UCLouvain

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Effects of dynamic balance on adolescent idiopathic scoliosis: motor response analysis

Assessed with the Equitest®

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I. Background

Adolescent idiopathic scoliosis (AIS) is the most prevalent form of scoliosis, accounting for approximately 80% of scoliosis cases in children (El-Hawary & Chukwunyerenwa, 2014). AIS is characterized by a three-dimensional deformity of the spine without any underlying congenital or neuromuscular abnormalities (Kuznia et al.,2020). This pathology is diagnosed by the presence of one or more curves, with a Cobb angle exceeding 10°, accompanied by apical vertebral rotation (Addai et al., 2020; Kuznia et al., 2020). The progression of AIS is notable during rapid periods of growth, particularly during puberty (Addai et al., 2020).

The etiopathology of AIS remains elusive. Current literature supports a multifactorial etiology encompassing genetics, mesenchymal stem cells, tissues, spine biomechanics, hormonal, environmental, lifestyle and neurological factors including central sensorimotor integration like the vestibular, visual and proprioceptive systems and impairment in body spatial orientation (Paramento et al., 2024; Peng et al., 2020; Marya et al., 2022). The vestibular system is responsible for collecting postural information by the head's acceleration and rotatory movements (Langeard, 2017). Vision has a major role to play in balance control by collecting visual information and transmitting it to the occipital cortex (Langeard, 2017). The cortex analyses this visual information and provides orientation in space. Proprioception refers to the perception of the position of different parts of the body and derives its sensory information in particular from neuromuscular fascicles and neurotendinous organs (Langeard, 2017). The body establishes a closed-loop control system consisting of appropriate motor responses and a sensorimotor system using proprioception, the vestibular system and vision (Peterka et al., 2018). Disturbances in balance control, involving impaired multisensory integration of vestibular, visual, and somatosensory inputs, would be present in patients with AIS (Catanzariti, 2014).

Pollock et al. (2000) defined balance control as the ability to regulate the relationship between the line of gravity of the body centred in one point commonly called center of mass (CoM) and the area of the base of support ie. in the anatomical position, a surface extending around the feet (Kingma et al., 1995). The body adjusts its positions to keep the CoM above the base of support to prevent falls in

static and dynamic conditions. Balance control is improved with a wider support base, a more centred CoM and/or a lower CoM (Pollock et al., 2000). Effective balance control involves maintaining an energy-efficient posture, performing voluntary movements, and reacting to external disturbances (Pollock et al., 2000). In patients with AIS, there is a displacement of the line of gravity from its typical position, affecting postural sway (Paramento et al. 2024).

Dufvenberg et al. (2018) has identified significant differences in center of pressure (CoP) between individuals with AIS and control groups, indicating a higher degree of postural instability in those with AIS. CoP represents the sum of the pressure forces by the ground on the feet. It is constantly adjusted in response to CoM movements to stabilise body. The movements of the CoP can be measured using force platforms to assess postural stability and give indications of an individual's ability to maintain balance control (Zurawski et al., 2020; Nault et al., 2002). Specifically, the review noted a consistent pattern of larger CoP positional shifts towards the posterior in the sagittal plane among AIS patients, suggesting a more constrained postural control strategy compared to controls. According to Nault et al (2002), the CoM motion represents balance control, whereas the CoP motion relates more to the ankle control to maintain balance. In his work, Nault et al. (2002) showed that AIS patients had a higher CoP–CoM differences and these were attributed to a greater neuromuscular demand to maintain standing balance.

Several elements contribute to a reorganization of both static and dynamic balance control in AIS patients i.e. biomechanical aspects and other sensorimotor issues (Paramento et al.; 2024). The biomechanical aspect is linked to morphological changes, muscular imbalance and to alteration in posture, orientation and deviation of the head, shoulders, scapulae, and pelvis in the 3 planes (Paramento et al., 2024). Indeed, an imbalance in paraspinal muscles is a notable concern marked by increased muscle volume (Paramento et al., 2024).

According to the literature, no study has shown that alterations in dynamic balance control in scoliotic patients can be linked to motor strategies that differ from those of healthy subjects. In fact, no data and conclusions concerning motor responses in healthy and scoliotic adolescents have been published. That's why, this work focuses on analyzing the motor responses of AIS compared with control subjects in a standing dynamic balance control exercise measured by a mobile force platform.

