YOU’VE GOT TO **MOVE IT!**
APPLICATIONS OF TECHNOLOGY FOR PHYSICAL ACTIVITY

CSM 2017
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**OBJECTIVES**

Upon completion of this course, you will be able to:

1. Discuss the use of technology to address physical activity rehabilitation goals
2. Describe the various types of technology that are feasible for use in rehabilitation to optimize physical activity
3. Describe how current modes of technology are used as measures of physical activity and within intervention to promote mobility
4. Identify obstacles to implementing technology into clinical practice

**CONFLICT OF INTEREST DECLARATION**

Conflicts of interest linked to the work presented will be listed.

**DOCUMENTING PHYSICAL ACTIVITY**

Previously
- Videotape: parent diaries (Adoph, et al., 1998)
- Kinematics/Kinetics in lab
  - Video-based (i.e., Vicon)
  - Wired SEMG
  - Magnetic tracking (i.e., Polhemus)
  - Direct supervision in rehab

Now
- Trackers/accelerometers/inertial sensors
- Wireless systems
  - Kinect, SEMG
- Indirect telerehab

**CLINICALLY VIABLE TECHNOLOGY**

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**TOPICAL QUESTIONS**

1. How do we quantify physical activity, motion and mobility?
2. What modes of technology are available today & what resources are needed?
3. What modes of technology are being researched, developed and close to implementation?
1. HOW DO WE QUANTIFY PHYSICAL ACTIVITY, MOTION AND MOBILITY?

- Observation
  - Can be a useful clinical tool.
  - Best done with consistent, systematic approach to body segments.
  - Requires significant training and experience.
  - Best suited for single plane, single segment assessment — inherent limitations.

2. QUANTITATIVE CONCEPTS - MOTION ANALYSIS

2D vs. 3D

- Limitations of 2D assessment (observation) – led to the need for 3D
- Limitations of vision
  - Events happening faster than 1/12 sec cannot be perceived by the human eye
  - Difficulty in observing multiple events at multiple body segments concurrently
- Limited to real-time trials with patient in clinic / no permanent record
- Difficulty in observing in multiple planes of motion
  - Ex: Internal femoral rotation with knee flexion may appear observationally as knee valgus

3. KINEMATIC (MOTION) PRINCIPLES & APPLICATIONS

- Video photogrammetry
  - Track motion to measure position, velocity & acceleration.
  - Marker location in space (requires 2 cameras).
  - Markers define segments.
  - Segments define anatomic model.
  - Calculate motion from position.

4. KINEMATIC HARDWARE

- Camera/video/marker technology
  - Multiple cameras capturing video at ≥120 Hz.
  - Markers affixed to body.
  - Technical considerations: strobe rate, IR source, lens filtering, interface to anatomy/model fidelity.

5. KINEMATIC INSTRUMENTATION

- Instrumented Patients
  - Sample Video-Based
  - 3D Representation

6. +KINETIC (FORCE) INSTRUMENTATION

- Internal joint reaction forces and moments.
- Use: Newton – Euler equations: F = ma, M = I α
- Include: ground reaction force measurements: Fx, Fy, Fz, Mx, My, Mz
- Solve kinematic (motion) equations.
- Solve kinetic (force and moment) equations.
- Hardware: ground reaction force plates.
MODEL ANALYSIS - HOW THEY WORK

• To calculate the kinematics:
  • Track key anatomical landmarks via reflective markers
  • Calculate joint centers
  • Create model segments
  • Calculate segment orientations
  • Calculate kinematics (motion)

• Limiting factors:
  • Assumptions of skeletal uniformity
  • Reliance on accurate marker placement
  • Effect of obesity or skeletal asymmetry


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MODES OF TECHNOLOGIES CURRENTLY AVAILABLE

- Video photogrammetry – just discussed
  - Absolute location of point markers
- Goniometry
  - Direct measurement of joint motion
  - Easy to use
- Electromagnetic digitizers
  - 6DOF of discrete sensors
- Inertial Measurement Units (IMUs)
  - Linear and angular accelerometry
  - Magnetometry
  - GPS

GONIOMETRY

- Positive
  - Direct measurement of joint motion
  - Easy to use
- Negative
  - Does not measure absolute position/attitude
  - Physical attachment to subject / fixture

