Locomotor Recovery After Stroke

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Objectives:
1) Participants will be able to identify key factors across the WHO ICF domains that should be considered when designing rehabilitation interventions for improving walking after stroke.
2) Participants will be able to discuss the importance of examining how key factors inter-relate to impact the effect of rehabilitation interventions for improving walking after stroke.
3) Participants will be able to discuss the role of exercise intensity for walking recovery after stroke.
4) Participants will be able to discuss motor learning strategies for walking recovery after stroke.

World Health Organization ICF model

Health Condition (Stroke)
Body function/structure  Activity  Participation
Environmental Factors
Personal Factors

One major goal of PT is to return patients to their previous level of function and community participation

Recovery of Function

Restoration  Compensation
Definitions
(inspired by Behrman et al. 2006; Kleim and Jones 2008; Levin et al. 2009)

Recovery: restitution of damaged structures? OR clinical improvement?
(Levin et al, 2009)

BACKGROUND

Definitions

❖ Recovery: return to, or emergence of, a desired level of function
  ▪ as viewed from the perspective of the patient and family
  ▪ “I want to be able to do what I want/need to do each day”

❖ Restoration: remediation of an impairment
  ▪ Example: return of optimal or baseline quadriceps muscle performance after surgery

❖ Compensation: atypical motor patterns are used to substitute for impairments.
  ▪ This can occur through the reorganization of movement by the subject or through the application of assistive devices or techniques

❖ These terms are most effectively used when followed by explanatory terms
  ❖ Recovery of what function?
  ❖ Restoration of what impairment?
  ❖ Compensation for which impairment?

Questions to consider

❖ When we are thinking about functional recovery is it either restoration or compensation or is it continuum?

❖ What is the empirical or theoretical evidence that compensatory movement patterns are detrimental to long-term recovery?
Questions to consider

- Is all PT, at the level of individual intervention, part compensation and part restoration?

Goal Setting

- Goals should be written at the level of Activity/Participation of the WHO ICF model
- What does the patient want to be able to do that they are not currently able to do?
- Details matter, may need to "drill down"

Principles of Neuroplasticity

Based on the article by Kleim and Jones, 2008

- The nervous system can adapt its processes, structure and function in response to a variety of input
- “…neural plasticity is the mechanism by which the brain encodes experience and learns new behavior.”
- “…currently learning is our best hope for remodeling the damaged brain…”

- …this process of functionally appropriate reorganization in the healthy brain is also the key to promoting reorganization… in the damaged brain.”
- Using learning, alone and in combination with other therapies to promote adaptive neural plasticity is an important focus of animal and human research into brain damage.

Kleim & Jones, 2008
After nervous system damage, compensatory behaviors will lead to reorganization (e.g., Jones & Shallert, 1994; Jones, Kleim and Greenough, 1996)

Damage to the brain can affect how it responds to learning

- Need for learning studies in persons with damage to the brain
- How much of what we know about the principles of motor learning has been shown to hold true in persons with brain damage?

Kleim & Jones, 2008

Principle 1: Use It or Lose It


- Studied 25 patients with chronic stroke and TBI
- 2 weeks of forced use through wearing a sling during all waking hours (allowed to remove for 30 min/day)
- Significant changes from baseline in a variety of functional tasks.
- First study to identify learned non-use in humans

Kleim & Jones, 2008

<table>
<thead>
<tr>
<th>Task</th>
<th>Target joints</th>
<th>Postural use</th>
<th>1 week</th>
<th>1 month</th>
<th>3 months</th>
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<td>All joints</td>
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<td>Task 4: forearms</td>
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<td>Task 5: hand</td>
<td>All joints</td>
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</tr>
<tr>
<td></td>
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</tr>
<tr>
<td>Task 6: hand</td>
<td>All joints</td>
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<td>-0.02</td>
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<tr>
<td>Task 7: hand</td>
<td>All joints</td>
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<td>-0.02</td>
<td>-0.01</td>
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<tr>
<td>Task 8: hand</td>
<td>All joints</td>
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<td>-0.02</td>
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<tr>
<td>Task 9: hand</td>
<td>All joints</td>
<td>-0.13 -0.08</td>
<td>-0.02</td>
<td>-0.02</td>
<td>-0.01</td>
</tr>
<tr>
<td>Task 10: hand</td>
<td>All joints</td>
<td>-0.13 -0.08</td>
<td>-0.02</td>
<td>-0.02</td>
<td>-0.01</td>
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<td>Task 11: hand</td>
<td>All joints</td>
<td>-0.13 -0.08</td>
<td>-0.02</td>
<td>-0.02</td>
<td>-0.01</td>
</tr>
<tr>
<td>Task 12: hand</td>
<td>All joints</td>
<td>-0.13 -0.08</td>
<td>-0.02</td>
<td>-0.02</td>
<td>-0.01</td>
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<tr>
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</tr>
<tr>
<td>Task 13: hand</td>
<td>All joints</td>
<td>-0.13 -0.08</td>
<td>-0.02</td>
<td>-0.02</td>
<td>-0.01</td>
</tr>
<tr>
<td>Task 14: hand</td>
<td>All joints</td>
<td>-0.13 -0.08</td>
<td>-0.02</td>
<td>-0.02</td>
<td>-0.01</td>
</tr>
</tbody>
</table>

NEUROPLASTICITY
Principle 2: Use It and Improve It

- Practice of specific tasks can increase areas of the brain that respond during the task

Kleim & Jones, 2008

- Treadmill training improves gait speed and endurance and leads to increased brain activation after stroke (fMRI) (Luft et al, 2008)
  - 71 chronic stroke survivors
  - 37 in aerobic exercise group (T-EX) and 34 in stretching group (CON) for 6 months
  - T-EX = 3 40 minute treadmill walking sessions/week at 60% HRR; CON=13 different stretches 3x/week
  - Improvements in peak VO2, walking speed during 6 minute walk test increased more in T-EX
  - Changes in subcortical activation were associated with improvements in T-EX group.

