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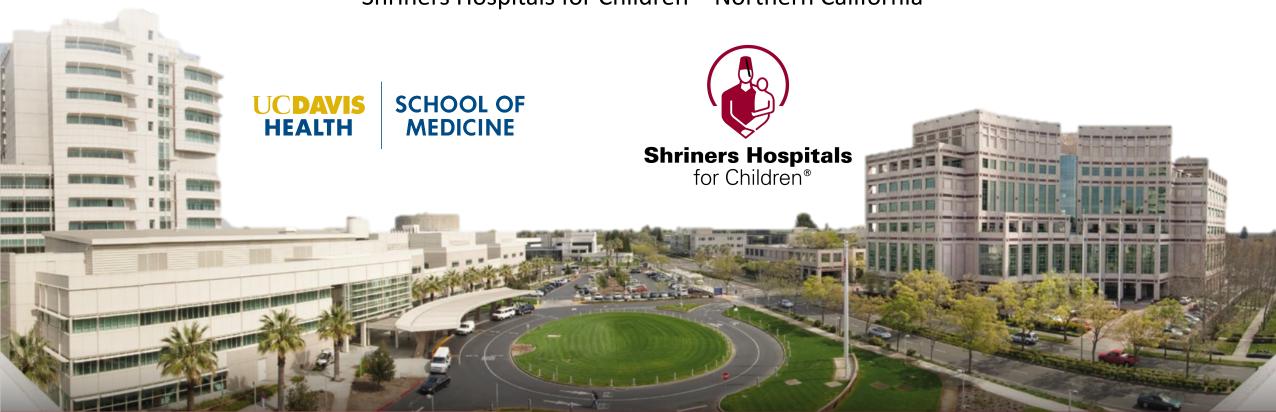
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Beware the Transverse Plane: Variability of "Normal Gait" In Typically Developing Children

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Gait Variability



Gait matures by 4-8 years of age



Complex Neurological Processing

Precision Surgery

- 3D Gait Analysis is the only quantitative method to study gait
- Provides accurate and reliable data on joint and body segment motion
- An important component of "precision surgery" for a child with a fixed gait abnormality



3D Gait Analysis



Current Literature

- Stride-to-stride variability for gait variables is low, but outliers do exist
- Choosing the wrong stride for analysis can lead to improper surgical decisions
- Better quantification of gait variability is foundational for proper surgical decision-making
- Existing studies have omitted trunk or pelvis measures in variability characterization

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The gait standard deviation, a single measure of kinematic variability



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Full length article

How normal is normal: Consequences of stride to stride variability, treadmill walking and age when using normative paediatric gait data



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Purpose

- 1. Quantify stride-to-stride variability in typically developing (TD) children using three-dimensional gait analysis (3DGA) in an expanded set of 14 kinematic variables.
- 2. Assess the effect of laterality, age, and sex on stride-to-stride variability

Methods









| | Sagittal Plane | Coronal Plane | Transverse Plane |
|---------------|--------------------|--------------------|------------------|
| Trunk: | Trunk Tilt | Trunk Lateral Bend | Trunk Rotation |
| Pelvis: | Pelvic Tilt | Pelvic Obliquity | Pelvic Rotation |
| Hip: | Hip Flexion | Hip Abduction | Hip Rotation |
| Knee: | Knee Flexion | Knee Flexion | Knee Rotation |
| Foot & Ankle: | Ankle Dorsiflexion | | Foot Progression |

Methods



20 Female 17 Male

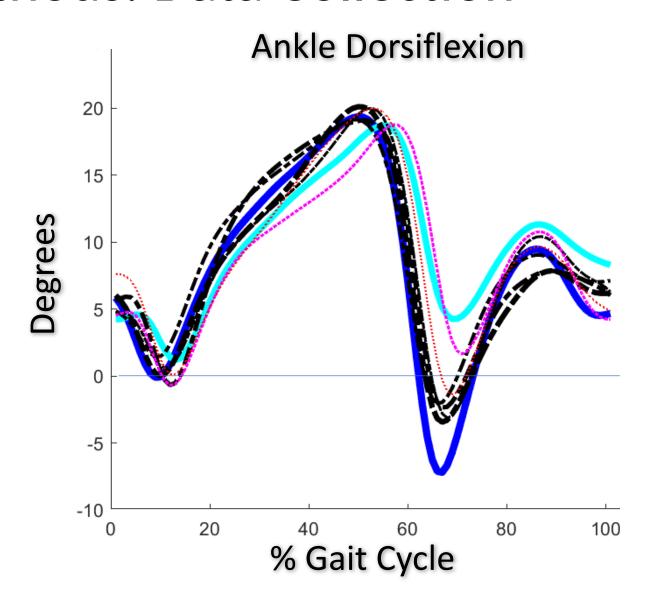


Ages 5 - 17



Average 7 strides

Methods: Data Collection



GVSD

Gait Variable Standard Deviation

(Best statistical measure of variability)

$$= \sqrt{\left(\sum_{t} SD(i,t)^{2}/T\right)}$$

where:

