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AQUATIC GAIT TRAINING

Comparing Land and Water Gait Sequences: What Can Best be Addressed Using Water Walking Interventions

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Learner Outcomes

At the conclusion of this course, participants will be able to:

I. Identify at least three differences between land and water walking with respect to tri-plane forces that occur, so as to be able to accurately address gait discrepancies.

II. Describe at least three differences in lower extremity muscle activation between land and water walking so as to effectively address muscle imbalances when gait discrepancies occur.

III. Discriminate between those gait conditions which would benefit from effective aquatic intervention versus those where a deleterious effect could occur if addressed by water therapy.

IV. Outline a logical intervention progression for commonly seen gait conditions utilizing aquatic and land therapy, and be able to recognize when to transfer between the two.

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Function of Walking

"Nothing epitomizes the level of independence and our perception of a good quality of life more than the ability to travel independently under our own power from one place to another." Patla

- Fulfills individual need to go from place to place
- Appearance of an effortless task
- Synchronous structural movements

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Review of Gait Descriptors

SPATIAL DESCRIPTORS	TEMORAL DESCRIPTORS
Stride-Length • Distance between 2 successive heel strikes 72 cm (28 inches)	**Cadence** • Number of steps per minute • 1.87 steps/sec or ≈ 110 steps/min
Step Length • Distance between 2 successive contacts of same foot • Normal Value: 144 cm	**Walking Speed** • Calculated in meters/seconds or mph • Based on age, height, weight, sex • Considered the best measurement of one's functional walking ability • Normal Values: 1.37 meter/sec (3.0 mph)
Step-Width • Lateral distance between heel center of 2 consecutive foot contacts • Adult normal: 7-9 cm.	

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LAND GAIT

Speed

- Best measurement of functional criteria for gait regardless of quality
- Slowed gait indicative of increased energy costs

Gait speed indicative of survival in older adults (JAMA 2011)

- Integrates unrecognizable disturbances in multiple organ systems.

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Gait SPEED
"the 6th vital sign" 3-4

Summary indicator of multiple physiologic system inputs—reflects overall health

- **< .6 M/sec:** Highly dependent; functional impairments; household walker
- **.6-1.0 M/sec:** Limited community ambulator; increased fall risk; cognitive decline within 5 yrs.
- **>1.0 M/sec:** Functional community ambulator
- **1.4M/sec and >:** crosses street safely; fit; able to climb multiple flights of stairs

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How We Pick Gait Speed

- individual health
- motor control
- muscle performance
- sensory + perceptual functions
- cognitive status
- motivation+ mental health
- characteristics of environment- *land or water*

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Land Gait Characteristics

Gait Sequence

Joint Involvements

Muscle Activation

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LAND GAIT

Gait Sequence

STANCE PHASE: 60% of gait sequence

- Weight acceptance to progress over supporting foot
- Double Limb Support (DLS): 20% of stance phase
  - Increased DLS indicative of underlying pathology

SWING PHASE: 40% of gait sequence

- Forward reach, preparation for initial contact

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LAND GAIT

Motion at the PELVIS

- **Sagittal**: 2-4°/step – increased motion noted with increased walking speed
  - Mid-stance = anterior
  - Push-off to mid-swing = posterior
- **Frontal**: For (R) stance the (L) iliac crests moves downward due to drop in COM
- **Transverse:** Pelvic motion increases step lengths
  - Dependent on hip position

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LAND GAIT

Motion at the HIP

- **Sagittal**: Requires 30°flexion and 10°extension
  - Decreased hip mobility increases pelvic/lumbar motion
- **Frontal:** Abducted in stance; Adducted in swing
- **Transverse:** Predominantly results from pelvic motion
  - Femur is fixed and pelvis must move over this

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LAND GAIT

Motion at the KNEE

Sagittal: Requires 60° flexion + full extension

- Lack of flexion affects swing phase
- Lack of extension affects stance and swing phases

Frontal: Minimal valgus noted in swing phase

Transverse: Since tibia rotates internally faster than femur during stance, there is net internal rotation at the knee

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LAND GAIT

Motion at the ANKLE

Sagittal: Requires 10°dorsiflexion + 20° plantar flexion for normal gait sequence.