Principle 3: Specificity Matters

- Changes in specific brain areas occur relative to the task that is practiced
- Skilled practice results in changes in neural connectivity

Nudo et al, 1996

- 80 chronic stroke survivors
- 4 groups - focus on BWSTT/UE-EX and CYCLE/UE-EX
- 1-hour sessions, 4 days per week, for 6 weeks

Sullivan et al. Phys Ther. 2007; 87:1588-1602
Principle 4: Repetition Matters

- Repetition of new task required to see neural changes
- Changes at the neuronal level not observed until significant repetition of new task, even when behavioral improvements observed

Kleim & Jones, 2008

- More repetition required for learning after stroke

Tyrell, Helm & Reisman, 2013


Hornby et al, 2015

- 201 sub-acute stroke survivors in inpatient rehab
- Participated in treatments focused on increasing the amount and intensity of walking practice
Principle 5: Intensity Matters

- Hebbian learning:
  - Cells that fire together, wire together
  - Depends on firing patterns

- Brief, intermittent, high frequency stimuli – long-term potentiation

- Frequency of activity (impulses per unit time) determines extent of short-term alterations in synaptic plasticity

Holleran et al, 2015

- Trained 12 persons with chronic stroke
- 12 sessions over 4-5 weeks
- 30 minutes of treadmill stepping and 10 minutes of overground walking at different training intensities, but with equivalent amounts of stepping practice.

Globas et al, 2011

- Trained 38 persons with chronic stroke
- Randomized to 3x/week for 12 weeks of high intensity treadmill training or conventional PT
- 30-50 minutes (start at 10-20 min) at 60-80% HRR (started at 40-50% HRR)

Conclusions

- Animal and human neurophysiologic studies provide substantial information regarding factors that impact neuroplasticity

- Optimal design of neurorehabilitation interventions incorporates these principles

Walking after Stroke
Many patients perceive improvement in their walking ability as the ultimate goal of rehabilitation (Bohannon et al. 1991).

Walking soon after stroke can predict if a patient will be discharged from the hospital to home (Mayo et al. 1999).

Walking soon after a stroke is a strong predictor of who will return to work after stroke (Vestling et al. 2003).

Why do we walk?

- To transport ourselves
- To transport objects
- For exercise

These are important concepts that we must consider when designing gait re-training programs...more on this later....

Basic facts about walking

- Average walking speed in healthy adults is ≈ 1.2 m/s (approx. 2.7 mph)
- Average speed when persons transition from walking to running is ≈ 2.0 m/s (approx. 4.47 mph)

To function independently in the community you should be able to carry packages averaging 6.7 pounds (Shumway-Cook et al., 2002).

To function independently in the community, you must be able to walk a minimum of 500-1000 feet (Hill et al., 1997; Shumway-Cook et al., 2002).

Basic facts about walking

Three classifications:

- Household ambulator < 0.4 m/s
- Limited community ambulator 0.4 - 8.0 m/s
- Unlimited community ambulator > 0.8 m/s

These findings corroborated by later studies:

- Improvements in speed are associated with improvements in self-assessment of disability as measured by SIS (Schmid et al., 2007)
- Patients in different categories were found to have significantly different amounts of daily step activity. Slower walking = less daily activity (Bowden et al., 2008)
Energy Cost

- Recent meta-analysis found that the median VO\textsubscript{peak} in stroke survivors is 14 mL/kg/min (Marsden et al. 2013).

- In adults aged 55-97 years, VO\textsubscript{peak} values below 18-20 mL/kg/min are associated with a loss of independence because activities of daily living become too tiring (Paterson et al. 1999; Cress et al. 2003).

- Given that basic activities of daily living, such as cooking and food shopping, require around 8.25 ml/kg/min, persons with stroke are working at a high percentage of their VO\textsubscript{peak} just to complete basic, daily activities.

- In adults aged 55-97 years, VO\textsubscript{peak} values below 18-20 mL/kg/min are associated with a loss of independence because activities of daily living become too tiring (Paterson et al. 1999; Cress et al. 2003).

- In healthy individuals the aerobic demand – speed relationship is U-shaped with higher aerobic demand occurring at speeds faster or slower than the self-selected walking speed (Martin et al. 1992; Bernardi et al. 1999; Malatesta et al. 2003).

- Older adults show the same U-shaped speed-aerobic demand response curve as young subjects, but the curve is shifted up such that for a given speed, older adults expend more energy per unit distance (Malatesta et al. 2003).

Energy costs of walking in persons with neurologic damage/disease

(Berryman et al. 2011)

(Bernardi et al., 1999)
What is the energy cost of walking faster than self-selected speed for a person with a neurologic condition or injury?

This is important when we consider the slow walking speeds often observed post-stroke and therefore, the goal to increase speed.
• Paretic propulsion strongly related to walking speed after stroke (Awad et al. 2016; Awad et al. 2015; Bowden et al. 2006; Hall et al. 2010)

Walking Activity

Determining daily walking activity after stroke

• Stroke survivors over-estimate amount of daily activity when compare self-report to objective measurement (Resnick et al. 2008)

WHY??

• One way to objectively evaluate walking activity is through monitoring step activity using an accelerometer based device

Research grade accelerometer based devices (SAM, Actical)

• Advantages: good accuracy and test-retest reliability in stroke and other neuro conditions (Macko et al. 2002; Rand et al. 2009)

• Disadvantages: expensive, not easy to use

Commercially available pedometers notoriously inaccurate in those with slow walking speed and/or asymmetric gait (Mocko et al. 2002)

Collaboration with George Fulk, PT, PhD at Clarkson University, Stephanie Combs, PhD, PT, University of Indianapolis, Coby Nirider, PT, Touchstone Neurorecovery

• Accuracy of Fitbit One in community dwelling persons with stroke and TBI is acceptable (ICC²,1 = 0.73)

• Accuracy decreased with walking speeds <0.58 m/s

• Improved accuracy in persons post-stroke when Fitbit worn on non-paretic ankle in community dwelling stroke survivors. 4.7% mean error (versus hand counting) for speeds ≥0.4 m/s, 15.8% error at 0.3 m/s (Klassen et al, 2016)

• 3.8% error Fitbit One compared to Actical in community dwelling stroke survivors, but error significantly increased at <0.58 m/s (Tang et al, 2018)

Inpatient rehab post-stroke (Klassen et al, 2017)

Fitbit error compared to SAM:
• 10.9% at walking velocities <0.4 m/s
• 6.8% at walking velocities between 0.4 and 0.8 m/s
• 4.4% at walking velocities >0.8 m/s.