In other words, it consists in maintaining and restoring balance during a sudden unexpected disturbance. The results will make it possible to highlight and discuss the strategies implemented by these 2 groups.Several techniques such as simulated forward fall, push/pull/ hit perturbation and sudden load on hands on solid ground; balance board; sudden horizontal translational perturbation with controlled stop or with free oscillation on force platform or treadmill technique and rotational perturbations on force platform are available for measuring balance control (Petró et al., 2017). To measure motor responses in dynamic balance control Computerized dynamic posturography (CDP) is the technique used to objectively assess postural control suitable for children with a standardized and accepted method (Petró et al., 2017). To our knowledge, no study has compared these two types of groups on motor responses with Motor control Test (MCT).

The objective of this study is to compare motor responses in dynamic balance firstly between the AIS subjects according to the location of the major curve (major thoracic, major lumbar and double major curve) and secondly between AIS subjects according to the Cobb angle amplitude (Cobb≤20°, 20°<Cobb<40°, Cobb ≥40°). Lastly, all these groups will also be compared with non-scoliotic adolescents (control group).

II. Methods

II.1. Participants

A total of 108 children aged between 9 and 15 years old participated in this study. Two groups were compared, an AIS group and a control group. The control group is composed of 54 healthy adolescents with no prior history of scoliosis and no balance function disorders. Subjects in this group were voluntarily recruited from local schools and were assessed at Saint-Luc's hospital in 2011. The AIS group consisted of scoliotic patients who were enrolled from the orthopaedic department of Clinique Universitaire Saint-Luc. The radiological measurements of the Cobb angle and the vertebral apical rotation were used to diagnose AIS. Eligible AIS had no history of surgical treatment of the spine or lower limbs, nor suffer from any pain. Finally, 54 adolescents with idiopathic scoliosis were included in this study. All these patients had not undergone any treatment at the time of the experiment. First, the AIS group was subdivided into three subgroups based on the major curve angle and planned treatment: children with a Cobb angle less than 20°, those with angles between 20° and 40°, and those exceeding 40°. We have called these subgroups Cobb≤20°, 20°<Cobb<40° and Cobb≥40° respectively. 14 subjects belonged to the Cobb≤20° group, 34 to the 20°<Cobb<40° group and 6 to the Cobb≥40° group. Second, the AIS patients were classified according to the location of their major curve considering the classification of Ponseti. Ponseti classified scoliosis according to its topographic shape on frontal radiography and defined by the apex vertebra of the curve (Ponseti & Friedman, 1950; Khouri et al., 2004). A thoracic curve is defined as a curve with the apical vertebra located in T6-T11 and a lumbar curve is characterized by an apical vertebra located at L2-L4 (Khouri et al., 2004). A double major curve is described as two structural curves in opposite directions of equal angulation (to within 10%) and similar rotation (Khouri et al., 2004). In short, 16 patients are in the major lumbar group, 33 in the major thoracic group and 5 in the double major group. None of the AIS group had major thoraco-lumbar curve. Each participant and their parents provided written consent and participated voluntarily in the study, which was approved by the local ethics commission (B403201523492).

II.2. Materials

To measure motor responses during body balance control exercises, a computerized dynamic posturography known as the Equitest® was used (Neurocom International, Clackamas, Oregon). It is considered as the gold standard in balance assessment and postural analysis in a variety of complex conditions (Petró et al., 2017). This system is composed of a dual-force platform (translation of the platform and measurement of the forces applied by the limbs), a visual panorama that surrounds the subjects on three sides, and a computer to configure the trials and record the platform's measurements (Fig.1). The Equitest® provided assessment of balance control and postural response to dynamic and static perturbations thanks to three protocols: the Sensory Organization Test (SOT), the Motor Control Test (MCT) and the Adaptation Test (ADT). According to this study, the MCT protocol was used to analyze participants' motor responses under six different conditions, including 3 backward translations and 3 forward translations with different magnitudes: small, medium, and large (Fig.2). The following abbreviations will be used to indicate the conditions analysed: translation small backward (TSB), translation medium backward (TMB), translation large backward (TLB), translation small forward (TSF), translation medium forward (TMF), translation large forward (TLF). Small translations represent a threshold stimulus and produce 0.7° sway for 250ms, whereas large translations necessitate the participant to produce a maximal response with 3,2° sway for 400 ms. Each condition (one magnitude with one direction) is executed three times, with a random delay of 1.5 to 2.5 seconds between repetitions. The data recorded is the average of the forces measured for the same translation during the 3 repetitions.