ELECTROMAGNETIC DIGITIZERS
ELECTROMAGNETIC DIGITIZERS

- **Positive**
  - 6 DOF for each body segment

- **Negative**
  - Limited workspace
  - Cables (new wireless)
  - Physical attachment to subject
  - Accuracy degraded by speed

INERTIAL MEASUREMENT UNITS

- **Positive**
  - Absolute attitude of body segments
  - Direct measurement of angular velocity
  - Direct measurement of acceleration
  - No marker occlusion
  - Large work space in unstructured environment

- **Negative**
  - Does not provide absolute location, translational velocity or rotational acceleration
  - Calibration is relative to anatomy
  - Soft tissue artifact
  - Data communication
  - < 100 Hz, medium resolution

MEMS IMU – CONSUMER PRODUCTS

- Games (WiiMote)
- PDA (iPhone)
- Camera stabilization

MEMS ACCELEROMETER (PROOF (INERTIAL) MASS)
MEMS ACCELEROMETER

A pair of test masses is driven to resonance. Their displacement from the plane of oscillation is measured to produce a signal related to the system's rate of rotation.

MEMS GYRO (TUNING FORK)

MEMS magnetometer (magnetoresistive)

- Signal
  - Analog voltage (0 to 3V)
  - Fixed frequency, variable duty cycle
  - Digital (internal A/D converter)
- Bandwidth
  - < 150 Hz

MEMS IMU OUTPUTS

- Triaxial accelerometer
  - ±3g, 300 mV/g, 550 Hz
- Triaxial gyro
  - ±300 deg/sec (dps), 3.3mV/dps, 140 Hz
- Triaxial magnetometer
  - 50 Hz
- On-board CPU, serial I/O

MEMS 9DOF IMU

- Minimal change in sensor orientation
- Hand/arm tremor
  - Extended arm, tracing spiral
  - Triaxial accelerometer, >150 Hz
- Postural sway
  - Supracranial accelerometer
  - Lumbar accelerometer

STATIONARY
SIMPLE ATTITUDE
- Body position during sleep
  - Treatment for sleep apnea
  - Triaxial accelerometer, very low sample rate
- Restless Leg Syndrome (RLS)
  - Monitor sudden movement
  - High frequency sample rate
  - Interested in event occurrence, not characterization

SIMPLE MOTION MEASUREMENT
- Planar lifting or reaching
  - Simple articulated model
  - 2D IMU provides position, velocity, acceleration
- Passive manipulation or drop
  - Assess spasticity
  - Compute jerk from acceleration

COORDINATED MOVEMENT
- Basic assessment
  - Triaxial accelerometer, >100 Hz
  - Number of strides, timing
  - Asymmetry of motion
    - Rehabilitation, prosthetic fitting
- Full body motion
  - Thirteen 9DOF IMUs
  - Multiple segment model

COMMERCIAL SYSTEMS
- Xsens MVN
- Biosyn FAB
- NexGen Ergonomics
- Microstrain wireless
- MEMSense
- Sparkfun WiTilt
- Nintendo WiiMote

TOPICAL QUESTIONS
1. How do we quantify physical activity, motion and mobility?
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3. What modes of technology are being researched, developed and close to implementation?

1. PORTABLE, LOW COST MARKER BASED MOTION ANALYSIS
- Cost effective technology – better outreach
- Analysis of tri-axial joint kinematics of various activities including:
  - Gait
  - Wheelchair & assistive device use (shoulder, elbow wrist)
  - ADLs (SHUEE, e.g. eating, drinking, hygiene)
  - Recreation (e.g. run, pitch, swing...)
1. PORTABLE, LOW COST MARKER BASED MOTION ANALYSIS

- Optical Cameras
  - Reflective markers
  - At least 2 cameras must "see" each marker
- Multiple cameras (8-18):
  - More cameras = larger capture volume
  - More cameras = less dropout

2. PORTABLE, LOW COST MARKERLESS SYSTEMS

- Community & Home Environments
- Analysis of tri-axial joint kinematics of various activities including:
  - Activities of Daily Living (SHUEE; e.g., eating, drinking, hygiene)
  - Motion during manual wheelchair use (shoulder, elbow, wrist)