Table 2. Accuracy of the Fitbit One Using Four Activity Categories*

<table>
<thead>
<tr>
<th>Activity Level</th>
<th>Participants</th>
<th>SAM Mean</th>
<th>SAM Std Dev</th>
<th>Fitbit Mean</th>
<th>Fitbit Std Dev</th>
<th>SAM Mean (95% CI)</th>
<th>Fitbit Mean (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.2 m/s</td>
<td>12</td>
<td>9.2 (1.1)</td>
<td>12.9 (3.1)</td>
<td>9.2 (9.0)</td>
<td>9.2 (9.0)</td>
<td>8.5 (7.5, 9.5)</td>
<td>8.5 (7.5, 9.5)</td>
</tr>
<tr>
<td>0.2-0.4 m/s</td>
<td>7</td>
<td>0.0 (0.1)</td>
<td>0.0 (0.1)</td>
<td>0.0 (0.0)</td>
<td>0.0 (0.0)</td>
<td>0.0 (0.0, 0.0)</td>
<td>0.0 (0.0, 0.0)</td>
</tr>
<tr>
<td>0.4-0.8 m/s</td>
<td>2</td>
<td>5.1 (0.2)</td>
<td>5.1 (0.2)</td>
<td>5.1 (5.1)</td>
<td>5.1 (5.1)</td>
<td>5.1 (4.2, 6.1)</td>
<td>5.1 (4.2, 6.1)</td>
</tr>
<tr>
<td>&gt;0.8 m/s</td>
<td>2</td>
<td>1.0 (0.0)</td>
<td>1.0 (0.0)</td>
<td>1.0 (1.0)</td>
<td>1.0 (1.0)</td>
<td>1.0 (1.0, 1.0)</td>
<td>1.0 (1.0, 1.0)</td>
</tr>
</tbody>
</table>

(Comprehend: confidence interval, PT: physical therapy, and SAM: Mapped Activity Monitor)

Take home message

Fitbit has best accuracy of commercially available devices, but is more inaccurate at speeds <0.3 m/s

How Physically Active Are People Following Stroke?
Systematic Review and Quantitative Synthesis
Fini et al, 2017 PTJ

• 5535 steps per day in sub-acute phase
• 4078 steps per day in chronic phase
• >78% sedentary time regardless of phase….However 2 studies measured sedentary time in acute phase and found a mean of 93.9% and a median of 87.0%!

7 studies measured activity change from subacute to chronic phase:
• 2 showed improvement within subacute phase, but plateaued from the late subacute to chronic phase
• 3 showed improvement from subacute to chronic phase
• 2 showed no change between subacute and chronic phases

Predictive impact of daily physical activity on new vascular events in patients with mild ischemic stroke
Kono et al, 2015 Int J Stroke

• Steps/day is significant predictor of death and hospitalization due to vascular events including stroke recurrence, myocardial infarction, angina pectoris and peripheral artery disease in stroke patients 3 months post-discharge.
Validation of a Speed-Based Classification System Using Quantitative Measures of Walking Performance Poststroke
Bowden et al, 2008 NNR

Steps/day:
• Household = 1411 ± 803
• Limited community = 2668 ± 1193.3
• Unlimited community = 3659 ± 1447.4

Predicting Home and Community Walking Activity Poststroke
Fulk et al, 2017 stroke

a priori categorized based on previous research
• Household = 100-2499 steps/day
• Most Limited community = 2500-4999
• Least Limited community = 5000-7499
• Unlimited community = ≥7500

441 participants:
43.08% = household ambulators
30.39% = most limited community ambulators
14.29% = least limited community ambulators
12.24% = unlimited community ambulators

• What factors are significant predictors of real world walking activity after stroke?
  - If we know this, then we know what to target in rehab
    • 6MWT distance ≥205m discriminated between home & community ambulators
    • 6MWT distance ≥288m discriminated between limited & unlimited community ambulators.
    • Distances <288m on 6 MWT may mean stroke survivors don’t have endurance for community mobility

• Many studies have shown that while walking capacity as measured by 6MWT distance or walking speed is important for steps/day, these capacity measures usually only explain 30-55% of variance (Mudge & Stott, 2009; Fulk et al, 2010)

• Moreover, significant improvements in walking speed and distance don’t result in significant improvements in steps/day (Mudge et al, 2009; Michael et al, 2009; Pang et al, 2005)

• What are the other factors, besides physical capacity, that are influencing real world walking after stroke?

