THE FRAMEWORK OF MOVEMENT and IMPLICATIONS FOR CLINICAL PRACTICE
IC 37
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1:30 – 3:30
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Postural Control
involves the control of the body’s position in space in order to obtain stability and orientation

(center of body mass (COM)
a location of the net mass of all the body segments in space
Stability – is the maintenance of the center of body mass (COM) within the base of support during static or dynamic activities

(center of pressure (COP)
measures the location of the vertical ground reaction vector at the surface of support
motion of the COP measured in terms of sway area represents an individual’s control of the body sway or preservation of stance stability
Base of support BOS is the possible range of the center of pressure COP

Functional Goals of Postural Control
• Postural orientation
the active alignment of the trunk and head with respect to gravity, support surfaces, the visual surround and internal references
• Postural equilibrium
the coordination of movement strategies to stabilize the centre of body mass during both self-initiated and externally triggered disturbances of stability

(Massion, 1998)
The purposes of that control are to maintain equilibrium and orientation in sitting and standing.

(Horak, 1992; Shumway-Cook & Woollacott, 1993)

Why this topic is important?

Cerebral Palsy

"Cerebral palsy (CP) describes a group of disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, cognition, communication, perception, musculoskeletal and/or behaviour, and/or by a seizure disorder."


What drives early postural control

- Combined reduction of equilibrium reactions
- Righting reflexes
- Bleck-1987-Of all the motor problems in CP deficient equilibrium reactions interfere the most with functional walking

Postural control

is no longer considered simply a summation of static reflexes but, rather, a complex skill based on the interaction of dynamic sensorimotor processes.

Contributors of Postural Control

A complex interaction of systems and higher level processes.

Adapted from Woollacott & Shumway-Cook, 2001.
Precarious Balance

Postural Performance

- Biomechanical constraints: alignment and spasticity, weakness
- Movement strategies: selective motor control, praxia
- Postural orientation: righting, equilibrium
- Sensory environment: visual, vestibular, proprioception
- Experience: developmental
- Cognitive resources

Postural Performance

“Sensory information from somatosensory, vestibular and visual systems is integrated, and the relative weights placed on each of these inputs are dependent on the goals of the movement task and the environmental context.”

Head Control as Basis

- Sensory organs for visual and vestibular
- Systems are embedded in the head, making refined head control of critical importance for both orientation and balance

Vestibular systems

- During posturography that sensory conditions in which children must rely primarily on vestibular cues cause instability and frequent falling in children with spastic CP

Deficits of Sensory function

- Tactile, kinesthetic proprioceptive information
- Needed to determine starting position of limb
- Correct errors for refinement of skills
- Neglect-learned non-use

Photos: www.Pathways.org
**Sensory**

- Proprioception
- Position sense is altered and biased
- Subjects were asked to place at certain position
- Joint-Position Sense and Kinesthesia in Cerebral Palsy
- Wingert et al

The amount of cognitive processing required for postural control depends both on the complexity of the postural task and on the capability of the subject’s postural control system.

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**Alignment**

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**Postural Balance in Children with CP**

- center of pressure calculations of path length per second, average radial displacement- sway excursion
- force plate evaluation of postural balance can detect impairment of specific components of postural balance
- 1/3 had deficits and the majority deficits were in radial displacement

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**Walking prognosis in cerebral palsy: a 22-year retrospective analysis**

- A retrospective study was performed of 272 patients with spasticity to determine criteria for the prognosis for ambulation based on the ages at which children with cerebral palsy attain important gross motor milestones. The variables analyzed were age at last clinical assessment, clinical type of cerebral palsy and ages at attainment of gross motor milestones. Achievement of head balance before nine months was an important parameter for good prognosis for walking and, after 20 months of age, an indicator for poor prognosis. Sitting by 24 months indicated a favorable outcome, and motor control of crawling at 30 months of age a predictor for good prognosis. Based on these data, a chart for walking prognosis in children with cerebral palsy is presented.

• The control of posture involves many different underlying physiological systems that can be affected by pathology or sub-clinical constraints
• The effective rehabilitation of balance to improve mobility and to prevent falls requires a better understanding of the multiple mechanisms underlying postural control.