MARKERLESS TECHNOLOGY

- Markerless Assessment System
  - Uses Kinect® sensors and musculoskeletal models
  - Portable, cost-effective solution for home, community, international applications
- Lower cost than marker-based system
- Pediatric Upper Extremity Movement Disorders
  - Activity of Daily Living (ADL) capability / SHUEE
- Pediatric Manual Wheelchair Use
  - Propulsion patterns and efficiency

MARKERLESS W/C EVALUATION SYSTEM

MARKERLESS MODEL FEATURES AND SCALING

- Can use static trial and input anatomical measurements (length of each segment, subject mass)
- OpenSim® scales size of bones, length of muscles, mass of each segment proportionally, and corrects marker locations to fit experimental static trial

3. NEW HORIZONS IN UE ANALYSIS

- Manual wheelchair users
- Assistive Device Users
- 6-DOF transducers
- Low cost marker-based systems
4. PEDIATRIC ROBOTICS
GOALS – PERSONALIZED; ENGAGING; LESS DEVICE; COST EFFECTIVE

A. Voluntary movement training and passive stretching of the lower extremities in children with CP
B. Novel off axis elliptical training for children with CP to reduce pivoting instability, increase isometric strength and balance, and reduce in-toeing
C. Robotic locomotor training with a cable-driven system to increase active involvement and assist pelvic orientation

4A) VOLUNTARY MOVEMENT TRAINING AND PASSIVE STRETCHING OF THE LE IN CHILDREN WITH CEREBRAL PALSY

- A portable rehab robot *
- Various sensors
- Servo motor
- Digital controller
- User interface
- Motivating games
- Configuration
  - Subject seated comfortably with the knee extended

* Intellistretch, Rehabtek LLC, Glenview, IL  60025.

Voluntary Movement Training with Game Play
- Motivates patients to exercise more

- Audiovisual & proprioceptive feedback for motor learning
- Assisted active movement
  - Robot detects movement & provides assistance
- Resisted active movement
  - Higher torque for muscle strengthening

* Intellistretch, Rehabtek LLC, Glenview, IL  60025.

4B) OFF AXIS ELLIPTICAL TRAINING FOR CHILDREN WITH CEREBRAL PALSY TO REDUCE PIVOTING INSTABILITY, INCREASE ISOMETRIC STRENGTH, IMPROVE BALANCE, AND REDUCE IN-TOEING

- Robot-assisted off-axis training with assistance/resistance and quantitative outcome evaluations
- Impaired motor control about the off axes (Internal/external, Mediolateral)
- Visual feedback and game guidance of 3-D motion control

* Intellistretch, Rehabtek LLC, Glenview, IL  60025.

4C) CABLE-DRIVEN LOCOMOTOR TRAINING TO INCREASE ACTIVE INVOLVEMENT WITH PELVIC ASSIST

- Cable-driven robotic system, provides controlled loads to the LE and Pelvis
  - Resistance to knees beginning in early swing
  - Assistance to ankles in late swing
  - LE orientation
  - Pelvic orientation
  - Variable orientation
  - Subject specific at Reduced cost

THANK- YOU!
MAKING USE OF TECHNOLOGY

ACCELEROMETERS/INERTIAL SENSORS

**Advantages**

- Minimal set-up
- Portable
- Allows home & community monitoring

**APDM Opal Sensor**

- Accelerometer, gyroscope, & magnetometer
- Long battery life
- 20-200 Hz sampling rate
- Stream in real time or log data to download later

UE ACTIVITY, INTERLIMB COORDINATION & TELEREHAB

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**Accelerometers/Inertial Sensors**

- APDM Opal Sensor
  - Accelerometer, gyroscope, & magnetometer
  - Long battery life
  - 20-200 Hz sampling rate
  - Stream in real time or log data to download later

**Advantages**

- < 2 years – TD & PBPI
- Accelerometry recorded during Alml Test of Handedness & HAI
- Day-long UE activity in TD infant & infant with PBPI

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FUNDING:

