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November 2017

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features

From the editor: High-tech care for kids

The brightly colored skateboard-like motorized device for infants looks like it could be the coolest new learning enhancement toy destined to sell out for the winter holidays, but it's an experimental medical device that can sense the motions of infants with cerebral palsy and respond with a powered assist to help them learn to crawl. It's one of the new pediatric medical technologies you can read about in this issue; others include powered exoskeletons and sophisticated virtual reality platforms that can help children with gait impairments improve their walking ability (see "Cutting edge: Treatment for kids goes high tech," page 8).

High-tech devices (wearable sensors) are also highlighted in our feature on tailoring balance interventions to kids' age-related needs (see "Firm foundation: Better balance for young patients," page 15) and in two November *LER* articles ("Assessing runners' gait using wearable sensors," page 43; and "Video overlay feedback helps improve biomechanics of sport-specific landing," page 11).

Yet, for a variety of reasons, pediatric medical technology often lags five to 10 years behind new technology for adults. The market is smaller and research is more complicated, but it's also an engineering problem, with snags arising from the physics of miniaturization and other issues writ small.

And, even with all of the potential and promise of technology for doing things other treatments can't—as well as doing it faster, more precisely, with less weight or bulk, and all the other allures of next-gen science—lower-tech methods and care still have an important role in pediatric care.

For one, they are typically well-tested and understood. Wearable sensors, for example, suffer from technical glitches and a lack of evidence-based validation. Low-tech options also may be more affordable and accessible.

As *LER*'s editor in chief Jordana Bieze Foster notes in her November editorial (see "Low tech, high value," page 9), "Hi-tech may be the way of the future, but low-tech approaches still have a lot to offer."

Emily Delzell, *Senior Editor*

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Wearing textured insoles in walking shoes improves ballet dancers' balance

Benefits accrue despite injury history

By Katie Bell

Textured insoles worn in walking shoes can improve the dynamic postural balance of young ballet dancers both with and without previous injury, according to study data from Canberra, Australia, which also suggested textured insoles can be useful as a routine intervention.

Lead author Nili Steinberg, PhD, associate professor of health at the University of Canberra, Australia, and Wingate College of Physical Education and Sports Sciences, Wingate Institute in Netanya, Israel, said, "Most dancers and dance teachers are continuously trying to discover methods that will improve dynamic postural balance ability, knowing better postural stability may reduce the risk for musculoskeletal injuries."

The 26 dancers (14 girls), who were full-time elite classical ballet students from the Australian Ballet School in Melbourne, were aged 13 to 19 years. Steinberg and colleagues divided them into two groups matched by sex and class level (four levels based on biological age, academic year, and skill/experience); group one wore textured insoles in their walking shoes for at least two hours a day during weeks one to four, and group two wore textured insoles in their walking shoes for the same period during weeks five to eight.

Fourteen dancers sustained an injury (most were to the ankle or foot) in the three months prior to study recruitment; 10 (71.4%) from group one and four (28.6%) from group two. All were fully healed at the study's start, and injury severity was not significantly different between groups.

The synthetic textured insoles featured four nodules, each 3 mm high and 1 mm in diameter, per square centimeter. The material was cut to fit into the dancers' own walking shoes, which included all types of shoes worn outside dance classes.

Researchers tested dancers' dynamic postural balance on the first day of the first week of the study and after four and eight weeks. They also compared at baseline and eight weeks the dynamic postural balance of dancers with a previous injury with that of uninjured dancers.

After measuring dynamic postural balance with an accelerometer during single-leg flexing and extending of the knee (the weightbearing *fondu* test), the researchers measured average acceleration magnitude (AAM), root mean square acceleration (RMSA), range, and mean frequency (MF), with all parameters analyzed for the mediolateral, anterior-posterior, and vertical axes, and the resultant three directions. With all parameters, smaller values suggest better stability.

Both groups had significantly greater dynamic postural balance after four weeks of insole wear compared with baseline. Group one showed an 11%, 12%, and 15% reduction in AAM, RMSA, and range, respectively, which was significant in the mediolateral direction. Meanwhile, group two showed a 10%, 13%, 22%, and 15% reduction in AAM, RMSA, range, and MF, respectively, in the mediolateral direction. A respective 7%, 27%, and 13% reduction in AAM, RMSA, and range in the resultant three directions was evident after wearing the insoles for four weeks compared with baseline in both groups.

> Study data suggest textured insoles can be useful as a routine intervention to improve postural balance.

The findings were published by *Medical Problems of Performing Artists* in June.

"Dancers with previous injury showed decreased postural balance ability [decreased AAM, RMSA and range] at baseline compared to the noninjured dancers [although nonsignificant], yet attained similar or better dynamic postural balance following the use of the textured insoles," Steinberg said. She and her coauthors think the postural balance improvements seen with the insoles were due to increased proprioceptive stimulation.

Jeffrey A. Russell, PhD, AT, FIADMS, assistant professor of athletic training and director of Science and Health in Artistic Performance at Ohio University in Athens, said, "Sources of increased tactile sensation, such as textured insoles, are thought to put an individual's proprioceptive system on 'alert,' thereby making proprioception more responsive in the event of an injury." (See "Using subsensory noise to improve balance, gait," *LER*, May 2016, page 37, and "Sensory-enhancing insoles improve agility performance in recreational athletes," *LER*, March 2017, page 15.)

Study participant demonstrating the dynamic weight-bearing *fondu* test. (Picture from Steinberg et al. *MPPA*, 2017; with permission.)

Steinburg and colleagues' study looked only at elite dancers, and she noted Rein et al in a 2011 *Clinical Neurophysiology* study compared postural control and ankle position sense of professional ballet dancers with those of amateur dancers and controls, finding professional dancers had better postural balance control at all standing positions.

Russell said less experienced dancers would likely see greater improvement with textured insoles because their less developed proprioceptive systems should respond more than those of more advanced dancers.