SD = standard deviation

i = gait variable of interest

t = time point

T = total number of time points (101)

GVR

Gait Variable Range

(Sensitive to outliers)

$$= \sqrt{\sum_{t} RNG(i,t)^2/T}$$

where:

RNG = range

i = gait variable of interest

t = time point

T = total number of time points (101)

Methods: Statistical Tests

- Paired t-Test used to compare laterality
- Unpaired t-Test to compare sex differences
- ANOVA with Tukey's Post Hoc to compare between planes of motion
- Linear regression to evaluate the effect of age

Results - Right Side

- Transverse Plane is the most variable at all body segments except for the knee
- GVSD is low, indicating that gait is consistent in TD children
- GVR is large, indicating that the range of joint motion is sensitive to outliers
- Choosing an outlier trial could affect clinical decision making

| | Measurement | (0) | , <i>o,</i> |
|--------|-------------------------|------------------|------------------|
| | | | |
| Trunk | Trunk Rotation | 9.4** | 3.4** |
| | Trunk Tilt | 6.4 | 2.3 |
| | Trunk Lateral Bend | 4.5 | 1.6 |
| Pelvis | Pelvic Rotation | 7.8** | 2.8** |
| | Pelvic Tilt | 4.4 | 1.6 |
| | Pelvic Obliquity | 2.9 | 1.1 |
| Hip | Hip Rotation | 8.3** | 3** |
| | Hip Flexion | 6.3 | 2.3 |
| | Hip Adduction/Abduction | 4.1 | 1.5 |
| Knee | Knee Rotation | 4.7 | 1.8 |
| | Knee Flexion | 8.8 [‡] | 3.2 [‡] |
| | Knee Varus/Valgus | 1.7 | 0.6 |
| Ankle | Foot Progression Angle | 10.4* | 3.8* |
| | Ankle Dorsiflexion | 7 | 2.6 |

GVR (deg)

GVSD (deg)

Kinematic

^{**} Significant Difference between Transverse and Sagittal/Coronal Planes

[†] Significant Difference between Sagittal and Transverse/Coronal Planes

^{*} Significant Difference between Transverse and Sagittal Planes

Results - Left Side

- Transverse Plane is the most variable at trunk, pelvis, and ankle. Knee has most variability at the sagittal plane.
- GVSD is low, indicating that gait is consistent in TD children
- GVR is large, indicating that the range of joint motion is sensitive to outliers
- Choosing an outlier trial could affect clinical decision making

| | Kinematic | GVR (deg) | GVSD (deg) |
|--------|-------------------------|-------------------|------------------|
| | Measurement | | |
| | Trunk Rotation | 9.5** | 3.3** |
| Trunk | | 6.7 | 2.4 |
| | Trunk Tilt | | |
| | Trunk Lateral Bend | 4.6 | 1.6 |
| Pelvis | Pelvic Rotation | 7.8** | 2.8** |
| | Pelvic Tilt | 4.4 | 1.6 |
| | Pelvic Obliquity | 3 | 1.1 |
| Hip | Hip Rotation | 8 | 2.8 |
| | Hip Flexion | 6.6 | 2.3 |
| | Hip Adduction/Abduction | 4.2 | 1.5 |
| Knee | Knee Rotation | 4.8 | 1.7 |
| | Knee Flexion | 10.1 [‡] | 3.5 [†] |
| | Knee Varus/Valgus | 1.7 | 0.6 |
| Ankle | Foot Progression Angle | 12* | 4.1* |
| | Ankle Dorsiflexion | 8.3 | 3 |