- SECTION ON PEDIATRICS, APTA

**Findings**

INTERLIMB COORDINATION

**Symmetrical**

**Asymmetrical**

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ASSessment of Interlimb Coordination in Children & Adults with Hemiparesis

FUNDING: ACADEMY OF HAND & UE PT, APTA

AMERICAN SOCIETY OF NEUROREHABILITATION

**Set-up Data**
TELEREHABILITATION

- Delivery of rehab services via information & communication technologies
- Access to professionals from home or community via webcam or tele-monitoring
- Assessment, supervision, education, intervention
- Potential parent-run intervention
- May include interactive gaming

http://infanthearing.org/ti-guide/img/privacy.jpg

SAMPLE PROGRAMS

Adults
ReJoyce plus FES
- Prochazka & colleagues
- 1 hr/day, 5x wk & weeks supervision by remote therapists
- Studies: SCI, stroke
- Kowalczewski et al., 2011; SCI improved hand function
- Buick et al., 2016; stroke survivors improved hand & upper limb function

Steve Cramer, MD – Multi-site
- UE videogame telerehab
- Adults post-stroke
- Ongoing, recruiting

GAME-BASED EXERCISE PROGRAM - TONY SZTURM, PT, PHD – UNIVERSITY OF MANITOBA

- Uses an inexpensive, low-tech motion Mouse™
- Easily attached with Velcro to “therapeutic” object
- Highly flexible & personalized

PEDIATRICS

EI for Rural Families
- Cason, 2009; enTECH
- Rehab 1x mo, travel = 400 mi
- Added 2-3x/wk 12 weeks, 2 families
- Benefits
  - More frequent rehab
  - Access to experts
  - Alleviate shortages
- Challenges
  - Room set up for telerehab

Golomb et al., 2010, 2011
- VR videogame telerehab
- Children with HCP
  - Improved hand function, forearm bone health & functional brain changes

THANK-YOU!

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SEGMENTAL ASSESSMENT OF TRUNK CONTROL (SATCO)

TEST REQUIREMENTS

- 10-15 minutes to conduct the test
- 2-3 testers
- Video recording is recommended
- Bench with strap system is recommended

TEST POSITION

- Child is seated on a bench
- Feet on floor or a stool
- Manual support is provided for upright posture
- Head is upright
- Hands and arms down or supported for HC, free for UT
- Strap system for thigh and pelvic alignment
- Additional support is allowed below the level tested
- Child is seated on a bench

THREE ASPECTS OF CONTROL

- Static (steady state) Align and maintain 5 seconds
- Active Hold alignment while turning head or reaching
- Reactive Maintain or quickly return to upright when perturbed

LFT = Learning Full Trunk Control
FTC = Has Full Trunk Control

Testing upper thoracic control
8 year old with CP

1. STATIC
2. ACTIVE
3. REACTIVE

Testing head control
12 year old with CP
Testing upper lumbar control
7 month old typical development

POSTURE TESTING DEVICE

Testing postural responses in 5 month old with typical development

Increase amplitude of postural sway
Compensatory strategies

Segmental Approach

Optimal Vertical Posture
Start with SATCo Level
Firm support below target level
Avoid compensatory strategies
Train Static, Active and Reactive control

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GOAL: IMPROVE GAZE STABILITY

• GAZE STABILITY: Ability to see clearly with head moving, especially greater than 100 deg/sec (limits of pursuit system).

• FUNCTIONAL ACTIVITY: Head movements require vestibular function for clear vision

• REQUIREMENTS: Functioning vestibulo-ocular reflex and oculomotor system.

IMPORTANCE OF CLEAR VISION DURING FUNCTION

• Precursor to motor development to infants who must first fix their eyes and orient their heads/bodies when moving or reaching toward objects of interest (Franchek, 2010; Kretch, 2014)

• CP: poor motor development is linked to delayed ophthalmic development and poor visual focus (Lew, 2015; Fazzi, 2012)

• 1 in 5 children have some form of vestibular related impairment (Li, 2016)

VESTIBULAR REHABILITATION

• Head movement while focusing on a letter or word
  • X1 viewing; X2 viewing; gaze shifting; remembered targets
  • Improvement of gaze stability requires an error signal (i.e. retinal slip)
  • Theories of recovery (Schubert, 2008):
    • Adaptation, Substitution, Habituation
    • Must be done daily, several times per day

• Problems with current treatment technique:
  • BORING
  • Unable to determine if child can see target and not motivating.