• Studies suggest that balance and balance self-efficacy may be important, however these studies measured activity subjectively (Robinson et al, 2011; Schmid et al, 2011)

• Depression and co-morbidities may also influence post-stroke activity and participation (Carod-Artal et al, 2009; Beniowsit et al, 2008)

• Need for a comprehensive model to look at the role of all of these factors in objectively measured post-stroke real world walking activity.
Walking Capacity
- Walking Economy (WE)
- Functional Gait Assessment (FGA)

Biopsychosocial Factors
- Geriatric Depression Scale (GDS)
- Fatigue Severity Scale (FSS)
- Modified Cumulative Illness Rating Scale (MCIR)

Self Efficacy Measures
- Walk 12
- Activities Balance Confidence Scale (ABC)

Interactions
+ ABC & FGA

R²=0.359
R²=0.414
R²=0.566
R²=0.612

*p<0.001


Motor Learning

Motor Learning is the foundation of neurorehabilitation

We have limited information regarding how stroke affects learning

Much of what we know about motor learning is from neurologically intact subjects doing tasks that are quite simple

Unclear how this applies to complex tasks taught in rehab to persons who have neurologic damage/disease

Types of Learning
Implicit vs. explicit
Procedural vs. declarative

Implicit, procedural learning
Explicit, declarative learning

Procedural Learning
- Develops slowly
- Requires repetition
- Traditionally thought to not require awareness, attention or other higher cognitive processes, however, because learning exists on a continuum, it is difficult to find tasks where this is completely true
Declarative Learning

- Results in knowledge that can be consciously recalled.
- Significant repetition can move declarative learning into procedural knowledge (e.g., initially patient has to tell themselves each step of a transfer, but eventually, with enough practice, they can just complete the transfer without consciously going through the steps).
- Traditionally thought to require awareness, attention or other higher cognitive processes, however, because learning exists on a continuum, the level of awareness varies.

Forms of Motor Learning

- Adaptation learning
  - Error-based
  - Cerebellum-dependent
- Reward-based learning
  - Binary responses; strategies
  - Dopamine systems?
  - Basal ganglia involved? Cortex involved?
- Use-dependent learning
  - Repetition-based; reward-irrelevant
  - Hebbian learning?
  - Cortex involved?

Split-belt treadmill

- Two treadmill belts controlled by two independent motors.
- Legs can be made to move at two different speeds.

This type of learning is thought to be quite implicit.

Persons post-stroke (not involving cerebellum) can adapt step length during split-belt treadmill walking (Reisman et al., 2007, 2009; Tyrell et al., 2014, 2015; Helm et al., 2016).

Neurologically intact subjects can adapt to walking on the split-belt treadmill and show after-effects (Reisman et al., 2005).
This adaptation can lead to improved symmetry (Reisman et al., 2007, 2009; Tyrell et al., 2015). ……

……and can transfer to overground walking (Reisman et al., 2009).

Adaptation is impacted by how subject is set-up on split-belt treadmill (Tyrell et al., 2015).

Depending on direction of baseline asymmetry, paretic leg on the slow belt could either exaggerate or reduce the subject’s asymmetry when the belt’s are initially split (Tyrell et al., 2015).

For this subject, because the paretic leg took a longer step than the nonparetic at baseline, putting the paretic leg on the slow belt initially exaggerated their asymmetry. The opposite was true when the nonparetic leg was on the slow belt (Tyrell et al., 2015).

Resistance Paradigms


When asymmetry is exaggerated subjects adapt back to baseline. When asymmetry is reduced, subject adapt less and appear to stay closer to symmetry (Tyrell et al., 2015).
Resistance paradigm

Both neurologically intact and subjects post-stroke adapt and show after-effects (Savin et al, 2012)

Error Augmentation

Earlier we showed that if we set up a stroke survivor “correctly” on the split-belt treadmill, we will augment their error. They will correct this error, such that when the belts are again tied, they will walk with symmetric step length.

Error Augmentation

If the stroke survivor has the capacity to use trial & error practice to correct gait deviations, why don’t they?

What is an error to the damaged nervous system?

May need to augment or “draw attention” to the error to get system to correct

• We don’t often use error augmentation in rehab. More on this later....

• In rehab we often use reward based or strategic forms of learning
  - Thought to require more cognitive processing
  - Often called skill-based learning
  - Instead of responding to a perturbation, person responds to verbal or visual feedback/information to develop strategies to accomplish the task

Visual feedback paradigm
Years of motor learning research in neurologically intact subjects suggests that learning of different tasks via variable practice enhances learning (contextual interference effect; e.g.- Shea & Morgan, 1979; Schmidt and Bjork, 1992; Brady, 1998)

Although recent work suggests that the advantage of variable practice may depend on the skill of learner and on the complexity of the task to be learned (Brady, 2008; Jones & French, 2007)

Contextual interference refers to variability of practice of tasks or skills. In rehabilitation it is important to consider not only variability of practice at this level, but also the variability of movement during practice of a given task or skill.
• Natural properties of neural networks may be disrupted when variability is not allowed (Cai et al, 2006; Ziegler et al, 2010)

Ziegler et al, 2010

• Greater stepping variability during training lead to greater step rhythmicity following 6 weeks of robotic training in mice with spinal cord transection (Cai et al, 2006)

Evidence Based Treatment for Locomotor Recovery after Stroke

Practical Considerations

• Monitor, Measure and Document
  – Include in EMR
  – Chart review related to documentation of intensity and repetition

• Calculate target HR for everyone

• Obtain necessary medical history and clearances for safety (e.g.-contact cardiologist for patients with significant cardiac history)

• Use signs or symptoms to determine when rest break is needed (e.g.-HR, RPE, shortness of breath)
What treatments can be applied related to intensity?

Key is to get heart rate up to 70-80% heart rate reserve (HRR).

Can calculate with Karvonen formula:

\[
\text{target training HR} = \text{resting HR} + (\% \text{ target} \times (\text{max HR} - \text{resting HR}))
\]

What to use for max HR…220-age?? Other options

- Use heart rate monitor to measure intensity during PT
- Educate clients re: target heart rate zone for intensity and encourage them to measure HR during exercise

How do I train at a high intensity?

Easiest manipulation is speed….have patients train at as fast a possible walking speeds.