Vinamatic

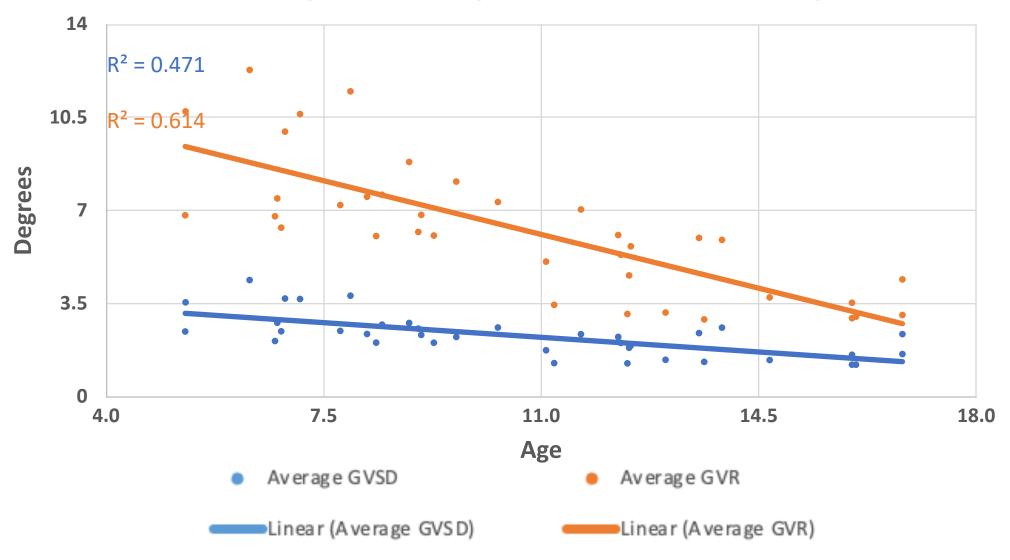
^{**} Significant Difference between Transverse and Sagittal/Coronal Planes

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^{*} Significant Difference between Transverse and Sagittal Planes

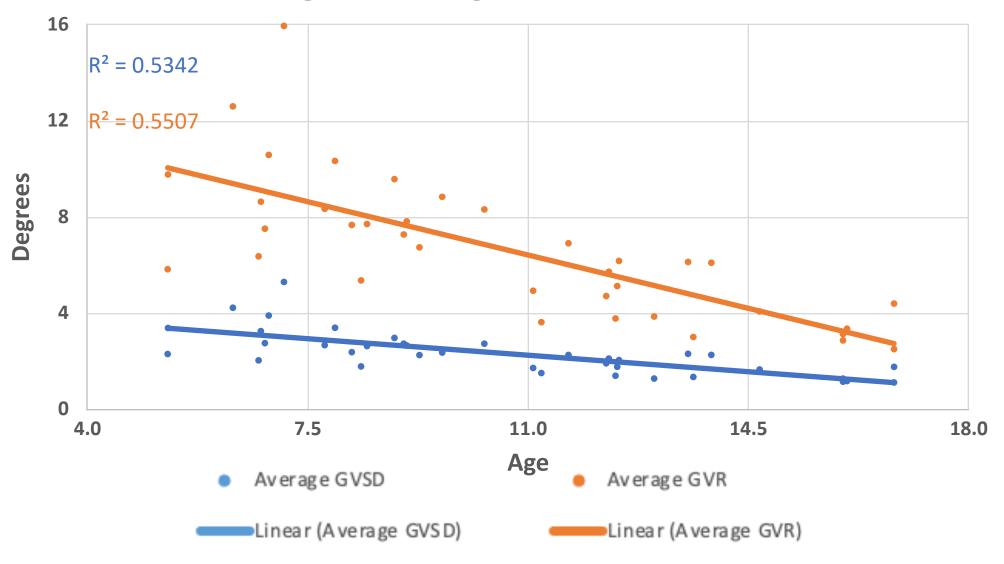
Results - Right Side

Effect of Age on Average GVR and GVSD for Right Side



Results – Left Side

Effect of Age on Average GVR and GVSD for Left Side



Conclusions:

- Statistically and clinically significant kinematic variability was the greatest in the transverse plane in all body segments except for the knee, where variability was greatest in the sagittal plane.
- Foot progression can have up to a 12° GVR, indicating that surgeons should not place emphasis on a single trial in isolation for surgical treatment.
- Variability of gait decreases in older children, so determination of fixed gait deviations will be more accurate closer to skeletal maturity.
- Sex and laterality had no statistically significant effect on variability.



Limitations & Further Research

• Limitations:

- Equal weight given to all 101 time points of the gait cycle
- Analysis limited to typically developing children

Future Directions:

- Expand analysis to children with neuro-developmental disorders
- Assess variability at clinically significant points in the gait cycle.
 - For example: Ankle position at initial foot contact.



Thank You!