Frontal: Early stance requires eversion /pronation for compliant foot; followed by supinated/rigid foot

- Pronation is the key for shock absorption + loading
- Supination—rigid lever-- critical for propulsion

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LAND GAIT

Trunk/Shoulders

- Trunk rotation noted at shoulder girdle = 7°
  - Absence of trunk rotation increases energy expenditure by at least 10%
- Shoulders rotate opposite to pelvis in transverse plane

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Land Gait

Muscle Activation

- Muscles work at approximately 20% max to walk
  - Increased effort needed to accelerate or change direction
- Adductors are *on* the most during walking:
  - With hip extension, assist with contralateral hip flexion
  - With flexion, help to stabilize hip and then assist to extension

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Land Gait

Hip Flexors: Concentric pre-swing to initial swing to advance LE (off 2nd half of swing)

- Eccentric activation in terminal stance to control hip extension

Hip Extensors: Eccentric action in terminal swing
  - Decelerates hip to prepare for weight acceptance
- Concentric Action: 0-30% gait to prevent "jack-knifing" at initial contact
  - Accepts weight/extends hip

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Land Gait

Abductors: In terminal swing prepare LE for contact

- Eccentrically control drop of contralateral pelvis and then concentrically raise pelvis
- Controls alignment of femur in frontal plane

Adductors: At contact, they stabilize hip and assist with extension

- Just after toe-off assist hip flexors to initiate flexion

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Land Gait

Internal Rotators: On a fixed femur rotator contralateral hemi-pelvis forward

External Rotators: Active during early stance to control alignment of femur

- Finalize advancement of hemi-pelvis to prepare for heel strike

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Land Gait

Knee Extensors: Active at late stage of swing to prepare for contact

- Major activity after initial ground contact with both eccentric and concentric activation

Knee Flexors: Active at late swing to eccentrically slow down knee extension preparing for foot contact

- After initial contact, assist hip extension
- Provide knee stability
- After toe-off minimally assists with knee flexion

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Land Gait

Dorsiflexors: Major activity after initial heel contact

- Eccentrically controls plantar flexion + pronation
- Provides ankle stability at push-off
- Swing Phase: Concentric dorsiflexion clears ground

Plantar Flexors: Eccentrically controls tibial displacement, prevents uncontrolled knee flexion and excessive dorsiflexion

- Provides overall stability of foot

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Land Gait

Trunk: Anterior Structures

- **Intervertebral Muscles:** Active slightly before contact to control forward momentum of trunk and after heel strike to prevent jack-knifing.

- **Rectus Abdominis:** Very low activation throughout gait cycle; burst activation of hip flexors to stabilize pelvis/spine

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Land Gait

Trunk Stabilizes: Control + limit movement

- Maintain neutral spine curve
- Respond to postural changes

Mobilizers: Insert/originate on thorax

- Respond to changes in line of action + magnitude of intrinsic load
- Initiate movement ; distribute load

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Water Walking

CONSIDERATIONS

BIOMECHANICS

SIGNIFICANT DIFFERENCES

FUNCTIONAL USE of WATER WALKING

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Transitioning to Water Walking Consider…..

- Immersion level + Speed affects forces
- Resistance imposed on body-
  - Water is 800x denser than air[11]
  - Lower self-selected walking speeds
  - More conscious movement control
- Apparent decreased body weight due to buoyancy= decreased musculoskeletal stresses
  - Decreased muscle activation as well

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Water Walking

- **Depth alters ground reaction forces (GRF) and joint compressive forces**
  - Anterior-Posterior GRF very distinct pattern
- **Increased drag adjusts cyclic phases of gait**
  - Changes are more obvious with speed adjustments
- **Drag Force alters posture**
  - changes lower extremity (LE) muscle activation
- **Internal net joint forces and torque are decreased** drastically affecting muscle activation

(Orselli, Barella, Masumoto)

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Water vs. Land Walking
Biomechanical Differences

1. Decreased body weight due to buoyancy requires less muscle activation to support body .
2. Increased need to maintain concentric muscle activation to overcome drag force as body advances through water.

Dependent on speed and how much body weight is reduced—depth + floatation equipment

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Water vs. Land Walking

1. Comparing Joint Forces + Torque Water vs. Land Walking

N: 10 (6 females 4 males)

Age: 24 + 3 yrs.