Balance-treatment options - part two

Efficacy and Effectiveness of Physical Therapy in Enhancing Postural Control in Children with Cerebral Palsy
Susan R. Harris and Lori Roxborough

Virtual reality as a therapeutic modality for children with cerebral palsy
LAURIE SNIDER, ANNETTE MAINEMER, & VASILI D A R S A K L I S

Effects of hippotherapy and therapeutic horseback riding on postural control or balance in children with cerebral palsy: a meta-analysis
MONIKA ZADWIGA & ANDREJ KAFRIN

• postural control / balance improved during hippotherapy and THR

Modifying the effects of cerebral palsy: The Gregg Mozgala story
Leon Chabon, MD, DO **, Tamara Regoff, Chiropractor *, Gregg Mozgala, Actor, Director *, Stefan Chevalis, Acı, Physician in Traditional Chinese Medicine *, Zachary Corneaux, DO, Professor of Osteopathic Principles and Practice *, John Hansen, DC, Associate Editor JNO *, Eyal Ludeman, PhD, DO, Professor **, Tom Myers, LMT, Anatomist, Reflex *
Wiiagnostics
Studying balance and function in cerebral palsy using video games
Mickey Kopstein, Iris Valeris PHD
2013 RIC Summer Extern

Discussion
• Wii Fit is able to accurately measure parameters related to balance
• More sensitive than traditional measures
• Potential to monitor outcomes accurately at home
• Can diagnose specific problem areas and cater therapy to patient

Compensatory and Anticipatory Postural Control

Postural Control Mechanisms
<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Typical time delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anticipatory postural adjustments</td>
<td>&lt; 0 ms prior to perturbation</td>
</tr>
<tr>
<td>Muscle and tendon elasticity</td>
<td>0 ms</td>
</tr>
<tr>
<td>Monosynaptic reflexes</td>
<td>30 ms</td>
</tr>
<tr>
<td>Polysynaptic reflexes</td>
<td>50 ms</td>
</tr>
<tr>
<td>Compensatory postural reactions</td>
<td>70 ms</td>
</tr>
<tr>
<td>Voluntary actions</td>
<td>150 ms &amp; onwards</td>
</tr>
</tbody>
</table>

Adapted from Latash 2008

Main Mechanisms of Postural Control
Anticipatory Postural Adjustments (APAs)
– Muscle activity prior to the onset of voluntary movement / perturbation
– Feedforward postural control
– Serve to counteract the predicted perturbation

Compensatory Postural Adjustments (CPAs)
– Occur after a perturbation
– Triggered by sensory feedback signals – feedback postural control
– Serve to reorganize posture and maintain balance

Timeline of APAs and CPAs
Postural Control Mechanisms

- CPAs: balance training programs commonly incorporate CPA concept (i.e., strengthening/strategies for recovering balance, multi direction stepping exercises)
- APAs not well understood/established in terms children and clinical interventions

COMPENSATORY POSTURAL ADJUSTMENTS

 DEVELOPMENT OF POSTURAL CONTROL IN INFANTS AND CHILDREN

CPAs First Six Months
- A repertoire of variable, but direction specific postural adjustments are seen before independent sitting
  - Minimal ability to adapt to the perturbation
  - As early as 3-4 months ability to balance flex/ext of the neck for head control in supported sitting
  - Inconsistent ability to inhibit dorsal mms (NE, TE) prior to activation of ventral muscles in FW translation (BW sway)

Semi-Reclined Position in Treatment
The semi-reclined position has been used to increase the activation of the neck flexors and develop improved strength and balance between neck flexors and extensors

Van der Fits & Hadders-Algra, 1998
By 6 months
- Infants can begin to select from a repertoire of direction specific patterns of muscle activation
  - Able to select patterns of muscle activity in response to the perturbation – forward vs. backward
  - Variation of responses decreases with age
  - Increased ability to inhibit dorsal mms (NE, Trunk Ext) prior to activation of ventral muscles in FW translation (BW sway)
  - Experience increased body awareness shown by ability to choose the best stabilization of the head for the movement paradigm

From Nine Months
- Consistent activation of direction specific muscles
- Ability to modulate response patterns is present by 9-10 months in sitting
  - With respect to velocity of perturbation
  - With respect to the pelvic position
  - With respect to load
- Fully developed CPAs in sitting at three years
- Fully develop adult patterns in standing on translational surfaces between 7-10 years

The postural response pattern is activated based on the direction of the perturbation
- **Backward translation** of the support surface causes a *forward weight shift* resulting in activation of the dorsal neck, trunk, lower extremity muscle groups.
- **Forward translation** of the support surface causes a *backward weight shift* resulting in activation of the ventral neck, trunk and lower extremity muscles

Postural Strategies
- **Ankle Strategy** – when perturbations are small, distal to proximal muscle activation is used to maintain posture
- **Hip Strategy** – when perturbations are large, causing changes in body geometry, proximal to distal muscle activity is recruited
- **Stepping strategy** – when the external perturbation is too great and limits of stability are exceeded, the individual takes a step to maintain Com within BOS

CPAs - Muscle Sequencing
- Based on the initial posture, there is a distinct sequence of muscle activity
  - Standing = distal → proximal activation
  - Sitting = cephalo-caudal activation