- Cost of transport ↓ with training at fastest possible speed

\[\text{energy cost of transport} = \text{pre} \times \text{resting HR} + (\% \text{ target} \times (\text{max HR} - \text{resting HR}))\]

\[\text{energy cost per meter walked} = \frac{\text{energy cost of transport}}{\text{distance walked}}\]


- High intensity interval training may be important

\[\text{FREE} \quad \text{FAST1} \quad \text{FAST2} \quad \text{FASTEST}\]

- Trailing limb angle
- Step length asymmetry

(Boyne et al, 2015)

(Reisman et al, 2011)

(Moore et al, 2010)
No serious adverse events with HIT training and preliminary studies show greater improvements with HIT than MAT

<table>
<thead>
<tr>
<th>Clinical Measure</th>
<th>HIT Group Change (n=11)</th>
<th>MAT Group Change (n=7)</th>
<th>HIT - MAT Change (n=4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerobic capacity (milliliters/min)</td>
<td>+0.5 (0.5, 0.9)</td>
<td>+0.2 (0.1, 0.3)</td>
<td>+0.3 (0.3, 0.9)</td>
</tr>
<tr>
<td>Fastest treadmill walking speed, m/s</td>
<td>+0.30 (0.20, 0.47)</td>
<td>+0.07 (0.41, 0.24)</td>
<td>+0.29 (0.06, 0.45)</td>
</tr>
<tr>
<td>Fastest (floor) walking speed (timed walk test), m/s</td>
<td>+0.13 (0.06, 0.19)</td>
<td>+0.01 (0.04, 0.03)</td>
<td>+0.12 (0.02, 0.14)</td>
</tr>
<tr>
<td>Comfortable walking speed (timed walk test), m/s</td>
<td>-0.15 (0.00, 0.14)</td>
<td>-0.04 (0.04, 0.00)</td>
<td>-0.15 (0.01, 0.10)</td>
</tr>
<tr>
<td>Metabolic cost of walking, ml/kg/m/min</td>
<td>-0.16 (0.15, 0.29)</td>
<td>-0.11 (0.15, 0.08)</td>
<td>-0.13 (0.21, 0.02)</td>
</tr>
</tbody>
</table>

Note: Subjects with chronic stroke were randomized to either HIT or MAT (n=11, 7, 4 weeks). All units are assessed outcomes.

New study:

**Moderate-Intensity Exercise Versus High-Intensity Interval Training to Recover Walking Post-Stroke: HIT-Stroke Trial**

**Lead site:** University of Cincinnati, Pierce Boyne, PT, PhD  
**Other sites:** University of Delaware, Darcy Reisman, PT, PhD; University of Kansas, Sandy Billinger, PT, PhD

How else can I increase intensity?

- Treadmill incline
- Weighted vest
- Resistance while walking (e.g.-Tband around waist/chest and pull back)
- Walking and carrying (e.g.- laundry basket with weights, medicine ball etc)

12 lb weighted vest and 15 lb weighted basket  
12 lb weighted vest and 6 lb weighted ball
What can we do to get enough repetition during treatment?

• Is it feasible to do more, particularly during inpatient rehabilitation?

<table>
<thead>
<tr>
<th>Training characteristic</th>
<th>Mean (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of stay (days)</td>
<td>28 (21-35, 201)</td>
</tr>
<tr>
<td>PT sessions per day</td>
<td>1.3 (0.9-1.2, 201)</td>
</tr>
<tr>
<td>Peak HR/session (rest max)</td>
<td>54 (52.56, 201)</td>
</tr>
<tr>
<td>(percentage maximum)</td>
<td>70 (62.76, 161)</td>
</tr>
<tr>
<td>Peak RPE/session</td>
<td>16 (15.17, 160)</td>
</tr>
<tr>
<td>Max percentage session RPE</td>
<td>38 (31.44, 157)</td>
</tr>
<tr>
<td>Daily stepping (steps/d)</td>
<td>1516 (1504-1666, 201)</td>
</tr>
</tbody>
</table>

Hornby et al, Feasibility of Focused Stepping Practice During Inpatient Rehabilitation Poststroke and Potential Contributions to Mobility Outcomes, Neurorehab Neural Repair 2015, Vol. 29(10) 923–932 2015

Repetition during treatment

• Use Fitbit to monitor steps taken in PT to determine repetition

• Provide Fitbits to clients to monitor repetition in real-world

• Preparation is key
  • Identify all aspects of the desired activity

• Need variety of objects, readily available or set-up by an aide so transitions can happen quickly
Interaction of intensity, specificity and repetition?

Yang et al, 2014

- Trained 20 persons with chronic spinal cord injury on obstacle walking (Precision group) vs. BWSTT for speed and endurance (Endurance group)
- Trained 1 hour/day 5 days/week for 8 weeks on one intervention, then no intervention for 2 months, then participated in the other intervention
- Primary outcome: SCI-FAP - (7 tasks: (1) Carpet, (2) Up & Go, (3) Obstacles, (4) Stairs, (5) Carry, (6)Step, and (7) Door).

Hypothesis was that task-specific over ground obstacle course training would result in greater improvements.

High specificity, but low intensity and limited repetition = less improvement


Considerations for practice with variability/error:

1) Safety

2) Task accomplishment

   What is task completion for walking? Continuous reciprocal stepping, positive step lengths, plantar surface contact, limb support during loading
   For reaching? Make contact with object on at least 2/3 of trials? complete at least ½ of trials for the complete task?

3) Error size and number of errors

   • errors that are too large may limit learning (Sanger, 2004; Guadagnoli and Lee, 2004)
   • too many errors may limit learning (Domingo & Ferris, 2010; Guadagnoli and Lee, 2004)

4) Sufficient repetition

Error Augmentation

Based on ideas from
Guadagnoli and Lee, 2004; Weinstein et al, 1994
Variable Intensive Early Walking Poststroke (VIEWS): A Randomized Controlled Trial
(Hornby et al, 2016)

- Sub-acute stroke (1-6 months post)
- Control group=conventional PT (n=17)
- Experimental group=variable, intense stepping practice (n=15)
  - High intensity forward treadmill walking (10min)
  - Skill-dependent walking (10min): walking in multiple directions, over inclines and obstacles, and/or with weighted vests and leg weights with limited handrail use as tolerated. Perturbations were applied such that 2 to 5 different tasks were randomly alternated and repeated within 10-minutes
  - Overground walking (10 min)-focused on high speeds or variable tasks as above
  - Stair climbing (10 min)

DePaul et al, 2015

- Stroke <1 year
- Control group=BWSTT (n=34)
- Experimental group=variable, overground walking training (n=30)
  - 7 core walking activities at every session: (1) short walks; (2) longer distance (≥50 m); (3) steps, curbs, and slopes; (4) obstacle avoidance; (5) transitions (eg, sit to stand and walk); (6) changes in centre of gravity (eg, pick up an object off floor); and (7) changes in direction.
  - Each activity practiced for equal amount of time per session, challenge level adjusted when subject could perform task without assistance

Differences compared to VIEWS:
- Less than ½ number of treatment sessions – variable practice effects may require more training
- No control over intensity in variable, over ground group. BWSTT group trained at above 0.89 m/s as soon as possible

As we discussed….