Fig.1. The Equitest® system (Neurocom International, Clackamas, Oregon) composed of a dual-force platform, a visual panorama and a computer. (https://www.interempresas.net)

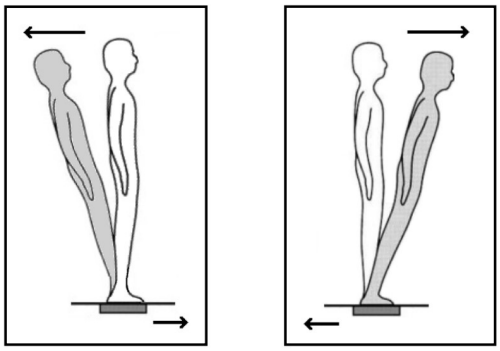


Fig.2. Forward and backward translations illustrated. (https://perform.concordia.ca)

II.3. Protocol

First, all the personal data of the subjects were registered in the system, including height, weight and age. Participants had to stand centred on the platform with their feet aligned with the markers (Fig.3). They were attached to a harness for safety reasons, particularly to avoid falls. As the visual panorama is fixed for MCT. They were asked to look straight ahead and to fix a point. Besides, the instructions were read out and explain to the subjects prior to each set of trials to inform them of what would follow. Preparation of participant and protocol to use Equitest® is clearly explained in the study of Vanicek and al. (2013).

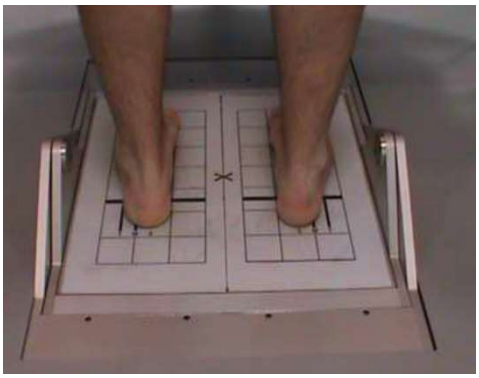


Fig.3. Position of feet on the Equitest® platform (Vanicek et al., 2013).

At each set of 3 repetitions for a given condition, the Equitest® software appraise four variables: the weight symmetry (in %), the relative strength of each leg (in °/s), strength symmetry (in %), the latency (in ms) and latency ratio (in %).

The weight symmetry analysis consists of the measure of the load distribution of the body weight on the different legs. 100% corresponds to an equal distribution between the right and left leg, <100% corresponds to more weight on the left leg and >100% corresponds to more weight on the right leg.

The strength analysis consists of measuring the strength applied to the right and left legs using both the relative response strength of each leg and symmetry.
Looking at relative response strength, i.e. leg by leg independently, the measurements were taken in units of angular momentum (°/s) and normalized to body height and weight.
The analysis of strength symmetry represents the strength distribution between the 2 limbs, 100% corresponds to equal distribution between the right and left legs, <100% corresponds to more strength on the left leg and >100% corresponds to more strength on the right leg.

Latency analysis includes the difference in time lapse (in milliseconds) between the onset of support surface translation and the participant's active force response, measured for each limb. To calculate latency ratio, we took the ratio of right limb's latency to left limb's latency, the total multiplied by 100 to obtain a percentage. If the ratio = 100, right limb's latency = left limb's latency, if the ratio < 100, right limb's latency > left limb's latency and if the ratio > 100, left limb's latency > right limb's latency.

II.4. Statistical analysis

Statistical analysis of the data was conducted using SPSS software. The significance level was set at $p \leq 0.05$. The normality of all groups and variables was analyzed by Shapiro-Wilk test. Except for the ratio latency variable, the distribution of values for the different groups and for each variable follows the Gauss's law. Variables that displayed normal distribution and equality of variance were reported as mean (± SD).

A one-way ANOVA (angle factor) was performed to compare motor response's variables in dynamic balance between the healthy subjects and each of the AIS angle subgroups (Cobb≤20°, 20°<Cobb<40°, Cobb ≥40°).