Six to Nine Months
- Able to adapt the magnitude of muscle activity in the en bloc pattern to match the degree of perturbation
- Coincides with ability to sit independently
- Between 6 – 9 months infants increasingly choose the en bloc postural pattern from their repertoire esp. when risk of loss of balance is high

Van der Fits & Hadders-Algra, 1998, 1999
Van der Fits & Hadders-Algra, 1998, 1999b
Shumway-Cook and Woollacott, 1985
Horak & Nashner, 1986
Horak & Nashner, 1986; 1990
Horak & Nashner, 1990; 1992
Woollacott & Shumway-Cook, 1990
Shumway-Cook and Woollacott, 1985

Van der Fits & Hadders-Algra, 1998, 1999
CPAs - Acquisition

- EMG activation during platform translations causing backward sway
- 27 month old – longer response time and cocontraction
- 5 year old – greater trial variability
- 7 year old – direction specific activation of Tibialis Anterior and Rectus Femoris

Postural Control

Children with CP
- Greater and regular sway
- Delayed response to perturbations
- Center of pressure of studies
- Trouble fine tuning
- Cephalic caudal recruitment

Anticipatory Postural Adjustments

APAs in Sitting
- Observed as early as 5 – 6 months prior to reaching
- Variable responses present at 8 - 9 months during reaching in long sit
- APAs reported at 9 months in infants sitting astride a knee a position that requires increased balance
- CNS can apparently accommodate for different postural tasks (long sit vs. short sit) as early as 9 months
**Development of APAs – In Sitting**

- Anticipatory postural adjustments emerge as diffuse directionally specific patterns as early as 6 mo during sitting, reaching tasks
  
  Van der Fits et al., 1999

- Variably present at 8 - 9 month during reaching in long sit
  
  Van der Fits et al., 1999

- APAs reported at 9 months in infants sitting astride a knee a position that requires increased balance
  
  Hadders/Woolacott, 1989

- It appears the CNS can accommodate for different postural tasks (long sit and short sit) as early as 9 months

**APAs – In Sitting**

- Consistent APAs in sitting by 15 - 18 months
  
  van der Fits et al., 1999

- Muscle activity scales with loads when weighted bracelets are placed on the arms of sitting children
  
  van der Fits, Hadders-Alpa et al., 1999

- Refined APAs in sit were correlated with onset of independent walking

- APAs in infants with CP were not consistent in sitting by 18 months
  
  van der Fits et al., 1999, 1999

**Development of APAs – In Sitting**

- APAs consistently present in sit by 15 -18 months
- Muscle activity scaled with load when weighted bracelets were placed in the wrists of the reaching children
- APAs similar to adults in spatial features (dorso-ventral ordering), temporal characteristics (top-down recruitment), and position dependency
- Refined APAs in sit were correlated with onset of independent walking
- APAs in infants with CP were not consistent in sitting by 18 months

Van der Fits et al., 1998, 1999

**APAs in Standing**

- Direction specific APAs present as early as 13 months in infants and children with typical motor development
  
  Barla and Jula, 1999

- Cocontraction is present before APAs emerge

- Standing infants can scale APAs with loads

- Anticipatory COP displacements in children prior to standing reach tasks

Riach and Hayes, 1990

**Development of APAs – In Standing**

- Transition from reactive to anticipatory strategies to maintain standing balance seen in infants who have begun to master independent walking (@13.5 mo olds)
  
  Barla et al. 1999

- APAs begin in stand - 13 – 14 months
- Well developed by 16 – 17 months

Witherington et al. 2002

**The Development of APAs in Infancy Drawer Pull Paradigm**

**Design**

- n= 34 infants
- Age: 10-17 months
- Pulling a cabinet drawer open
- EMG collected from the gastrocnemius and biceps brachii
APAs – In Standing

- Transition from reactive to anticipatory strategies to maintain standing balance seen in infants who have begun to master independent walking (@13.5 mo olds)
  - Cocontraction is present before APAs emerge
    Barilla et al. 1999

- APAs begin in stand - 13 – 14 months
- Well developed by 16 – 17 months
- Scale with magnitude of load

Witherington et al. 2002

Development of APAs in Older Children

Unilateral arm raising task in standing (visual stimulus)
- Children 4 – 14 years (n=32)
- Anticipatory changes in COP were present as early as 4 yrs.
- Both AP and lateral COP changes observed
- Younger children had longer reaction times and relied on lateral COP shifts during choice reaction time tasks

Raich and Hayes, 1990

Summary of APA Development

- Based on the literature, development of CPAs precedes development of APAs at each developmental stage
- Theory that internal representation of body in space is necessary for APAs to emerge
  Haas et al. 1989
- By age seven typically developing children demonstrate anticipatory mm activity and COP displacements similar to adults for bilateral, unilateral and reciprocal US movements
  - Direction specificity
  - Sequencing
  Girolami et al, 2010