- Stroke survivors have low levels of real world walking activity
- Some of this can explained by physical factors (capacity), but biopsychosocial factors also play major role
- So how do we treat to address both capacity and other factors?

Step Activity Monitoring Program

- Measuring activity and providing feedback
- Setting goals
- Identifying barriers and facilitators (motivational interviewing techniques)

Combining Fast walking training with step activity monitoring program
- 2 groups – FAST and FAST+SAM
- 3x/week for 12 weeks
- Hypothesized that those with low levels of activity at baseline would benefit the most

**PROWALKS**
- Promoting Recovery Optimization with WALKing Exercise after Stroke (PROWALKS)
- 1 R01 HD086362-01A1
- Began September, 2016
- ClinicalTrials.gov #NCT02835313
- FAST=Fast walking training
- SAM=Step activity monitoring program
- Outcomes:
  - Primary= steps/day
  - Secondary= 6MWT, walking speed, energy cost
  - Exploratory= MACCE (secondary prevention)

**Key characteristics of SAM:**
- Goal setting should occur by asking the participant how many additional steps they feel they can achieve each day; beyond what they are currently doing. SUBJECTS SHOULD ARRIVE AT THEIR OWN GOAL.
- Evaluation of daily activity will occur at each training session and goal setting will occur at every 6-8th visit
- In order to advance the goal, subjects need to attain 3 days of goal achievement over ~10-14 days.

*At each session:*
- Patients should be told the number of steps they have taken and a discussion should occur about goal achievement.
- Patients will use this information to help them understand how much walking activity they performed during certain daily activities, like walking to the mailbox or walking laps around their home, and how that added to their total steps per day.
- The PT’s role in this discussion is as a facilitator
- Utilize techniques from Motivational Interviewing:
  - The goal of MI is to strengthen the importance of change from the patient’s perspective (Burke, Arkowitz, & Menchola, 2003)
Four basic principles to enhance motivation from MI (Miller & Rollnick, 2002):
(a) expression of empathy,
(b) development of discrepancy,
(c) rolling with resistance, and
(d) the support of self-efficacy

Examples:
• “From what you have been sharing with me, I know you feel as though it will be difficult to walk more, but what ARE ways in which you think you can improve your daily walking activity?”
• “I understand that you feel as though it’s much harder to physically walk since you’ve had a stroke. We are working to build your endurance week by week and goal by goal with the aim being that you walk more by the end of the monitoring program.”
• “You did a nice job meeting your current goal, how will you tackle meeting the advanced goal for next week? I know in bad weather you choose to walk at the mall. If it rains this week like projected, will you do more laps in the mall as opposed to the track, like you have been doing?”

Clinical Practice Guidelines for Improving Locomotor Function Following Acute-onset Neurological Injury

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University of Delaware

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Inpatient Rehabilitation
Kessler Institute of Rehabilitation, West Orange, NJ

Introduction

• Multiple varied interventions utilized to treat patients with neurological injury with multiple physical impairments (Lang 2007, 2009, Kimberly-Jones 2011, Moore 2010, Zbogar 2016)

Research to provide answers?

• Hundreds of studies have evaluated the efficacy of specific interventions to improve function
  – Many demonstrate positive results
  – Available meta-analyses suggest positive outcomes for many interventions

• Clinical Practice Guidelines may provide a mechanism to delineate specific recommendations to guide clinical practice

APTA Clinical Practice Guidelines

• Strategic objective: CPGs enable PTs and PTAs to understand the state of evidence in an effort to:
  – Decrease unwarranted variations in practice
  – Minimize the knowledge translation gap
  – Optimize movement

• Reframing the CPG question
  – Typical focus: What interventions facilitate improvements in function in patients with neurological injury?
  – Current focus: What interventions optimize performance of a specific function?

CPG for Locomotor Outcomes

• Application for Locomotor Clinical Practice Guidelines to APTA
  – Goal: provide concise recommendations supported by systematic literature review of the efficacy of specific interventions to improve locomotor function in persons > 6 months following stroke, traumatic brain injury (TBI) or incomplete spinal cord injury (SCI)
  – Timeline:
    • CPG workshop at APTA (Alexandria, VA) – July 2014
    • CPG application submission - March 2015
    • CPG application acceptance – July 2015
    • Anticipated end date – June 2018
Selected patient populations – SCI, TBI, CVA

- Acute-onset episode resulting in partial damage to supraspinal or spinal pathways influencing motor function
- Rationale for combining diagnoses
  - Common pathways and mechanisms underlying motor performance, adaptation and learning (Dobkin 2008, Holleran 2018)
  - Improved performance/learning may rely on plasticity in spared neural networks vs discrete mechanisms within separate diagnoses
  - Similar mechanisms underlying muscular and cardiopulmonary plasticity

Selected patient populations – chronic stages post injury

- Attempts to minimize contributions of spontaneous neurological resolution
- Minimize variability in recovery patterns