A second one-way ANOVA (location factor) was performed to compare motor response's variables in dynamic balance between the healthy subjects and the scoliosis group subdivided according to the location of their major curve (major-thoracic, major-lumbar, double major).

For significant outcomes, a post hoc analysis was conducted utilizing a comparisons test by Tukey.

For the comparison between groups for the ratio latency variable, the statistical test performed is Kruskal Wallis.

III. Results

III.1. Participants' characteristics

Firstly, demographic data classified according to the groups: control, angle subgroups (Cobb≤20°, 20°<Cobb<40°, Cobb≤40°) and location subgroups (major thoracic, major lumbar, double major) of scoliosis are presented in table 1.

Table 1: demographic data of different groups

	Control Group	Scoliosis Group - Angle Subgroups			Scoliosis Group - Localization Subgroups		
		Cobb≤20°	20°<Cobb<40°	Cobb≥40°	Major thoracic	Major lumbar	Double major
	(n=54)	(n=14)	(n=34)	(n=6)	(n=33)	(n=16)	(n=5)
Sexe (% girl)	No data	78,57	82,35	83,33	81,82	87,5	40
Sexe (% boy)	No data	21,43	17,65	16,67	18,18	12,5	60
Age (years)*	11,13 (1,65)	13,07 (1,69)	13,13 (1,70)	12,33 (1,21)	12,74 (1,83)	13,31 (1,40)	13,80 (0,45)
Height (cm)*	148,08 (10,79)	159,86 (12,33)	158,25 (11,93)	155,83 (6,88)	159,13 (8,84)	161,63 (8,82)	167,4 (3,05)
Weight (Kg)*	38,54 (7,31)	48,08 (11,30)	48,96 (9,22)	49 (3,92)	47,96 (11,16)	47,64 (5,58)	55,6 (4,45)
Risser score (/5)*	-	1,33 (1,44)	1,87 (1,33)	1,50 (1,22)	1,45 (1,38)	1,93 (1,38)	2,4 (0,55)
Angle curve (°)*	-	16,71 (3,67)	29,32 (4,82)	48,00 (11,66)	29,42 (11,83)	26,31 (7,86)	25, 40 (8,79)

*Mean (Standard deviation)

To answer the research questions, all the results are summarised in two tables and commented on below according to the variables:

1. Comparison between scoliosis angle subgroups and between control subjects (table 2).

2. Comparison between scoliosis location subgroups and between control subjects (table 3).

Columns represent the different subgroups and rows the different variables according to condition. Significant differences are indicated by a marker and refer to the rows. The indicators are presented as an * or " accompanied by small numbers: * represents a significant difference in the right leg, " a significant difference in the left leg and the small numbers refer to the concerned subgroups. For example, there is a difference in strength between the 20°<Cobb<40° group and the control group in the analysis of the right leg, this will be indicated by *[5].

Table 2 : Data in terms of weight, strenght and latency of scoliosis angle subgroups and control group in all translations