Method: Walking at comfortable, self-selected speeds land and **chest depth**. Analyzed with force plate + video for 2-dimensional gait analysis

Orselli MIV. Duarte M. *J Biomechanics 2011.*

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Water vs. Land Walking

Orselli MIV. Duarte M. *J Biomechanics 2011.* [6]

VARIABLE	ENVIRONMENT	
	LAND	**WATER**
Stride Length (m)	1.38 + 0.08	1.28 + 0.15
Stride Period (s)	1.12 + 0.08	**2.79 <0.001**
Stride Velocity (m/sec)	1.23 + 0.10	**.46 + 0.04**
Vertical GRF* (%N/BW)	117 + 6	**37 + 4**
Impulse of Ant/Post. GRF	-0.4 + 0.5	**9.1 + 1**
* GRF = ground reaction forces		

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Water vs. Land Walking

Orselli MIV. Duarte M. *J Biomechanics 2011.*

VARIABLE	ENVIRONMENT	JOINT		
		ANKLE	KNEE	HIP
Range of Motion	Land	30 ± 3	65 ± 5	37 ± 4
	Water	30 ±7	66 ± 15	37 ± 5
Flexor Torque Peak	Land	0.22 ± 0.10	5.3 ± 1.1	6.5 ± 1.8
	Water	0.49 ± 0.10	4.6 ± 1.0	5.4 ± 1.0
Extensor Torque Peak	Land	19.8 ± 2.0	4.7 ± 1.8	8.4± 1.7
	Water	**5.9 ± 0.7**	**2.5 ± 0.4**	**8.1 ±1.7**
Compressive Force	Land	114 ± 6	106 ± 6	94 ±5
	Water	**38 ± 4**	**37 ± 4**	**36 ± 4**
Shear Joint Force	Land	34 ± 7	36 ± 5	23 ±5
	Water	**13 ± 4**	**9 ± 1**	**10 ± 3**

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Water vs. Land Walking

Orselli MIV. Duarte M. *J Biomechanics 2011*

- Decreased water walking speeds = decreased angular speeds at the joints
- Joint torques: comparing Water with Land
  - Flexor torque similar for hip and knee
  - Extensor torque of ankle + knee were reduced
    - Change due to amount of weight supported by each joint
- Hip torques did not differ between land/water during support phase
  - Drag force demanded more from hip to execute its function

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Water Walking: Implications for Rx

Orselli MIV. Duarte M. *J Biomechanics 2011.*

Water walking:

- Decreases internal joint forces on LE joints except hip
- Does not necessarily offer decreased musculoskeletal loads compared to land locomotion
  - Load determinants: Water depth + moving velocity
  - Decreased internal loading noted for chest deep water
- Similar kinematics noted land to water, but with decreased angular speeds .

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Water vs. Land Walking

Barela AMF. Duarte M. *J Electromyography and Kinesiology 2008.*

Comparing Spatial-Temporal Gait Parameters, LE joint angles, GRF and EMG activation for older adults.

N: 10 (6 males, 4 females)

Age: 70 $\pm$ 6 yrs.

Method: Walked at self-selected speeds x 10 occasions for both land and in chest-deep water with UE's positioned out of the water.

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Water vs. Land Walking

Barela AMF. Duarte M. *J Electromyography and Kinesiology 2008*

SPATIAL-TEMPORAL	LAND		WATER	
	ELDERLY	ADULT	ELDERLY	ADULT
Stride Period (sec)	.99	0.95	**2.02**	**2.41**
Length (m)	1.17	1.32	0.97	1.19
Speed (m/sec)	1.20	1.39	**0.97**	**1.19**
JOINT ANGLE-Initial Contact (°)				
Ankle	5.3	3.8	**-1.6**	**-2.8**
Knee	4.4 ± 3.9	7.0 ± 5.0	**16.0 ± 5.6**	**8.1 ± 8.8**
Hip	18.2 ± 3.9	18.2 ± 5.7	22.1 ± 3.9	18.5 ± 4.4

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Water Walking: Implications for Rx

Barela AMF. Duarte M. *J Electromyography and Kinesiology 2008*

Comparing water vs. land walking for older adult:

- Significantly slower speeds, shorter strides than young adults
- Increased ankle plantar flexion noted during stance
- Initial stance originated from flat foot
- Increased knee flexion noted both at initial and end stance phase – but smaller range throughout cycle
- Increased hip joint flexion noted throughout gait sequence

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Water Walking: Implications for Rx with Older Adults

Barela AMF. Duarte M. *J Electromyography and Kinesiology 2008*

Compare older adult vs. young adult

- Significantly slower speeds, shorter stride lengths, increased stance period, lower stride duration
- Increased knee flexion at initial contact, with increased knee/hip flexion noted throughout cycle
- Decreased dorsiflexion

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Kinematic Adaptations

Cadenas-Sanchez et al 2016

Comparing Spatial/Temporal Gait Parameters
Forward + Backward Walking/ Land vs. Water