He suggested further study, and asked: "Is there twice the benefit when you wear [textured insoles] twice as long? Highly doubtful. What is the threshold of wearing time above which no further benefit is seen? Would the results be better if dancers wore the insoles during dance instead of just in their casual shoes for a couple of hours a day? You can see there are still many questions, and this is the mark of a good research project: it creates more new research questions than it answers."

Katie Bell is a freelance writer based in New York City.

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Preteen tennis players prefer roomier footwear than adults

Widest shoes rated most comfortable

By Hank Black

Young male tennis players prefer a wider shoe with more interior volume, while upper stiffness matters less, according to a new study from France that correlated the players' perceptions of comfort with measurements taken with innovative textile pressure sensors.

"We found children who play tennis prefer roomier tennis shoes than adults," said lead author Alexis Herbaut, PhD, a research engineer for Decathlon, a sportswear company based in Villeneuve d'Ascq, who in 2016 investigated optimal inner shoe volume in adult tennis players.

All 16 of the current study participants (all boys, aged 8-12 years) were asked to don prototypes of six commercially available tennis shoes of a style familiar to them. The shoes had narrow, medium, or wide lasts with either a stiff or soft upper construction as determined by a dynamometer-based traction test. All shoes were 10 mm longer than participants' mean foot lengths.

The researchers' 2016 study had identified the narrow last as having optimal (most preferred) inner shoe volume for adults; the medium last differed only in having a 7-mm larger metatarsal girth. The wide last was 14 mm larger at that point, 4 mm wider at the metatarsals, and 4 mm wider at the heel than the narrow last.

Researchers measured participants' foot dimensions in a half-body weightbearing state with a digital caliper and tape measure, the scenario they thought most representative of children's real-world tennis shoe fitting experience.

The tennis players donned a sock with eight interwoven pressure sensors and stood still while the devices recorded pressure from lateral and medial surfaces at fore-, mid-, and rearfoot locations as well as two dorsal surface positions. To evaluate comfort, players tied their shoes as they normally would for tennis, and researchers recorded static pressure measurements for the six shoes, asking participants about comfort at each sensor location.

The widest shoes produced the lowest pressure on the external side of the first and fifth metatarsal heads, the medial midfoot, and the medial and lateral heel; players perceived them as the most comfortable shoes at the top of third metatarsal head and external side of the fifth metatarsal head, fifth metatarsal base, and the medial and lateral heel. *Applied Ergonomics* epublished the study in July.

"Child tennis players perceived the shoe with the wide last as more comfortable than those made with thin and medium lasts, both globally and for most sensor locations," Herbaut said. Asked whether results might differ in girls, he said he thought not, noting, "The children were mostly preadolescents, when boys' and girls' feet have the same proportion. It is only later that men have a wider foot. A question that remains is: Do girls have the same [perceptions of comfort] as boys?"

The relative stiffness of the upper had little effect on comfort, with no effects found except at the top of the third metatarsal head, where the soft upper was perceived as more comfortable; pressure in this location, however, wasn't significantly higher in the stiffer shoes. Herbaut noted, "Tennis requires more frequent braking and displacements than most other sports, but pediatric displacements are less intense than adults' and require less work from the shoe upper to prevent the foot from moving around inside."

> "For kids, there must be a compromise between too much and not enough space."
> —Alexis Herbaut, PhD

Herbaut said designing tennis shoes for children is challenging. "Adult and child shoes are proportionally different, with the child's wider in relation to length," he said. "And pediatric feet are still growing, more than two sizes a year at certain ages, so for kids, there must be a compromise between too much and not enough space."

He has observed parents buying shoes for their kids and noted, "They often buy ones big enough for the child to 'grow into,' but they usually only put their thumb on the toe to check shoe length, and ignore shoe width."

The textile sensors were crucial for his study, Herbaut said, and could open new research opportunities. "Since they are woven into the sock, with tiny wires that extend only to the top of the sock, they stay in position. In addition, they are not apparent to the wearer as compared with stick-on sensors." (See, "Cutting edge: Treatment for kids goes high tech," page 8.)

That worked well for static measurements, but a later unpublished trial attempting dynamic measurements was partially stymied because of textile stretching. "We await advanced sensors for that step," he said.

Neeru Jayanthi, MD, associate professor of orthopedics and family medicine at Emory Sports Medicine Center in Atlanta, GA, commented: "While this is a relatively small study, it does bring up an important point regarding decisions about footwear in young tennis players. Decisions should not be solely based on their potential for foot growth but also should include consideration of individual foot type, including width."

Jayanthi, who is president of the La Grange Park, IL-based Society for Tennis Medicine and Science, said this is important to youth tennis players, especially those playing competitively, because they spend a lot of time on their forefoot.

He said, "That subjects them to more forefoot overload than most sports. Paying attention to the forefoot component, where more pressure is typically found, would be an important consideration when choosing shoe type in a growing child."

Hank Black is freelance medical writer in Birmingham, AL.

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Cutting edge: Treatment for kids goes high tech

From a skateboard-like motion-sensing device that helps infants with CP learn to crawl to powered exoskeletons that sync with muscles to new advanced-imaging views of motor and sensory processing, technology for pediatric care is on the move. Here are some of the highlights.

By Hank Black

Research for conditions of childhood has always trailed that for adults. The pediatric market is smaller, and the money available for medical devices and other technologies is commensurate. And, once an adult product such as a robotic prosthetic foot is on the market, downsizing it to child-size may be stymied by the limits of physics of miniaturization or materials.

The National Institutes of Health (NIH) is working on ways to better include children in studies, according to Alison Cernich, PhD, ABPP-Cn, director of the National Center for Medical Rehabilitation Research at the Eunice Kennedy Shriver National Institute for Child Health and Human Development (NICHD) in Bethesda, MD.

The agency held a workshop on pediatric devices in 2016, but proposals from manufacturers and scientists have lagged. "We need more interest in children's devices and other research," she said.

NICHD-initiated projects designed to encourage greater mobility in toddlers and even infants have achieved at least partial success due to either technical advances or to modification or aggregation of existing technologies.