TECHNOLOGY

• The DynaComp system is currently being developed at UAB.
  • The technology will utilize a Bluetooth accelerometer and laptop computer.
  • The clinician will be able to select & modify treatment parameters, collect data about success with home program.
  • Games will be motivating and fun!

• OUTCOME MEASURE: DYNAMIC VISUAL ACUITY
  • WILL IT ALSO IMPROVE MOTOR SKILLS?

BACKGROUND

• Ambulatory children with cerebral palsy (CP) have significant limitations in their community-based walking activity and participation (Bjornson, 2007, 2013; Fauconnier, 2009).

• Walking limitations in children with CP has been documented to have a negative influence on their level of participation in daily life (Fauconnier, 2009; Lepage, 1998).

• Daily walking performance measured with accelerometry has been documented to be positively correlated with participation in mobility-based life habits (Bjornson, 2014).

• Community participation to date has been sampled primarily through child or parent reported questionnaires.

What are they really doing? Community Walking Activity in Cerebral Palsy: StepWatch & Global Positioning System (GPS)

Bjornson KT, Hurvitz P, Kerfeld C, Kristie.bjornson@seattlechildrens.org

Funding: SCRI CHBD Stimulus Fund 2013 NIH R21 HD077186

Community Walking Activity in Cerebral Palsy: StepWatch & Global Positioning System (GPS)

Bjornson KT, Hurvitz P, Kerfeld C, Kristie.bjornson@seattlechildrens.org

Funding: SCRI CHBD Stimulus Fund 2013 NIH R21 HD077186
AIMS

• Describe a novel combination of accelerometry-based walking activity and global positioning system (GPS)
• Quantify the walking and community participation of children with CP with/without assistive device at home versus in the community.

PARTICIPANTS

• 6 children with bilateral CP
• Gross Motor Function Classification System Levels I=1, II=3, III=2
• Age range 5.0-11.1 yrs
• 3 girls
• Walking Assistance:
  • 4 independent walkers (IW)
  • 2 assisted walkers (AW)
• StepWatch (SW) accelerometer & GPS
  all waking hours for 7 days.

METHODS: STEPWATCH

• Ambulatory activity was derived from the average of 5 days of StepWatch accelerometry data.
• Walking stride rate is classified as:
  • Low 1-30 strides/min
  • Moderate 31-60 strides/min
  • High > 60 strides/min
(Bjornson, 2014)

METHODS: GLOBAL POSITION DEVICE (GPS)

• Locational data was sampled with the Qstarz BT-Q1000XT GPS data loggers (Taipei, Taiwan).
• Collects instantaneous data at specific intervals:
  • latitude
  • longitude
  • altitude
  • speed
  • distance from previous point
  • precision estimates at configurable intervals
• Both devices worn on the ankle inside a knit cloth cuff.

METHODS: COMBINED SW & GPS

• SW documented total time and bouts walking/day.
  • “Bouts” = blocks of at least 3 minutes walking
  • Grouped if separated by up to two minutes of non-walking.
• Synchronized SW & GPS data:
  • Quantified walking at home or in the community each day
    • distance walked
    • % time
  • # strides at low, medium, high stride rates
  • Maps of location by stride rates of walking activity captures where in the community relative to home the child is walking.

RESULTS

• Time walking each day averaged
• Distance walked
• Of all walking time
• Walking at home
• Walking in community
CONCLUSIONS

- AW < IW - distance and levels of community walking
- Appears sensitive to the expected community mobility levels for IW versus AW.
- Synchronized walking and GPS data has potential to quantify community-based walking activity/participation.
- Mapping of the combined accelerometry & GPS data allows for qualitative analysis of personal and environmental factors.
- Further work is warranted to validate this novel methodology to other measures of mobility-based community participation.