	Cobb≤20° (n=14) Mean (SD)			**20°<Cobb<40° (n= 34)** Mean (SD)			**Cobb≥40° (n=6)** Mean (SD)			**Control group (n=54)** Mean (SD)		
	Right	Left	Symmetry (%)	Right	Left	Symmetry (%)	Right	Left	Symmetry (%)	Right	Left	Symmetry (%)
Translation small backward												
Weight	-	-	98,36 (10,82)	-	-	98,12 (7,22)	-	-	91,83 (4,96)	-	-	98,5 (9,65)
Strength (°/s)	3,21 (3,47)	3,86 (3,46)	84,21 (18,75)	3,82*⁵ (2,18)	3,97"⁵ (2,28)	98,00 (16,17)	2,17 (1,60)	2,67 (1,51)	86,17 (16,66)	2,19*⁵ (1,29)	2,48"⁵ (1,55)	92,57 (26,62)
Latency (ms)	138,57 (8,64)	135,71 (9,05)	102,43 (8,06)	127,06 (25,53)	129,12 (12,40)	98,55 (19,33)	125,00 (10,49)	130,00 (10,95)	96,43 (8,06)	127,78 (29,31)	134,44 14,49)	95,06 (20,59)
Translation medium backward												
Weight	-	-	98,79 (12,29)	-	-	98,71 (8,91)	-	-	92,00 (6,45)	-	-	99,15 (10,14)
Strength (°/s)	5,5*⁷⁸ (3,16)	6,64 (3,52)	89,36 (16,28)	7,80*⁵⁸ (3,33)	8,03"⁵ (3,52)	98,03 (16,80)	4,67*⁷ (1,21)	6,83 (2,041)	81,67 (9,67)	4,65*⁵ (2,05)	4,83"⁵ (2,22)	98,19 (18,33)
Latency (ms)	119,29 (36,47)	125,71 (7,51)	95,11 (28,32)	114,86 (30,81)	116,29 (30,78)	93,65 (25,23)	118,33 (13,29)	118,33 (4,08)	100,00 (5,25)	119,26 (32,73)	122,22 (20,25)	97,47 (21,04)
Translation large backward												
Weight	-	-	100,21 (12,94)	-	-	98,29 (8,81)	-	-	91,67 (4,41)	-	-	98,83 (10,07)
Strength (°/s)	7,71 (3,97)	8,07 (4,23)	97,21 (12,03)	9,49*⁵⁹ (3,92)	9,83"⁵ (3,83)	96,31 (17,35)	5,33*⁹ (1,63)	7,00 (1,67)	85,33 (6,83)	5,83*⁵ (2,63)	5,96"⁵ (2,78)	98,76 (16,29)
Latency (ms)	124,62 (13,30)	120,71 (9,17)	96,37 (30,54)	119,09 (11,00)	119,09 (11,21)	96,69 (20,21)	118,33 (7,53)	118,33 (7,53)	100,70 (15,98)	120 (13,32)	115 (35,59)	98,18 (12,84)
Translation small forward												
Weight	-	-	101 (12,07)	-	-	96,97 (9,16)	-	-	91,17 (8,86)	-	-	99,04 (9,99)
Strength (°/s)	3,79*⁴ (2,33)	3,5 "⁴ (2,38)	103,43 (25,67)	4,26*⁵ (2,27)	4,06"⁵ (2,22)	102,51 (17,80)	3,17 (1,94)	3,17 (1,47)	97,83 (15,63)	2,35*⁴⁵ (1,36)	2,13"⁴⁵ (1,26)	105,78 (26,71)
Latency (ms)	140,71 (12,69)	144,62 (14,50)	97,07 (6,36)	140,57 (16,08)	138,82 (14,72)	101,59 (8,99)	140,00 (8,94)	141,67 (4,08)	98,88 (6,91)	133,15 (48,32)	136,30 (43,49)	93,66 (30,94)
Translation medium forward												
Weight	-	-	100,43 (12,12)	-	-	97,97 (8,97)	-	-	93,83 (3,71)	-	-	99,24 (10,46)
Strength (°/s)	6,07 (2,94)	5,86 (2,48)	100,57 (22,94)	7,43*⁵ (3,02)	6,8"⁵ (2,61)	103,03 (15,27)	5,67 (1,75)	5,83 (1,84)	98,67 (8,48)	4,37*⁵ (2,05)	4,35"⁵ (2,21)	101,41 (16,90)
Latency (ms)	138,57 (12,92)	136,43 (12,77)	101,76 (5,82)	131,00 (13,97)	131,43 (13,316)	96,70 (17,78)	133,33 (10,33)	128,33 (7,53)	103,85 (4,24)	131,67 (23,37)	133,15 (22,22)	96,97 (15,60)
Translation large forward												
Weight	-	-	99,71 (14,53)	-	-	98,71 (8,98)	-	-	93,33 (9,16)	-	-	100,2 (9,37)
Strength (°/s)	6,93 (2,59)	6,93 (2,27)	98,29 (14,88)	8,40*⁵ (3,20)	8,03"⁵ (3,15)	101,69 (15,81)	6,67 (0,52)	7,17 (2,48)	98,00 (14,66)	5,48*⁵ (2,27)	5,42"⁵ (2,59)	101,02 (14,34)
Latency (ms)	134,29 (10,16)	130,71 (9,17)	102,84 (5,85)	128,29 (14,45)	127,71 (12,85)	100,56 (7,04)	123,33 (8,17)	120,00 (6,33)	102,77 (4,29)	133,52 (15,19)	132,96 (12,23)	100,76 (9,24)