Here, we review some experimental and commercially available technologies, including devices and procedures, that hold promise for improving lower extremity care in children.

Learning to crawl

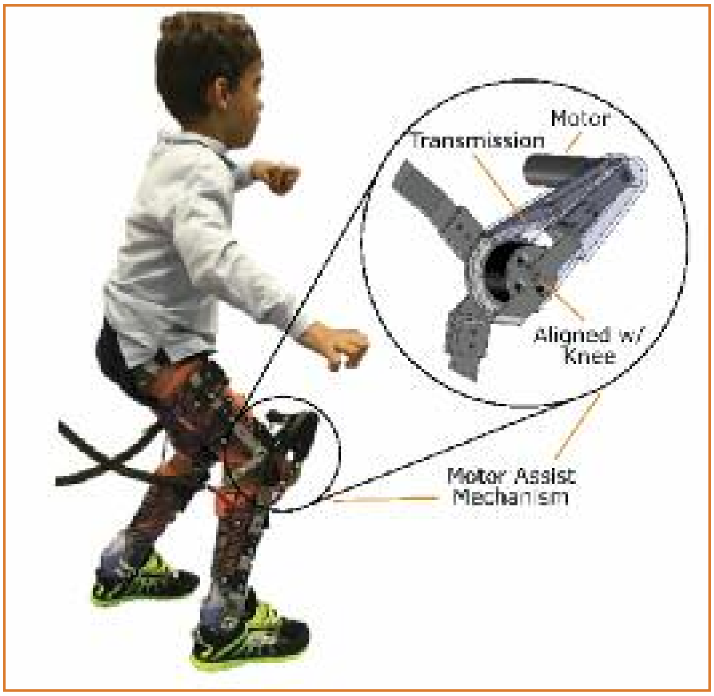
Thubi Kolobe, PhD, PT, FAPTA, professor and director of research in the Department of Rehabilitation Sciences at the University of Oklahoma Health Sciences Center in Oklahoma City, designed a simple skateboard-like high-tech device to help infants with cerebral palsy (CP) learn to crawl and explore.

"These infants can kick but don't generate force to push off on their legs and arms to move forward, so when they do try they need to be assisted and rewarded," she said. "We wanted to use technology to harness their spontaneous movement and reward it, while at the same time take away some of the infants' difficulty in lifting the body while allowing them to continually move."

NIH scientists are studying this powered KAFO exoskeleton for treatment of crouch gait in children with CP. (Photo courtesy of Thomas Bulea, PhD, and the NIH Clinical Center, Bethesda, MD.)

Kolobe's team developed the first algorithms for how babies crawl, leading to the creation of a platform with motorized wheels and a computer underneath connected to sensors threaded into a kinematic suit, a "onesie," worn to detect and record any effort to move.[1] They call it the Self-Initiated Prone Progression Crawler (SIPPC). With babies on their bellies strapped to the board, a computer senses any subtle cues when the baby moves, and immediately the wheels augment the effort.

One version of the SIPPC (pronounced sip-see), prompts movement from the force babies generate on the ground with their hands



NIH PI Thomas Bulea, PhD, thinks the exoskeleton technology might be extended beyond knee extension deficiencies to weakness-based pathologies, such as muscular dystrophy. (Photo courtesy of Thomas Bulea, PhD, and the NIH Clinical Center, Bethesda, MD.)

or feet, but the device can also be activated by movement of their limbs in space, without touching the floor, she said.

In the latest iteration, the team added electroencephalogram (EEG) electrodes (embedded in a cap) to capture critical information about how the device may aid learning and development and how a damaged brain might show changes associated with using the SIPPC.

Next step: to miniaturize the SIPPC, making it portable and controllable with a simple computer tablet for home use.

Virtual reality, exergaming, robotics

Robotic-assisted gait training (RAGT) was introduced years ago in hopes of providing children with CP and other movement disorders increased therapeutic time and intensity,[2] as well as task-specific and goal-oriented programs that improve outcomes.[3] Yet RAGT, with exceptions, has not proved clearly effective.[4,5]

Now researchers are adding virtual reality (VR) platforms combined with simple exercise-based video games (exergaming) in an attempt to keep children engaged while providing repetition, feedback, and motivation.[6,7] VR, beginning with rehabilitation programs,[8] spurred the explosion in simulation centers for medical training, and shows promise of becoming a key adjunct to traditional physical therapy interventions for pediatric and other populations.

Italian bioengineer Emilia Biffi, PhD, researcher at the Eugenio Medea Institute in Bosiso Parini, is one of few researchers involving children in an immersive VR platform to determine its efficacy for improving walking pattern in kids with acquired brain injury (ABI) and cerebral palsy (CP).

Her institute uses an integrated platform with a dual-belt treadmill, 2° of freedom motion frames, force plates, multiple video cameras, and a motion capture system. Synchronized VR environments are projected on a 180° cylindrical projection screen. Data are collected and processed in real time. The system is controlled by proprietary software that synchronizes all aspects, including the relationship between the subject, the scenario, and interactive feedbacks and stimulations.

The initial protocol of 10 30-minute sessions, four times weekly for three weeks for children with ABI, improved their walking abilities and enhanced their engagement during the training. The children experienced significant improvements in gross motor abilities (especially standing and walking), endurance, autonomy in daily life activities, and spatiotemporal parameters and knee joint range of motion, which moved toward normality and symmetry recovery. Participants also had a significant decrease of the Gillette Gait Index for the impaired side and a general increase of symmetry.[9]

Ongoing for Biffi and colleagues is a 20-session trial of children with ABI with a longer protocol that she said seems to be producing even greater improvements, including significant increases in walking speed, maximum power at the ankle during flexion-extension, and knee flexion at initial contact.

Exoskeletons

Thomas C. Bulea, PhD, was principal investigator for a study of a powered exoskeleton, a type of knee ankle foot orthosis (KAFO), that found the device feasible for treatment of crouch gait in children with CP.[10] Bulea is a staff scientist in the rehabilitation medicine department at the NIH Clinical Center in Bethesda, MD.

