento, outros estudos que trabalhem com estes indivíduos no sentido de mudar a estratégia são necessários. Estudos com o uso de *feedback* muscular durante o balanço talvez possam esclarecer se as respostas adaptativas usadas pelos indivíduos SD podem ou não ser mudadas sem prejuízo da função motora.

IV. REFÊNCIAS BIBILOGRÁFICAS

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