*⁵: p<0,001 ; *⁷: p=0,041 ; *⁹ : p=0,023 ; *⁴ : p=0,044 ; *⁸: p=0,034 ; "⁵: p<0,001 ; "⁴ : p=0,048

Table 3 : Data in terms of weight, strenght and latency of scoliosis location subgroups and control group in all translations

	Major Thoracic (n=33) Mean (SD)			Major Lumbar (n= 16) Mean (SD)			Double major (n=5) Mean (SD)			Control group (n=54) Mean (SD)		
	Right	Left	Symmetry (%)	Right	Left	Symmetry (%)	Right	Left	Symmetry (%)	Right	Left	Symmetry (%)
Translation small backward												
Weight	-	-	97,91 (8,62)	-	-	96,88 (8,27)	-	-	96,60 (6,43)	-	-	98,5 (9,65)
Strength (°/s)	3,33 (2,92)	3,52 (2,93)	94,09 (18,74)	3,44 (1,55)	3,88 (1,71)	93,44 (15,39)	4,60 (2,51)	5,40"³ (1,82)	85,60 (20,66)	2,19 (1,29)	2,48"³ (1,55)	92,57 (26,62)
Latency (ms)	128,18 (26,04)	129,09 (11,28)	99,42 (20,02)	132,50 (12,38)	133,13 (11,38)	99,66 (6,73)	132,00 (8,37)	136,00 (15,17)	97,57 (6,71)	127,78 (29,31)	134,44 14,49)	95,06 (20,59)
Translation medium backward												
Weight	-	-	98,29 (10,22)	-	-	96,75 (9,62)	-	-	100,00 (7,58)	-	-	99,15 (10,14)
Strength (°/s)	6,32*¹ (3,51)	7,03"¹ (3,55)	93,29 (17,85)	7,63*² (3,10)	8,13"² (3,42)	96,19 (15,98)	8,20*³ (2,39)	9,20"³ (1,30)	92,20 (14,45)	4,65*¹²³ (2,05)	4,83"¹²³ (2,22)	98,19 (18,33)
Latency (ms)	115,59 (31,35)	118,53 (22,45)	94,27 (25,45)	115,00 (33,27)	125,00 (11,55)	94,27 (25,45)	126,00 (11,40)	102,00 (57,62)	101,66 (3,71)	119,26 (32,73)	122,22 (20,25)	97,47 (21,04)
Translation large backward												
Weight	-	-	98,50 (9,65)	-	-	96,88 (11,20)	-	-	98,80 (7,73)	-	-	98,83 (10,07)
Strength (°/s)	7,79*¹ (3,95)	8,38"¹ (4,05)	94,38 (16,30)	11,20*² (4,27)	9,69"² (3,65)	97,75 (14,34)	11,20*³ (4,27)	11,80"³ (1,30)	94,20 (16,18)	5,83*¹²³ (2,63)	5,96"¹²³ (2,78)	98,76 (16,29)
Latency (ms)	120,97 (12,74)	118,79 (10,23)	92,97 (31,27)	119,38 (11,24)	122,86 (10,69)	98,13 (11,03)	120,00 (10,00)	118,00 (8,37)	101,66 (3,71)	120,00 (13,32)	115,00 (35,59)	98,18 (12,84)
Translation small forward												
Weight	-	-	98,15 (10,40)	-	-	96,63 (9,97)	-	-	94,40 (10,36)	-	-	99,04 (9,99)
Strength (°/s)	3,94*¹ (2,32)	3,88"¹ (2,20)	99,71 (18,47)	3,69*² (1,92)	3,50"² (1,97)	103,69 (18,75)	5,60*³ (2,41)	4,40"³ (3,05)	114,80 (27,94)	2,35*¹²³(1,36)	,134,83"¹²³ (1,26	105,78 (26,71)
Latency (ms)	140,59 (15,94)	140,29 (16,05)	100,61 (8,49)	140,63 (12,37)	142,14 (8,02)	98,60 (8,88)	140,00 (12,25)	138,00 (13,04)	101,62 (5,95)	133,15 (48,32)	136,30 (43,49)	93,66 (30,94)
Translation medium forward												
Weight	-	-	98,47 (9,84)	-	-	96,94 (9,85)	-	-	99,80 (7,29)	-	-	99,24 (10,46)
Strength (°/s)	6,24*¹ (2,81)	6,18"¹ (2,47)	98,88 (14,06)	7,50*² (2,78)	6,88"² (2,50)	104,13 (18,58)	9,40*³ (2,07)	7,00 (3,08)	115,60 (23,57)	4,37*¹²³ (2,05)	4,35"¹² (2,21)	101,41 (16,90)
Latency (ms)	132,35 (13,94)	131,47 (14,38)	100,81 (4,41)	136,25 (12,04)	135,00 (10,33)	101,05 (6,60)	128,50 (17,00)	130,00 (7,07)	77,54 (44,55)	131,67 (23,37)	133,15 (22,22)	96,97 (15,60)
Translation large forward												
Weight	-	-	98,06 (10,99)	-	-	97,63 (10,84)	-	-	103,00 (7,42)	-	-	100,2 (9,37)
Strength (°/s)	7,06*¹ (2,70)	7,35"¹ (2,89)	97,50 (12,66)	8,81*² (2,95)	8,31"² (2,80)	102,50 (15,18)	10,00*³ (3,08)	7,60 (3,36)	113,60 (25,68)	5,48*¹²³(2,27)	5,42"¹² (2,59)	101,02 (14,34)
Latency (ms)	129,419 (13,47)	128,24 (12,42)	101,03 (6,24)	128,13 (12,23)	127,50 (10,65)	100,56 (6,04)	132,00 (16,43)	124,00 (11,40)	106,42 (8,80)	133,52 (15,19)	132,96 (12,23)	100,76 (9,24)