"This is a new way of providing these kids with more intense and higher doses of physical therapy," Bulea said. "With it, children safely change posture while walking. We won't drive the whole walking motion, but give bursts of assistance at specific points in the walking cycle."

The study found children's muscle activity worked in tandem with the exoskeleton. Bulea thinks the technology might be extended beyond knee extension deficiencies to weakness-based pathologies, such as muscular dystrophy.

Bulea and colleagues recently developed a new rehab paradigm for the pediatric CP population that joins the novel exoskeleton and exercise video gaming system with EEG. The user gains points in the game by successfully completing appropriately timed and sized knee flexion or extension motions to hit the targets. Results showed children maintained or significantly increased knee extensor muscle activity during knee extension with synergistic robotic assistance compared with baseline, and EEG data showed kids were consistently engaged.[11]

Coming up, said Bulea, are projects to evaluate the exoskeleton in the home setting.

Others are exploring pediatric uses for robotic exoskeletons: Patane et al, for example, designed a different untethered powered KAFO to assist drop foot in children with CP with software that allows adjustable stiffness. In preclinical testing, the device provided effective torque assistance to knee and ankle joints corresponding to volitional movements.[12]

Brain imaging

Researchers such as Diane L. Damiano, PT, PhD, are finding ways to understand the basis for movement issues by peering into the brain. She is chief of the Bethesda, MD-based NIH Clinical Center's functional and applied biomechanics section. "Magnetic resonance imaging [MRI] usually is too confining and noisy for this [pediatric] population, but with EEG and near-infrared spectroscopy [nIRS] we can see neural mechanisms behind their incoordination during a wide range of motor tasks here in our lab," Damiano said.[13]

One finding: In typically developing controls, a movement of a lower limb is usually localized to one side and area of the brain, but in

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When babies using the SIPPC reach for an engaging toy, the device's wheels give a motorized assist to encourage them to move around in their environment. (Photo courtesy of the Human Development Laboratory, Department of Rehabilitation Sciences, at the University of Oklahoma Health Sciences Center.)

children with CP, brain activity occurs more widely. "They often use many more muscles than a normal person would for a task, and we found the more effort used, the more generalized the neural activity was," she said.

Many children moving one leg may also move the other at the same time, which in bilateral CP is likely related to increased connections across the two sides of the brain. However, functional MRI studies found a reduction in the excessive neural connections in this population after training with an elliptical exercise device for several months.[14] "We're starting to relate motor changes to brain changes, showing we can alter the neural pathways," she said.

Magnetoencephalography (MEG) is a functional neuroimaging technique for mapping brain activity, measuring magnetic fields around active brain areas. Available in fewer than 50 US institutions, MEG is used primarily to confirm seizure location prior to epilepsy surgery, according to Max Kurz, PhD. But he uses it to evaluate motor and sensory processing in kids with early brain damage, such as with CP.[15]

Kurz is associate professor at University of Nebraska Medical Center's Munroe-Meyer Institute Sensorimotor Learning Laboratory in Omaha.

"With this technology, we can see what is happening in the brain as the child is planning a movement, and even before executing it," Kurz said.

"Children sit in a chair with their head in a helmet-type device where sensors are located. We provide a puff of air on the bottom of a foot. The robustness of the response in the brain is tightly related to the child's mobility and the motor errors they have in movement."

Kurz also uses MEG to evaluate therapeutic outcomes and how the brain changes and improves its sensory processing with gait training therapy. He said MEG improves researchers' ability to measure somatosensory processing and the motor actions the children perform, as well as to understand the location of brain deficiencies to build effective individualized treatment programs.

Wearable sensor technology

The number-one fitness trend, based on a 2016 American College of Sports Medicine survey,[16] is the use of noninvasive wearable sensor technology, or inertial measurement units (IMUs). Not even on the survey a year earlier, "wearables" monitor personal health metrics, help to improve movement performance, and assist in health recovery and rehabilitation. Spurring the field are miniaturized sensor technology, wireless transfer, web-based storage of individual data, and longer-lived batteries.[17] (See, "Assessing runners' gait using wearable sensors," *LER*, November 2017, page 43.)

This field exploded so quickly that most commercially available sensor devices haven't been scientifically evaluated and face such problems as movement artifacts and inadequate sampling frequency. Once scientific and ethical objections to reliance on in-house validation studies and exaggerated marketing claims are resolved, the technology promises to become a central tool in the fitness and health industries.[18]

Sensor-based systems can collect, analyze, and store data and compare it to normative values.[19]

Most commercially available sensor devices haven't been scientifically evaluated and face such problems as movement artifacts and inadequate sampling frequency.

In his initial work with wearables, Michael S. Orendurff, PhD, director of the Motion and Sports Performance Laboratory at Stanford Children's Health, Palo Alto, CA, used a simple physical activity monitoring device that revealed people, including children, usually walk in very short bursts.[20,21] "Forty percent of steps [for both children and adults] were twelve in a row or less," he said. "We don't spend much time looking at that paradigm in the gait lab or rehab, but advanced, body-worn sensors can let us see gait and other patterns in the real world."

Wearable GPS sensors could determine how active children with decreased mobility could be on a playground, he said. "Now we're using wearable sensors, including a GPS operating ten times a second, 3D accelerometer, 3D gyroscope [to measure angular velocity and foot and leg angle], and 3D magnetometer [to estimate changes in body orientation]," Orendurff said. Those multifaceted sensors can cost up to $5000 each, compared with GPS-only sensors that cost $300 each.

In the athletic performance arena, such sensors may track a young athlete's training load to determine overtraining that may lead to a lower limb stress fracture, he said.