Consideration of Evidence: study selection

- Decision to accept only randomized clinical trials
  - Many interventions show a positive effect on function (Duncan 1998, 2003, 2011)
  - Non-randomized trials provide little indication of optimal intervention
- Evaluation of the treatment groups?
  - What were the experimental and control interventions?
  - Unequal duration therapies
    - No intervention or intervention unlikely to improve locomotion
    - Additional therapy (X intervention + PT vs PT only)

Consideration of Evidence: intervention categories/search terms

- Survey results:
  1. Over-ground walking (91%)
  2. Balance (64%)
  3. Treadmill (40%)
  4. Strengthening (27%)
  5. Neurofacilitation (26%)
  6. Functional electrical stimulation (18%)
  7. Aerobic training (13%)
  8. Robotic-assisted walking (8%)
  9. Circuit training (4%)
  10. Tai Chi (1%)
  11. Aquatic (0%)
  12. Vibration platform (0%)

Methodology

- CPG development follows a formal process and a rigorous methodology
  - Ensure completeness
  - Meet a standard criteria (AGREE II)
  - Transparency
- ANPT Evidence-based Document Manual
  - Released 2015
  - Updated based on APTA recommendations 2018

Guideline Development Team

- Research Content Expert
- Clinical Content Expert (NCS)
- CPG Methodologist (Advisory Committee Member)
- Assistants (2) PTs
- Appraisers (8) (paired researcher with clinician)
- Stakeholder Review Committee (e.g., MD, RN, SW, OT, SLP, Policy/payors, Consumer/Italian)
- Medical Librarian (2)
Summary of Methodology

First Literature Search

- Ensure CPG on this topic does not currently exist
- Refine scope of CPG
  - Identify PICO questions (Patient, Intervention, Comparison/Control, Outcomes)
  - Development of key conceptual and operational definitions
- Ensure sufficient information exists on this topic

Second (formal) Literature Search

- Database (Pubmed, CINAHL, Embase, CENTRAL)
  - RCTs from 1995-2016
  - 4778 articles after de-duplication
  - Using intervention search term: locomotor/exercise/treadmill/overground = 2483
- Systematic Reviews and Meta-analysis – screening for additional appropriate articles

Development of Appraisal Process

- APTA Critical Appraisal Tool for Experimental Interventions (CAT-EI v. 2016)
  - Part A: contextual information
  - Part B
    - Items 1-12: overall quality of the study
    - Items 13-20: individual outcomes of the study
  - Part C: impact of the study
- Piloted appraisal on 9 strength articles
  - Identified items for extraction
  - Developed database
  - Developed manual for appraisers

Appraiser Training

- 8 appraisers successfully completed training
- Training:
  - Review criterion manual for article evaluation
  - View CAT-EI training module
  - Appraise 1 sample article with answer key
  - 2 test articles
    - “Easier” vs “harder” article
    - 90% cut-off score
- Appraisers paired based on primary role
  - Researcher-clinician paired
  - If not consensus, provide both scores (~1 pt difference in B score)

Grading Levels of Evidence

I. Evidence obtained from high-quality diagnostic studies, prognostic or prospective studies, cohort studies or randomized controlled trials, meta analyses or systematic reviews (critical appraisal score 250% of criteria, B score ≥ 10).
II. Evidence obtained from lesser-quality diagnostic studies, prognostic or prospective studies, cohort studies or randomized controlled trials, meta analyses or systematic reviews (eg. weaker diagnostic criteria and reference standards, improper randomization, no blinding, <80% follow-up) (critical appraisal score <50% of criteria, B score < 10).
III. Case-controlled studies or retrospective studies
IV. Case studies and case series
V. Expert opinion
Evidence Table

- Evidence for a specific intervention
  - Article, level/score, diagnoses (CVA, SCI, TBI)
  - Outcomes (10 m, 6 min) –
    - “-” not tested
    - “0” – not significantly different between groups
    - “+” – significantly different between groups
  - Intervention (Experimental v Comparison)
    - no or matched vs. unmatched intervention
    - FITT parameters
  - Other findings – additional significant outcomes

Example Evidence Table (strength)

<table>
<thead>
<tr>
<th>Strengthening exercises</th>
<th>Length (weeks)</th>
<th>Intensity</th>
<th>Other Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flansbjerger 2008</td>
<td>1</td>
<td>13</td>
<td>CVA</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

CPG update

Strength of Recommendation

<table>
<thead>
<tr>
<th>Grade</th>
<th>Level of Obligation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Strong</td>
<td>- moderate to high level of certainty of moderate to substantial benefit, harm, risk or cost (most Level 1 or 2)</td>
</tr>
<tr>
<td>B</td>
<td>Moderate</td>
<td>- moderate to high level of certainty of slight to moderate benefit, harm, risk or cost (based on most Level 2)</td>
</tr>
<tr>
<td>C</td>
<td>Weak</td>
<td>- weak level of certainty for moderate to substantial benefit, harm, risk or cost (Level 2-5)</td>
</tr>
<tr>
<td>R</td>
<td>Research</td>
<td>- an absence of research on the topic or disagreement among conclusions from higher-quality studies on the topic</td>
</tr>
</tbody>
</table>

Benefit-Harm Assessment

<table>
<thead>
<tr>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improves walking function (greater efficacy)</td>
</tr>
</tbody>
</table>

| Harm |
| Cost |
| Risk |
| 

Use of “should” recommendation

- Strength of Recommendation: A (Strong) or B (Moderate)
  - moderate to high level of certainty of benefit
- Intervention should be performed
  - Mostly better than conventional or alternative therapy
  - >66% studies show benefit

Use of “may” recommendation

- Strength of Recommendation: C (Weak)
  - weak level of certainty of benefit
- Intervention may be considered
  - Sometimes better than conventional therapy (33-66% studies show benefit)
  - Mostly better than no intervention (>66% show benefit)
Use of “should not” recommendation

- Strength of Recommendation: A (Strong) or B (Moderate)
  - moderate to high level of certainty of harm, risk or cost
- Intervention “should not” be performed
  - Mostly not better than conventional therapy or alternative strategy (< 33% show benefit)