TSB : "³: p = 0,019 - TMB : "¹: p=0,002 ; "² : p<0,001 ; "³: p=0,006 ; *¹: p=0,022 ; *²: p<0,001 ; *³p=0,028

TLB : "¹: p=0,004 ; "²: p<0,001 ; "³: p=0,001 ; *¹: p=0,029 ; *²: p<0,001 ; *³: p=0,003

TSF : "¹: p<0,001 ; "²: p=0,034 ; "³: p=0,034 ; *¹: p<0,001 ; *² : p=0,046 ; *³: p=0,001

TMF : "¹: p=0,002 ; "²: p=0,001 ; *¹: p=0,003 ; *²: p<0,001 ; *³: p<0,001

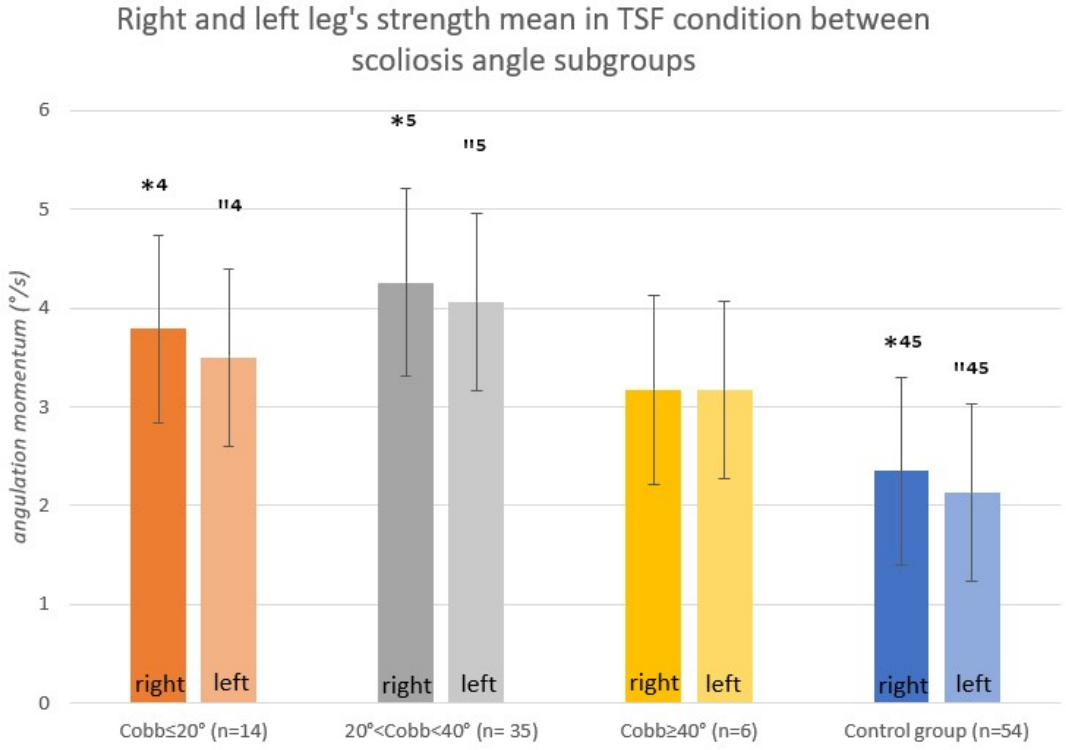
TLF : "¹: p=0,006 ; "²: p=0,001 ; *¹: p=0,0024 ;*²: p<0,001 ; *³: p=0,001