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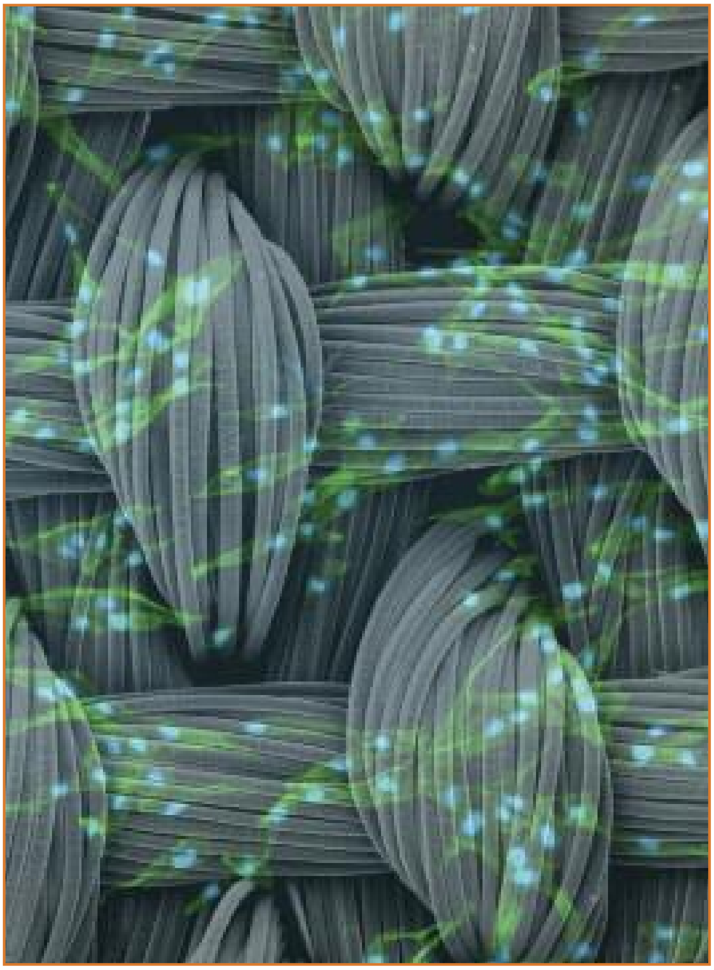

Stem cells (green) seeded on a 3D-woven biomaterial scaffold. (Image courtesy of the Guilak Laboratory and Cytex Therapeutics.)

He's also using them to look at rehabilitation outcomes from orthopedic injuries. "When children with an ACL [anterior cruciate ligament] repair are cleared to return to running, we put [wired] sensors on in the gait lab and take careful data to make sure the forces in moments coincide with their developmental level. We then take them to the field to monitor them with wearable sensors as they come up to their expected fitness level."

Most commercially available fitness-tracking devices are designed for adults, as Fiona Mitchell, PhD, MSc, lecturer in the School of Psychological Sciences and Health at the University of Strathclyde, in Glasgow, Scotland, found in a recent behavioral intervention involving a self-monitor and aimed at increasing physical activity in youths aged 7 to 16 years with type 1 diabetes.[22,23]

Mitchell said the wrist self-monitors, which the study found a critical component in increasing physical activity, were too large, causing devices to malfunction and participant and parent distress. She called for more devices designed specifically for children.

Another ACSM-presented study showed how the addition of magnetic inertial measurement units (MIMUs) to the wearables toolbox provides a global reference frame outside the laboratory to examine, for example, how a lower extremity is oriented through space in movement.

Author Jasper Reenalda, PhD, MSc, lecturer and senior researcher at the University of Twente in Enschede in the Netherlands, said MIMUs compared well with lab-based vertical GRF measurements during running.[24]

A living artificial hip joint grown from human fat stem cells seeded on a 3D-woven biomaterial scaffold. (Image courtesy of the Guilak Laboratory and Cytex Therapeutics.)

"This technology opens up new possibilities for kinematic studies outside the motion analysis lab," Reenalda said. The study was done in adults, but his team has started using the technology for a study of gait analysis in children with CP.

He sees an advantage of using varieties of MIMUs for the kids because set-up is quick and provides reliable 3D kinematics in only a few minutes. "Commercial devices are often optimized for a general adult population, and sensors may require specific algorithms and software for children," he said.

Cherilyn Cecchini, MD, a pediatrician in Washington, DC, advises a manufacturer in clinical trials of sensors and smartphone apps to enable parents and practitioners to monitor and track child health.

"Sensors and applications can provide a wealth of data and insight, but they are not actionable until inputs and algorithms meet standards of evidence-based care," she said. She sees benefits for the lower extremities in children, such as monitoring capillary refill, blood flow or vascularity, and, eventually, the activity of bone-building cells in children with conditions like juvenile osteoporosis. Needed now: sensors for children to replace painful electromyography, Cecchini said.

Regenerative medicine

Plasma-rich protein and concentrated bone marrow aspirate are among orthobiologic treatments for improving the body's healing response.[25] The use of orthobiologics in children has involved spinal surgery, tibial pseudoarthrosis, and benign bone lesions.[26] But, for the same purpose, Farshid Guilak, PhD, in preclinical trials, produces bioengineered cartilage by removing a patient's cells, altering and programming them with new gene-editing technology, then reinserting the tissue.

"We hope we can use this method both for genetic disorders, such as hip dysplasia, or for traumatic injuries to the cartilage and joints, for which there are few viable treatment options, for children in particular," said Guilak, professor of orthopedic surgery and codirector of the Center of Regenerative Medicine at Washington University as well as director of research for Shriners Hospital, both in St. Louis, MO.

The entities are building what Guilak said will be the nation's largest musculoskeletal research laboratory.

Guilak said the technology he's studying benefits from 3D weaving, an advanced method of making cell scaffolding with a polycaprolactone polymer. "Instead of layering materials on each other, we are using interwoven fibers to produce porous, long-lasting structures, inside of which cells can grow," he said.

The living tissue will stretch and grow with the joint, making it a potential option for children who have arthritis or failing joints early in life. "This makes it a potential game-changer for young patients," he said.