Children with APA deficits

CP, Down syndrome, spina bifida, muscular dystrophy, hypotonia, toe walkers, orthopedic conditions, DCD, sensory integration disorder, hearing impairment, autism spectrum disorders, learning disability, etc

Early APA Research

Belenkii, Gurfinkel, Pal’tsev 1967
Primary Goals of APAs

- Counteract COM displacement associated with the forthcoming movement (Bouisset and Zattara, 1997)
- Counteract the effect of inertial forces on body segments and minimizing changes in body geometry (Pozzo et al. 2001)
- Accelerate the COM in the direction of motion (Stapley et al., 1999, Commissaris et al. 2001)

APAs in children with CP: Shoulder Flexion

APAs depend on:
Direction of Perturbation/Mvt – Sagittal Plane

APAs in children with CP: Shoulder Flexion

APAs depend on:
Direction of Perturbation – Transverse Plane

Unilateral R Shoulder Flexion:
Difference between TD and CP

- The pattern is present but the APA amplitude is smaller
- APA onset delay observed for some children with CP

APAs depend on:
Magnitude of the Perturbation

Arm movement (Horak et al. 1984, Lee et al. 1987)
- Movement speed
- Inertial load

Loading (i.e., catching) (Lacquaniti and Maioli, 1990)
- Mass
- Mass/height for catching

Unloading (i.e., dropping a bookbag) Aruin and Latash, 1995:
- Mass

APAs depend on:
Magnitude of perturbation--Catching

TASK: Catching loads of different masses
- Dorsal LE/trunk muscle activity scales with mass
- Arm muscle activity scales with mass

APAs depend on:
Magnitude of predicted perturbation -- Catching

TASK: Catching 1.1 kg load released from different heights
- Dorsal LE/trunk muscle activity scales with height
- Arm muscle activity also scales with height

Loading Perturbation: CP

Left: Hemi, 11.5 yrs old, GMFCS I, GMFM88= 96%
Right: Di, 12 yrs old, GMFCS II, GMFM88= 85%

APAs depend on:
Types of perturbation -- Unloading

TASK: release a 2.2 kg held in front of the body with quick shoulder abduction

Decrease in muscle activity in the dorsal muscles (ES and BF) prior to unloading
APAs depend on:

**Mechanical Stability**

**TASK:** Pull on a handle while supported or unsupported at the shoulder

- **Unsupported:** Prior to self initiated pull (biceps onset), gastroc and hamstrings activates
- **Supported:** APAs decrease in Gastroc

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**Mechanical Instability**

**TASK:** Unilateral shoulder flexion while standing on unstable surface

- APAs decrease on unstable condition
- Same effect can be observed for load releases on tilt boards

**WHY?**

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**Fear of Falling (Perceptual Instability)**

**TASK:** Rising onto toes at the edge/away from edge at different heights

- Fear of falling decreases APAs and task performance

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**Effective body weight-- Immersion in Water**

**TASK:** Pull or push while standing in different levels of water

- ↓ body weight ↓ s APA activity
APAs modulate with:
- Direction of arm movement/Direction of perturbation
  - Sagittal
  - Transverse
  - (Frontal and Mix)
- Magnitude of the perturbation
  - Speed/inertial load
- Loading and unloading perturbation
- Stability
  - Mechanically unstable to stable
  - Perceptually unstable or stable

Tasks/ Parameters for Designing Exercises
- Direction of arm movement/Direction of perturbation
  - Sagittal
  - Transverse
  - (Frontal and Mix)
- Magnitude of the perturbation
  - Speed/inertial load
- Loading and unloading perturbation
- Stability
  - Mechanically unstable to stable
  - Perceptually unstable or stable

APAs in Children with CP
What do we know?
- Decreased adaptability to task demands
- Decreased ability to generate mm activity during APAs
- Different postural strategy (mm co-contraction) when generating APAs
- Changes in timing of muscle activity

Hypothesis
APAs decrease in PTs with postural control difficulties because
- Incorrect estimation and generation of APAs can increase instability
- Increase reliance on CPAs and less on APAs
- APAs are modulated with limits of stability
  - PTs with postural deficits likely have smaller limits of stability

APA and Learning
- Novice versus expert dancers
- Learning to generate APAs for novel tasks in healthy adults

Assessment Options
Segmental Assessment of Trunk Control (SATCo)


Table 1. Summary of Balance-Evaluation Systems Test (BESTest) Items Under Each System Category

POSTURE AND BALANCE


BESTest

Model summarizing systems underlying postural control make up the sections of the Balance Evaluation Systems Test (BESTest)

Test form and directions for administration:

Cerebral Palsy