Walking- Aerobic

- 12 Level I articles
  - High intensity vs low intensity (5 articles)
    - high intensity: HIIT or 70-85% HRR/VO₂ peak
    - Low intensity: 40-50% HRR
  - High intensity vs passive/no intervention (5 articles) –
    • 60-80/85% HRR or age predicted HRmax
    • stretching, passive exercise, some balance, massage
  - Fast vs slow walking (2 articles) – fast as safely possible vs self-selected speed

Examples of evidence from 2 categories of intervention

<table>
<thead>
<tr>
<th>Article</th>
<th>Level</th>
<th>Score</th>
<th>Dx</th>
<th>6 MWT</th>
<th>10 MWT</th>
<th>Intervention</th>
<th>Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gordon, 2013</td>
<td>1</td>
<td>16</td>
<td>CVA</td>
<td>‘+’</td>
<td>‘+’</td>
<td>PAS, ST, EX, BT, BP, BAL, MM, CB</td>
<td>Gait compared to control</td>
</tr>
<tr>
<td>Luft, 2006</td>
<td>1</td>
<td>13</td>
<td>CVA</td>
<td>‘+’</td>
<td>‘+’</td>
<td>PAS, ST, EX, BT, BP, BAL, MM, CB</td>
<td>Gait compared to control</td>
</tr>
<tr>
<td>Ivey, 2015</td>
<td>1</td>
<td>11</td>
<td>CVA</td>
<td>‘+’</td>
<td>‘+’</td>
<td>PAS, ST, EX, BT, BP, BAL, MM, CB</td>
<td>Gait compared to control</td>
</tr>
<tr>
<td>Mustari, 2016</td>
<td>1</td>
<td>16</td>
<td>CVA</td>
<td>‘+’</td>
<td>‘+’</td>
<td>PAS, ST, EX, BT, BP, BAL, MM, CB</td>
<td>Gait compared to control</td>
</tr>
<tr>
<td>Hollerman, 2015</td>
<td>1</td>
<td>12</td>
<td>CVA</td>
<td>‘+’</td>
<td>‘+’</td>
<td>PAS, ST, EX, BT, BP, BAL, MM, CB</td>
<td>Gait compared to control</td>
</tr>
<tr>
<td>Yang, 2014</td>
<td>1</td>
<td>12</td>
<td>SCI</td>
<td>‘+’</td>
<td>‘+’</td>
<td>PAS, ST, EX, BT, BP, BAL, MM, CB</td>
<td>Gait compared to control</td>
</tr>
<tr>
<td>Awad, 2016</td>
<td>1</td>
<td>11/14</td>
<td>CVA</td>
<td>‘+’</td>
<td>‘+’</td>
<td>PAS, ST, EX, BT, BP, BAL, MM, CB</td>
<td>Gait compared to control</td>
</tr>
<tr>
<td>Sullivan, 2002</td>
<td>1</td>
<td>11</td>
<td>CVA</td>
<td>‘+’</td>
<td>‘+’</td>
<td>PAS, ST, EX, BT, BP, BAL, MM, CB</td>
<td>Gait compared to control</td>
</tr>
</tbody>
</table>

Summary: Walking- Aerobic

Aggregate Evidence Quality:
- High intensity walking vs passive exercise/stretching – 4/5 showed greater benefit
- High intensity walking vs low intensity walking – 4/5 showed greater benefit
- Fast walking vs slow walking (no measure of intensity) -2/2 showed no differences

Action Statement: Clinicians should use moderate to high intensity walking training interventions for improving locomotor function in patients with chronic CNS injury (Level I, Grade A).

Risks, harm, costs: Potentially increased risk of cardiovascular events during higher intensity training walking training without appropriate cardiovascular monitoring

Walking- Body weight supported treadmill training (BWSTT)

- 9 articles met criteria (6 level I, 3 level II)
  - BWSTT vs over ground walking (3 Level I, 3 Level II)
  - BWSTT + conventional PT vs conventional PT (1 Level I)
  - BWSTT vs conventional PT (1 Level I)
  - BWSTT vs no intervention (1 Level I)

- FITT categories
  - Type – all BWS with PT assist as needed vs overground or other
  - Frequency/time – Indication of duration/frequency
  - Intensity – HR parameters rarely described, detail of amount of BWS and PT assist
Summary: Walking- BWSTT (con’t)

Action Statement:
A. Clinicians should not perform body weight supported treadmill training in lieu of over ground training for improving locomotor function following chronic CNS injury (Level 1, Grade A).
B. Clinicians may use body weight supported treadmill training interventions as an additional intervention for improving locomotor function following chronic CNS injury (Level 1, Grade C).

Risks, harm, costs: Body weight-support systems are expensive, assistance from multiple therapists costly and often not feasible.

Summary: Walking- BWSTT

Aggregated Quality Evidence:
- BWSTT vs over ground walking - 6/6 no greater benefit of BWSTT and 1 showed over ground better
- lower intensity of BWSTT?
- BWS, PT assistance, limited speed with increased focus on kinematics

BWSTT compared to PT or no intervention
- 1 study showed benefit of additional BWSTT (BWSTT + PT vs PT alone)
- 1 study found no greater benefit of BWSTT vs PT
- 1 study found BWSTT better than no intervention

Implementation

- ANPT Practice Committee
- Recruited and selected Implementation team:
  - Co-Chairs: Casey Holleran & Lisa Goodwin
  - Committee members: Meredith Banhos, Estelle Gallo, Allison Miller, Sue Peters, Meghan Bretx, Lauren Szt...
Collaboration

Undergraduate fellows
Stacey Cifelli
Jen Breihupt
Chris Wagner
Jill McElligott
Shreya Jammula
Dana McCoy
Lucas Brady
Menki Chen
Jen Byrnes
Justin Pepper
Ania Lipat
Emmeline Oltmanns

LAB – Past and Present

LAB

STAR Campus
Health Sciences Complex