Design of a pivotal preclinical study is ahead. If approved for human trials, Guilak stressed, long-term studies must determine the effectiveness of bioengineered tissue replacements.

"Currently, we are also trying to rewire cells and program them to respond to environmental stimuli such as inflammation by producing a drug to fight it [controlled release of anti-inflammatory biologics]," Guilak said. "When the inflammation resolves, the cell will stop making the drug, avoiding the risk of high, continuous doses of medication." The programmed cells can be turned on and off with an exogenous drug.

Overcoming limits

If regenerative medicine, on the shoulders of gene-editing technology, is positioned for major advances, physical limitations hold back processes necessary to accommodate children with disabling lower extremity conditions, according to engineers interviewed by *LER: Pediatrics*.

Adam Arabian, PhD, PE, associate professor of mechanical engineering at Seattle Pacific University in Washington, tried to develop a child-sized adaptive hydraulic ankle foot prosthesis as principal investigator of the federally funded Advanced Biofidelic Lower Extremity Kids (ABLE Kids) program. He said researchers keep bumping up against "the hairy edge of physics" in their effort to miniaturize systems smart enough to accommodate children's needs as their bodies develop.

"We invented and patented a new approach for a smaller valve but still found it needs another twenty-percent reduction," he said. "And, in hydraulics, we found fluids moving at really high speeds through tiny lines stop behaving in the ways we thought they would."

David Boone, BSPO, MPH, PhD, chief executive officer of Orthocare Innovations in Edmonds, WA, found durability a problem with the ABLE Kids prosthesis, as well as the inability to effectively seal the joint against dust and moisture.

Boone sees promising developments in pediatric O&P that include: using microprocessors for controlling hydraulic systems[27] because of their power and quietness versus electrical systems; development of energy capture-and-reuse systems;[28] increased use of recently cheaper titanium;[29] and use of hydraulic actuators to control more energy.[27]

"The significant thing is being smart about using little bits of energy at the appropriate moment so we don't have to build for full, continuous use," he said.

Regardless of the obstacles to helping children with lower extremity conditions, Arabian is not discouraged: "We have most of the basic technology, we're just waiting for developments to enable us to go the last mile." Insights might come, he said, from any industry, and perhaps incrementally rather than in a flash. (ler)

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References are available at lerpediatrics.com.

After treatment with orthotic and physical therapy interventions, Emma Grace Hall, whose balance is impaired by idiopathic ataxia, no longer needs assistive devices to walk. (Photo courtesy of Morgan Hall.)

Firm foundation: Better balance for young patients

Children with neurological conditions often have balance issues, and healthy kids can struggle, too. Interventions should be tailored to their short attention spans and need for feedback, and include devices that improve alignment and stability and training to enhance strength and equilibrium.

By P.K. Daniel

Balance is a key component for athletes, whether it's a beginning gymnast trying to stick the landing on her dismount or a National Football League player tip-toeing down the sideline and into the end zone. Static and dynamic balance, or postural control, is established through a complex multisensorial task based on vestibular, visual, and somatosensory information.

Some researchers and practitioners stress that the ability to neutralize forces that would otherwise disturb equilibrium is a skill that can be developed in healthy adults, youth athletes, and even in children with neuromuscular conditions. In fact, some treatment strategies commonly used to improve balance in children with neuromuscular diseases—including strengthening, balance training, and orthotic devices—also have value for managing balance issues in healthy kids.

"In my opinion, only no training at all is worse than any training," said Michael Wälchli, MSc, a PhD student at the University of Fribourg in Switzerland and lead author of a recent study published in *Pediatric Exercise Science* on age and balance training.[1]

> "In neurological and typically developing populations, kids aren't just little adults. There are developmental considerations to understand in both sensory and motor contributions to balance." —Joseph Krzak, PT, PhD, PCS

Kid-friendly balance work

Some research suggests balance interventions designed for adults may not be effective in children, especially younger children. A 2011 study from a different Swiss research group found conventional balance training in young children (mean age 6.6 years) was not associated with significant improvements in postural sway, plantar flexor force, or jump height.[2]

With this in mind, making balance-related interventions more kid-friendly was an area of emphasis for Wälchli and colleagues.

"I believe training [for children] should be variable and challenging in the sense that the children get motivated by the training content itself," he said. "In contrast to adults [who can motivate themselves by thinking about the outcome], children are only executing things which are exciting to them at this distinct moment."

The goal of Wälchli's study was to test whether postural control

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can be improved with child-oriented balance training in children as young as 6 years and to compare their training-induced adaptations with those of older children and adolescents.

In the five-week study, 77 participants (38 girls) were assigned to twice-weekly balance training during their physical education classes (n = 48) or to a control group that did no training other than their usual physical education classes. Between-group differences were assessed for three age groups (6-7, 11-12, and 14-15 years).

The intervention was associated with decreased dynamic postural sway, particularly in the youngest group, and increased explosive plantar flexor strength. The degree of difficulty for exercises and activities was frequently modified and adapted to avoid monotonous repetitions.

"The intervention for children should be more holistic and playful than for adults," said Wälchli. "One important point is that the difficulty level should be adapted to the abilities of the participant."

The decision to use static or dynamic balance-oriented interventions, he said, depends on the situation and the goal.

"Balance exercises seem to be very specific," he said. "The main principle should be to train in the exercise in which you want to get better. So, if you want to improve static balance, it is recommended to train exactly this task. However, if your aim is to improve your 'general' balance abilities, I believe that the training should be as variable as possible."

He said the main objective is to develop an interesting training program.

"A multimodal protocol offers far more possibilities to change and vary the content," he said. "[But], if the main purpose is to improve balance, then balance training should be assessed to provoke the largest improvements possible in postural control."

Even high-functioning youth athletes can have vestibular or proprioceptive limitations.[3-5] Robbie Bowers, ATC, a certified athletic trainer at Rancho Bernardo High School in San Diego, attributes some injuries to underdeveloped neurological pathways, which can manifest in balance deficits.

