COORDINATED INTRA-LIMB RELATIONSHIPS AND CONTROL IN GAIT DEVELOPMENT VIA THE ANGLE-ANGLE DIAGRAM

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INTRODUCTION: The purpose of this study is to explain developmental process of gait via angle-angle diagram to understand how coordinated relationships and control change with age. Twenty-four female children, from one to five years of age were the test subjects for this study, and their results were compared to a control group consisting of twenty-one adult females. The Vicon 370 CCD camera, VCR, video timer, monitor, and audiovisual mixer was utilized to graph the gait cycle for all test subjects. Both coordinated Intra-limb relationships, and range of motion and timing according to quadrant were explained through the angle angle diagram. Movement in the sagittal plane showed both coordinated relationships and control earlier than movement in the coronal or transverse plane. In the sagittal plane, hip and knee coordinated relationships developed first (from one year of age.) Coordinated relationships in the knee and ankle and hip and ankle developed next, respectively. Both hip and ankle and knee and ankle development were inhibited by the inability of children to completely perform plantar flexion during the swing and initial double limb support phases. Children appeared to compensate for this by extending at their hip joint more than adults during the third phase, final double limb support. In many cases the angle angle diagram for children had a similar shape as adult's angle angle diagram. This shows that children can coordinate their movements at an early age. However, the magnitudes and timing of children's angle angle diagrams still varied greatly from adults, even at five years of age. This indicates that even at this age, children still do not possess full control of their movements.
Purpose : The purpose of this study is to explain developmental process of gait via angle-angle diagram to understand how coordinated relationships and control change with age.

METHODS:
A. Subjects: Twenty-four children between the ages of one and five served as the test subjects of this study. The control group consisted of twenty one adult females who had not experienced pregnancy (pregnancy alters the shape of the pelvis and consequently effects gait.)
B. Equipment: The Vicon 370 CCD camera, VCR, video timer, monitor, and audiovisual mixer was utilized to graph the gait cycle for all test subjects.
C. Coordinated Relationships within Joint Segments: Twelve analytical categories were used to describe the intra-joint relationships in the angle-angle diagram. The variables in these categories were coupled or decoupled, curved or linear, and the direction of movement. Couple movement indicated a simultaneous change of both x and y values, and decoupled movement indicated only the change of one value (either x or y) while the other value remained constant. Curved and linear simply describe the shape of the graph, and direction specifically refers to an increase or decrease of either x or y values. The categories are as follows:
1) Coupled-curved-xy increase
2) Coupled-curved-xy decrease
3) Coupled-curved-x increase y decrease
4) Coupled-curved-x decrease y increase
5) Coupled-linear-xy increase
6) Coupled-linear-xy decrease
7) Coupled-linear-x increase y decrease
8) Coupled-linear-x decrease y increase
9) Decoupled-linear-x increase (y constant)
10) Decoupled-linear-x decrease (y constant)
11) Decoupled-linear-y increase (x constant)
12) Decoupled-linear-y decrease (x constant)

Turning point synchronization is a term used to describe the point where an angle angle diagram reverses its trajectory.

D. The Four Quadrants: Movements were also categorized according to the four quadrants. The quadrants not only described the appearance of the diagram, but also described the action of the joints (simultaneous flexion or extension, or alternate extension / flexion.)

i) First Quadrant: Movement in this range indicates that both limbs only flex from their original starting position and only extend back to their original starting position.

ii) Second Quadrant: Movement in this range shows one limb (represented on the x axis) extending past the original starting position, while the other limb (represented by the y axis) only flexes from its original starting position and only extends back to its original starting position.

iii) Third Quadrant: Movement in this range demonstrates that both limbs are extending past their original starting position. Flexion in this range only brings the limb back to its original starting position.

iv) Fourth Quadrant: Movement in this range shows one limb (represented on the y axis) extending past the original starting position, while the other limb (represented by the x axis) only flexes from its original starting position and only extends back to its original starting position.

E. Coordinated Relationships and Control: The twelve descriptive categories for angle-angle diagrams were then utilized to determine both coordinated relationships and control. Adult diagrams were used as a standard to determine both. Coordinated relationships were quantitatively evaluated based on the similarity in shape and form between children's angle-angle diagrams and adults diagrams. The concept of control was based on not only similarity in shape and form, but also on the degree of difference between magnitude, position, and timing of the graphs. Control was determined when children's angle angle diagrams possessed a magnitude, position, and timing was similar to that of adults.

RESULTS:

1. Movement in the sagittal plane showed both coordinated relationships and control earlier than movement in the coronal or transverse plane.
2. Children's movement displays coordinated relationships before control is apparent. Greater control of these movements comes later in development.
3. Coordinated relationships between the hip and knee joint in the sagittal plane developed first among children (one year of age), and this movement played the biggest role in walking.
4. The second area to show coordination was the knee and ankle in the sagittal plane. Coordinated relationships appeared from three years of age.
5. Compared to other phases in the sagittal plane, the second phase, single limb support, developed last for every joint.
6. The last joint to show a coordinated relationship was the hip and ankle joint in the sagittal plane. Even at the age of five, this relationship was not completely coordinated.
7. The last movement to develop coordinated relationships and control in the sagittal plane was plantar flexion in the ankle joint. This can be seen during the last part of the fourth phase (swing) of the hip and ankle and during the first phase of the knee and ankle diagrams.
8. During the third phase in the sagittal plane, children's hip extension is far greater that of adults. Adult graphs for both the hip and ankle and the knee and ankle show substantially more dorsi plantar flexion than children's graphs. It is possible that children over-extend at the hip in order to compensate for a lack of dorsi plantar flexion.
9. The sagittal plane, a coordinated relationship between the knee and ankle during double limb support develops before swing and single limb support.
10. In the relationships between all joints, flexion develops before extension. Knee movements develop before other joints and in the case of the ankle, dorsi flexion develops before plantar flexion.
11. Even at the age of five, the magnitude of the graphs in every plane was quite different. So control of these movements was still very different from adults.
12. Three different relationships between the joints were observed in the angle-angle diagram: coupled curved, coupled linear, decoupled linear. Another characteristic, turning point

synchronization, was also observed.

CONCLUSION: A major difference between children's and adult's gait is plantar flexion. Children are not fully capable of plantar flexion and have noticeably exaggerated hip and knee extension during single limb support through the age of five. This hip and knee extension assists in forward acceleration since children lack plantar flexion.
The adult relationships between movements in two joints were used as the standard for determining coordinated movement. Although children did not have movement that was coordinated identically to adults, they were still capable moving successfully. This can be explained by children's independent movement strategies. This is evidenced in the way children utilize both hip and knee flexion in order to compensate for their lack of plantar flexion. So although children do not have "adult-like" coordinated relationships between joints, this may not indicate that they are uncoordinated; it might just mean that they are moving differently than adults. While children may have their own coordination strategies, these strategies produce a less efficient pattern of movement than adults. This can be seen in the visible differences in children's and adults angle angle diagrams.