	Land FORWARD	**Water** FORWARD	**Land** BACKWARD	**Water** BACKWARD
Speed (m/sec)	0.88± 0.07	0.62 ± 0.03	0.58 ± 0.06	0.55 ± 0.08
Stride Lengths (m)	1.23 ± .12	0.90 ± 0.08	0.90 ± 0.10	0.76 ± 0.07
Step Lengths (m)	0.66 ± 0.05	0.47 ± 0.04	0.45 ± 0.04	0.39 ± 0.03
Support Phase (%)	66.4 ± 2.12	60.9 ±2.81	68.8 ± 3.24	60.0 ± 4.06

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Kinematic Adaptations

Cadenas-Sanchez et al 2016

Joint Angles: initial Contact /Final Stance Forward + Backward Walking/ Land vs. Water				
	Land FORWARD	Water FORWARD	Land BACKWARD	Water BACKWARD
Initial Contact Ankle (°)	90.0 ± 2.95	87.0 + 3.33	71.1 ± 3.15	91.6 ± 1.59
Knee (°)	178.0 ± 1.59	168.1 ± 7.1	166.1 ± 4.7	161.2 ± 4.9
Hip (°)	17.4 ± 1.05	23.5 ± 2.02	7.0 ±1.33	7.6 ± 0.79
Final Stance Ankle (°)	101.6 ± 6.82	99.1 ± 1.79	95.7 ±2.16	119.2 ± 3.88
Knee (°)	135. 0 ± 4.9	131.1 ± 6.66	170.2 ± 1.03	169.0 ± 2.97
Hip (°)	-21.3 ± 1.77	-13.2 ± 1.24	-15.2 ± 2.18	-11.3 ± 1.57

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Comparison

Water vs. Land Gait Parameters

- **Speed**: 36%of land walking speed
- **Stride Frequency**: **57% of land**
- **Stride Length**: **90% of land**

*Dependent on age, depth and comfortably selected walking speeds

(Barela, Orselli)

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continuED™

Comparison
Water vs. Land Gait Sequence Muscle Activation

Lower Extremity:

- Gastrocnemius/Soleus: Similar pattern to land but delayed 10%
  - Decreased activation noted during various speeds
  - Increased plantar flexion first 60% of stance phase
- Tibialis Anterior: Remains activated throughout both phases of gait

(Barella, Chevutschi, Hitoshi)

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Comparison
Water vs. Land Gait Sequence Muscle Activation

Lower Extremity

- Tensor Fascia Lata: increased activation during swing phase
- Biceps Femoris: Increased Activation during stance phase
- Rectus Femoris: Most intense activity is just prior to and with heel strike; is more intense than land

(Barella, Chevutschi, Hitoshi)

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Comparison
Water vs. Land Gait Sequence Muscle Activation

Trunk

- Rectus Abdominis: Increased activation noted at extremes of the swing phase
- Erector Spinae: Increased activation at the end of stance and remained activated during swing phase
- Increased speeds tend to facilitate trunk flexed position
  - Increased arm usage facilitates trunk rotation

(Barella, Chevutschi)

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Comparison
Water vs. Land Gait Joint Forces

- **Hip:** Equal to land with extension predominating throughout stance phase
  - No significant difference in ROM
  - Hip muscles support body against gravity on land and are required to pull thigh up/forward.
  - Load in water is decreased BUT water resistance increases the work, therefore **extensor propels** body forward
  - Function of Hip is different water vs. land

(Myoshi, Barela)

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Comparison
Water vs. Land Gait Joint Forces

- **Knee:** Angular displacement differs water vs. land.
  - ROM decreased for both mid- and late stance phase in water
  - Extension peaks occurs at late stance phase in water vs. 2 extension peaks on land
  - Decreased flexion during first 15% stance phase—acceptance phase– translates to increased extension

(Myoshi, Barella)

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Comparison
Water vs. Land Gait Joint Forces

- **Ankle:** Decreased support required of ankle joint during water walking
  - Peak dorsiflexion during late stance on land shifts to mid-stance for water walking and last longer
  - Decreased plantar flexion moment possibly due to decreased vertical load

(Myoshi, Hitoshi, Barella)

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Water vs. Land Comparison Summary

- Decreased speed
- Shorter Stride
- Reduced vertical GRF
- Increased horizontal impulse
- Decreased Knee ROM
- Increased Ankle Extension + knee flexion with heel strike
- No change in the relative duration of swing and stance phases
- Anterior-Posterior GRF altered
- EMG pattern for LE muscles affected by water depth

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Considerations for Incorporating Aquatic Gait Training in Therapy

Does gait training in water positively translate to land skill acquisition?