"You wonder how much better an athlete this person could be if they performed with these systems functioning," Bowers said. "Your feet and lower extremities are like another set of eyes. If they're not communicating—or communicating well—with your central nervous system, you're not going to function as well. It helps you understand why some have had repeat injuries."

When using interventions to address balance deficits with youth athletes, Bowers goes back to basics. He strips away extraneous stimuli, such as opponents and moving objects. Sometimes he gets pushback from varsity athletes, and has been asked: "Why are you making me stand on one leg like a stork?"

Bowers explains to his student-athletes that just going through the motions isn't going to get them back into the game. He places them on wobble boards and requires their attention.

"You have to make that neuro-connection first," he said. "I have them think about their bodies' position in space. I want them to feel with their brain, I want them to see with their brain."

Neurological conditions and balance

Given the prevalence of balance issues in healthy children and youth athletes, it may not be surprising postural control issues also affect kids with neurological conditions, and that balance-related therapies in those populations can be equally challenging.[6-11]

Emma Grace Hall was on the verge of walking. But three days before her first birthday, while navigating a push-toy, she fell—hard and headfirst into a kitchen table leg. Nothing had tripped her up. Nobody ran into her. She just lost her balance.

"The fall really opened our eyes as to what was going on with her," said her mother, Morgan Hall, who is director of public relations at Shriners Hospitals for Children Medical Center in Lexington, KY.

Emma Grace has ataxia—a neurological disorder caused by damage, degeneration, or loss of cerebellar nerve cells that affects muscle control or coordination of voluntary movements.[1]

In addition to affecting one's balance, ataxia can create difficulties with speech, eye movement, and swallowing. Ataxia is the symptom, meaning there is an underlying condition. Brain degeneration, multiple sclerosis, inherited defective genes, and other factors can cause the condition,[1,2] but in Emma Grace's case, its cause is unknown.

Experts say interventions, such as adaptive devices, can help improve children's balance. Orthotic devices can be helpful if a child has significant weakness, low muscle tone, or spasticity that alters foot and lower extremity positioning and affects balance and stability. Emma Grace, who turned 4 in September, was fitted for orthotic devices at age 14 months, moving on to a walker when she was aged 18 to 26 months.

"Braces are often provided as an external support for joints/body segments that a child cannot control," said Joseph J. Krzak, PT, PhD, PCS, a senior physical therapist at the Motion Analysis Center (MAC) at Shriners Hospitals for Children—Chicago. Krzak, an assistant professor of physical therapy at Midwestern University in Downers Grove, IL, has extensive clinical experience managing balance deficits in children with neuromuscular and musculoskeletal disorders.

Raven Smalls, PT, DPT, who works in the rehab department and in the motion analysis lab at Greenville Shriners Hospital in South Carolina, agreed orthotic devices can provide additional support to the ankle, knee, hip, and trunk, and help improve body alignment so children with neuromuscular disorders can feel more stable standing, walking, running, jumping, and performing typical activities.

"However, it is also important to address all of the components that may be affecting a child's ability to stay upright, which may include strength, muscle flexibility and range of motion, motor control, motor planning, and body and safety awareness," Smalls said. "For example, if one doesn't have the strength required to stand and perform functional tasks, or if [they can't] scan their environment for obstacles, this can lead to tripping or falling. Additionally, it's important to address the different aspects of the balance system, including vision, proprioception, and the vestibular system, while assessing a child's balance and creating a treatment plan."

Krzak echoed Smalls' assertion that there are additional considerations when managing balance issues in this population.

"The sensory information from the environment [visual, sense of body location, and inner ear function] allows us to know where we are in space," he said. "The motor response allows us to move where we want to move [whether from point A to point B or remaining still during an unexpected balance perturbation]. As clinicians and researchers, we need to understand the contributions of both sensory and motor impairments to balance issues, identify exactly where the deficiency occurs, and consider all components of balance when recommending specific interventions."

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Krzak emphasized that, in neurological populations as in typically developing populations, children are not just little adults. “There are developmental considerations when understanding both sensory and motor contributions to balance,” he said.

On Emma Grace’s first visit to Shriners, clinicians told her mother to prepare for the high probability her child might never walk. Treatment plans usually include physical, occupational, and speech therapies. Emma Grace receives all three. She started physical therapy (PT) and occupational therapy (OT) at Shriners three days a week at age 15 months. One day was dedicated to PT, another for OT, and a third for a combination of the two. She improved so much that when she was about two and a half, her visits were reduced to one day of PT and one of OT. And she no longer requires an assistive device for walking. Emma can also run—or at least her definition of running, which is shaky with some side-to-side movement and occasional toe dragging, according to her mom.

Hall attributes Emma Grace’s progress to the various interventions she has received. Although Emma Grace’s balance deficits still prevent her from standing on one leg or riding a bike, therapists work with her on these skills every week. The types of intervention, however, that are used for Emma Grace and other children need to be adapted to the patients’ unique learning needs.

Emphasizing play

“Interventions should be presented as play activities,” said Margaret Damron, DPT, who is Emma Grace’s physical therapist. “Kids play and like games, so a PT should plan activities to address specific areas [strength, balance, endurance] but present them as a game or an art activity or use characters/items the child enjoys.”

Damron said kids’ PT sessions should include many more activities than a traditional adult PT session because of children’s decreased attention span. An emphasis on manual cues and demonstration is also important with children because they haven’t established their best means of learning, so multiple inputs and approaches should be used, she said. These can include repeated demonstration, hand-over-hand assistance, and verbal cues.

“Children with balance issues may also demonstrate issues with motor planning and have increased difficulty learning and completing multiple-step activities,” Damron said. “Interventions should also be altered to be attainable because success increases confidence, motivation, and willingness to participate with the PT.”

Smalls noted impairments or delays in speech and cognition can be barriers to teaching, instructing, and learning.