CUSTOMIZED ACTIVE VIDEO GAMES: DOSING INTERVENTIONS TO PROMOTE FITNESS, PHYSICAL ACTIVITY AND FUN IN YOUTH WITH CP

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BACKGROUND

- Ambulatory youth with cerebral palsy (CP)
  - Have limited access to community resources for active recreation (Rimmer et al., 2008)
  - Are faced with barriers to physical activity and fitness opportunities (Verschuren et al., 2012)
  - Are more sedentary than youth with typical development (Innes et al., 2013)
  - Are more deconditioned than youth with typical development (Verschuren et al., 2010; Maltais et al., 2014)
  - Show improved fitness & physical activity after active video game (AVG) sessions (Mitchell, 2012)
AIMS

• Measure PA intensity and level during AVG sessions
• Evaluate youth and parent perspectives of AVG sessions

PARTICIPANTS

• 12 youth with bilateral CP
• GMFCS Levels
  • II= 7 (58%)
  • III= 5 (42%)
• Mean Age: 15.7 years (SD: 3.7 years)
• Boys: 9 (75%)

METHODS

• Youth participated in 3 or 4 AVG sessions
• AVG session: 3 games & 3 conditions
• Game Phases
  • Rest 5 minutes
  • Warm-up 5 minutes 40-60% MHR
  • Exercise 10 minutes 60-80% MHR
  • Cool-down 5 minutes 40-60% MHR
  • Recovery 5 minutes
• Parents and youth completed AVG evaluations

METHODS

• Game Conditions
  • Sit, Stand, Steps
  • Nine themes
  • Icons
    • Hand & feet

SETTING GAME PARAMETERS

Flexible gaming parameters
Saving Player Profiles
Avatar & Calibration Screen
Game data collection
  • Duration
    • Game Time
  • Intensity
    • Wave Speed
  • Performance
    • Scores
    • Waves Completed
METHODS

• Measures
  • Physical Activity Intensity = HR & OMNI RPE
    • HR monitor & RPE (Fragala-Pinkham et al., 2015)
  • Physical Activity Level = Activity Counts (AC)
    • ActiGraph accelerometers (O’Neil et al., 2015)

• Data Analysis
  • Aim 1: Repeated Measures ANOVA (condition x phase) with Tukey post hoc tests
    • Heart rate: 2 X 6
    • Activity counts: 2 X 3
  • Aim 2:
    • Descriptive statistics

RESULTS

Heart Rate (n=12)    Activity Counts (n=8)

CONCLUSIONS

• Considerations for using AVGs to promote fitness and physical activity
  • Intensity (HR)
    • Higher in standing vs. sitting
    • Higher in conditioning & cool-down vs warm-up
  • Level (AC)
    • No difference in standing vs. sitting
    • Higher in conditioning vs warm-up & cool-down
• Considerations for using AVG in PT interventions
  • Youth & parents were positive about AVGs
  • AVGs may help promote adherence to PT in clinics and home exercise programs

THANK YOU!

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CASE #2

15 year old boy
- GMFCS III – bilateral CP (spastic diplegia)
- Sophomore in high school
- s/p surgery – about 2-3 years ago
  - Hamstrings lengthening
  - TAL
- Weight gain & increased sedentary behavior

PT Goals:
- Increase physical activity and fitness (endurance)
- Needs to take 3-5 steps backwards for getting into car and using the bathroom

PT Interventions:
- Strength, Aerobic Training, Physical Activity, Balance & Overall Fitness

PT INTERVENTION STRATEGIES

Intervention
- LE exercises, hip flexion, hip extension, hip abduction, heel/toe raises, squats
  - 1 Weights; 1 Reps; 1 Sets
- Standing balance activities with support (reaching, stepping, balance beam)
  - 1 hand support; unilateral stance
- Sitting balance activities
- Gait training
  - ↑ increase speed; running
- Types of Exercise
  - Weights, Walks, Swimming activities
  - AVGs
- Measures of Daily Physical Activity
  - Accelerometers & GPS

FITNESS PRESCRIPTION: FITTE

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Time</th>
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<tbody>
<tr>
<td>Aerobic Ex: 6-7 d/wk</td>
<td>Aerobic Ex: 30-60 min/session</td>
</tr>
<tr>
<td>Strength Ex: 2-4 d/wk</td>
<td>Strength Ex: 20-30 min/sessions</td>
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Enjoyment

- VIDEO!