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Water Walking-Considerations

- Backward walking facilitates hip/knee extension
- Lateral walking is easier due to decreased surface area
- Marching accentuates hip/knee flexion, increases single leg stance, assists balance
- Increased exercise intensity expected in unskilled client

Water Walking- Broad Uses

SPEED: Multiple studies demonstrate improved land speeds post bout of water Rx

- Emphasis on increased step lengths + steps/min

HIP EXTENSION: Facilitated by water walking with increased activation noted during stance

- Due to drag force

What About Retro-Walking?

Masumoto K. et al 2005, Cadenas-Sanchez et al 2015

- Thoracolumbar paraspinals activation enhanced at all speeds
  - Enhances duration of activity of muscle groups
  - Greater emphasis on paraspinal muscle conditioning
- Postural adjustments—specifically trunk flexion– must be accounted for
  - Choice of equipment to facilitate upright posture
- Increased metabolic effect as well
  - Deconditioned CLBP pt generally is deconditioned

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Retro-Walking, cont.

- Increased dorsiflexion over both forward water and backward land walking
- Increased plantar flexion noted
  - Promotes pushing off
  - Considerations for individuals with decreased gait speed

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A Word About GAIT SPEED UPGRADES

- Increased anterior force required to overcome viscosity
  - Increased effort for hip flexors which are gait "drivers"
    - Can strengthen hip flexors
  - Contralateral extremity use facilitates trunk flexion/balance
- *Multiple studies using water to enhance LE ROM, strength, balance demonstrate improved gait speed*

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Water Walking- Broad Uses

TRUNK ROTATION: Facilitated by "pulling the body" through the water chest/shoulder depth

- Walking at shallow depths using visual cues

KNEE/HIP FLEXION/EXTENSION: Flexion is facilitated by buoyancy

- Marching facilitates hip/knee flexion
  - buoyancy assists with flexion at toe-off

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Water Walking- Broad Uses cont

- **KNEE/HIP EXTENSION:** Facilitated with toe-walking; long-strides to target
- **ANKLE DORSIFLEXION:** Facilitated with retro-walking
- **ANKLE PLANTARFLEXION:** Facilitated with toe-walking and retro-walking
  - Increasing speed to just short of running facilitates plantar flexion

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Treatment Considerations for Specific Diagnoses

Knee OA

Hip OA

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Considerations for Knee OA Rx

Land Gait Changes Seen with Knee OA

- Decreased walking speed
- Shorter/inconsistent step-lengths
- Increased postural sway-laterally away from affected side
- 6-20% less knee motion in gait
- Decreased hip flexion
- Decreased quadriceps > hamstring strength
- Self-reported decreased walking distance due to pain

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Specific Use of Water Walking Rx Knee (OA) Client

- Decreased joint forces decreases pain -able to walk longer
- Increased speed due to quadriceps activation
- Planned increased/consistent step-lengths in water facilitates equal stepping
- Walking in water facilitates hip extensor usage
- Rapid directional changes facilitated without risk for falls
- Toe-walking improves calf strength and facilitates knee extension during mid-stance
- Retro-walking promotes knee/hip extension + dorsiflexion

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Considerations for Hip OA Client

Changes Seen with Hip OA

- Decreased walking speed and walking distances
- Shorter/inconsistent step-lengths partially due to decreased adductor strength
- Increased postural sway, if laterally away from affected hip
- Decreased weight-bearing on affected side
- Decreased hip extension > hip flexion

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Specific Use of Water Walking Rx Hip OA Client

- Decreased joint forces
  - Decreased pain with activity of walking so potentially able to walk longer or for exercise
- Increased speed increases force generated from quadriceps
- Planned increased/consistent step-lengths in water facilitates equal stepping
- Walking in water facilitates hip extensor usage
- Improve paraspinal strength to assist with upright posture vs. lateral trunk flexion

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Considerations for ACL Deficit Client

- Decreased knee extension—promoted with retro-walking
- Decreased knee flexion-promoted with marching
- Poor toe-off-promoted with retro-walking

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Last Thoughts
Water Walking *Does Not*

- Promote normal land-required walking speeds
  - Painful clients tend to walk even slower
- Facilitate—unless planned—normal, land-appropriate step-lengths
- Encourage land-appropriate knee flexion
- Accentuate land-appropriate trunk posture
- Require land-appropriate dynamic balance demands

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THANK YOU

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