“Even young children without cognitive delays lack the maturity and intellect to understand important concepts used in therapy,” she said. “Children may need to perform activities that make them feel off balance, or feel like they are falling, to work on the skills needed to regain their balance. However, this can be very scary to some children … Having a creative mind is very important when working in pediatrics to find ways to bypass these barriers.”

Like Damron, Smalls incorporates play into treatments for children.

“Playing is a major part of their daily activities and function,” she said. “Therefore, incorporating games, toys, and enjoyable engaging activities into their therapy sessions can help motivate children and help them to focus on the task at hand because, while they are having fun, they may not realize they are performing challenging tasks targeted at improving their balance.”

Krzak was a coauthor of a pilot experiment that included 17 children with cerebral palsy (CP) and 68 typically developing children ranging in age from 6 to 16 years.[13] The researchers included 10 typically developing children as controls and five children with diplegic CP, gross motor function classification system level II. The average age participants was 8 years in CP group (range, 6-12 years), and 12 years in the control group (range, 7-16 years).

The balance of children with CP was assessed while they were barefoot and wearing braces and standing on a force platform that unexpectedly rotated five times in a toes-up direction. The braces were bilateral plastic articulated ankle foot orthoses (AFOs). All braces were constructed with a tibial shaft length 3 cm distal to the fibular head, a rubber ankle joint allowing for free dorsiflexion with a 0° plantar flexion stop, a flexible toe break, and strapping of the tibia and over the talus to maintain the position of the hindfoot and forefoot relative to the foot plate.

When barefoot, the children with CP lost their balance after each perturbation. When braced, none fell, and their response to the perturbation improved across the five trials.

“Such findings demonstrate that once children with cerebral palsy were biomechanically aligned [and stabilized by the brace], they were able to learn from each trial and improve their strategy after each subsequent trial,” he said.

Krzak uses technology to give kids the feedback they crave when learning a new motor task.

“With the development of newer technology and gaming systems, children can be provided with real-time augmentative visual feedback characterizing their motor responses during balance training activities/treatment,” he said. “Such systems are often game-based, which provides motivation for the child to stay engaged and attentive. We’re able to quantitatively evaluate these children to get a better understanding of their sensory as well as motor contributions to balance.”

One of Krzak’s patients was a boy, aged 13 years, who presented with idiopathic toe walking. He underwent surgery, including bilateral Achilles tendon lengthening and plantar fascia release, to help lower his heels during gait. As a result, he had trouble balancing. Practitioners used computerized dynamic posturography to evaluate the sensory and motor components affecting his balance, giving the patient real-time visual feedback on how he moved in space.

An image representing the location and path of the patient’s center of gravity (COG) during weight-shifting activities was represented on a screen at eye level. As he shifted his weight, the force plate tracked and displayed his COG’s position and path. Krzak used the information to create a patient-specific prescription of exercises, games, and weight-shifting activities to retrain his balance.

The boy was treated for about four months. Following surgery and therapy, his toe walking was eliminated, his balance improved, and the quality of his ankle motion during walking more closely resembled that of typically developing children.

Rebecca Rouse, DPT, a physical therapist with Shriners Hospital for Children—Twin Cities, explained external factors, such as pavement, grass, gravel and access via ramps, stairs, and other means also need to be considered. Shriners’ Minneapolis, MN, location serves a large Amish population, she said, noting, “They often have to walk along dirt roads or over grass to not only access their homes and school but to complete their chores.”

Walking on a surface other than flat even ground involves additional balance challenges and may require more equipment, said

Rouse. "Patients are required to recruit more muscles in order to maintain balance and posture while walking over uneven ground," she said.

She is able to replicate a similar environment. "We are lucky to have an awesome outdoor space that we can use for some 'off-road' training, and then make adaptations to [patients'] mobility as needed," she said.

Static vs dynamic balance

Although studies have shown chronological age is a significant predictor of single-leg squat (SLS) performance, with younger children having poorer SLS scores than their older counterparts, children with neurological deficits have other considerations.[13]

Determining whether interventions should focus more on static balance or dynamic balance, Smalls said, depends on the patient's abilities and limitations. For example, a child with CP may be able to walk 30 feet without falling but have difficulty maintaining balance when they are prompted to stand still in the school lunch line. On the other hand, Smalls noted, another child with the same diagnosis may be able to perform static standing without any difficulty but struggle with balance when asked to reach for a ball outside of their base of support or to ambulate short distances without tripping.

Damron echoed Smalls' observation that a child can have good or fair static balance and poor dynamic balance, which will greatly affect their gross motor skills and ability to play and participate with peers.

"Focus on static or dynamic balance should be based on findings in the evaluation," Damron said. "However, I always include static balance to address strength, stability, and proprioception as increasing these areas usual leads to global improvements."

Balance-specific training is beneficial when one is working on a specific task and refining the patient's skills so he or she can improve balance and perform a specific balance task safely, Smalls said.

"However, children with neuromuscular disorders are often complex, so their inability to perform a task such as single-limb stance could affect their ability to ambulate, run, and kick a ball because these are all activities that require brief moments of single-limb support," she said. "Additionally, children may have other impairments—including decreased lower extremity strength, range of motion, increased tone, poor safety or body awareness, and impaired motor control—that may also affect their risk of falling. Therefore, a multimodal protocol can be very beneficial when developing treatment plans for children."

Understanding the environmental conditions in which balance issues are present will help clinicians develop patient-specific interventions, Krzak said. He determines whether the child loses their balance during slips and trips or when bumped (ie, unexpected perturbations). He asks if they have balance issues when they are the ones that initiate movement, or when they are in situations with limited sensory information (visual or somatosensory).

"The ultimate goal of any form of training is to maximize functional activity and participation," Krzak said. "Balance issues may be only one of the impairments resulting in limitations in functional activity. Also, you cannot assume that addressing sensory and motor impairments during static balance training will directly carry over to all functional activities. Once improvements in balance are achieved during therapeutic interventions, they should be applied to functional training activities based on the patient's/family's goals for therapy."

References are available at lerpediatrics.com.