III.2. Weight symmetry

Weight symmetry on the legs showed no significant difference between the control and any of the three scoliosis angle groups nor between control and the three scoliosis location groups in any condition.

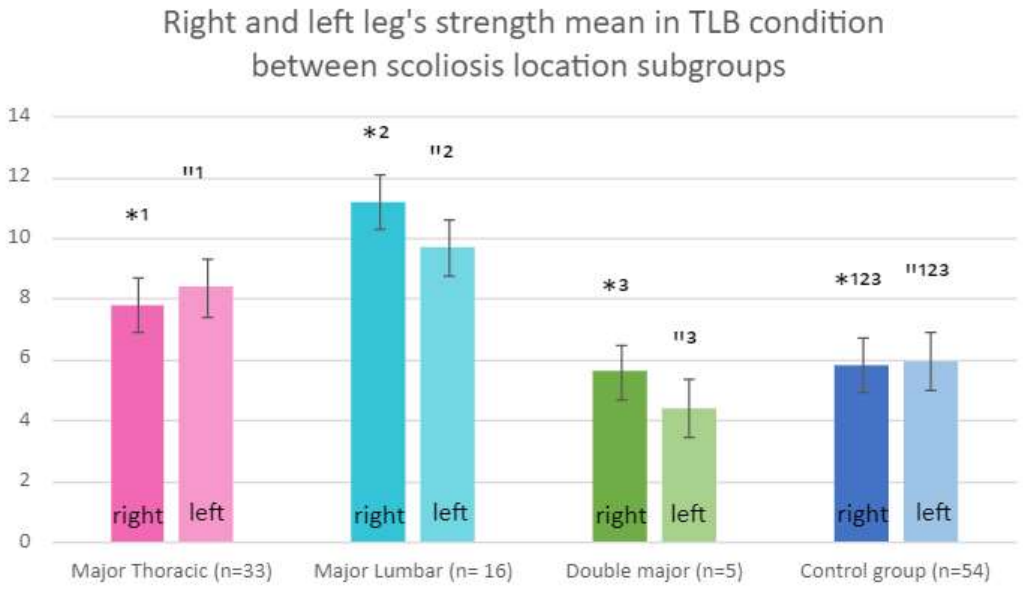
III.3. Strength

In both, right and left limb's strength analysis between the three scoliosis angle groups, statistical tests showed a significant difference in mean between the control (blue) and 20°<Cobb<40° (grey) groups in all translation conditions (*[5] and "[5] on graph 1 and table 2). Graph 1 illustrates a significative difference for the right and left leg between the Cobb≤20° (orange) and the control group (blue) in TSF condition. Others significative differences (*[8] and *[7] on table 2) can be observed between the 20°<Cobb<40° (grey) and Cobb≤20° (orange) groups and between the Cobb≥40° (yellow) and Cobb≤20° (orange) in the right leg in the TMB condition. In TLB condition, we observe a significant difference between the 20°<Cobb<40° (grey) and the Cobb≥40° (yellow) indicated by *[9] on table 2.



*Graph 1: Right and left leg's strength mean in TSF condition between scoliosis angle subgroups. On Y-axis, strength in angulation momentum (°/s). These differences are illustrated with an * for the right leg and " for the left leg using the example of TSF condition.*

Comparison of the strength exerted by the right and left limb of the scoliosis location subgroups shows significant differences in all conditions except for the comparison of the TSB condition and for the double major subgroup in TMF and TLB condition (See detail below). On graph 2 is illustrated the results of TLB with the differences highlighted by * and “.



Graph 2: Right and left leg's strength Mean in TLB condition between scoliosis location subgroups. On Y-axis, strength in angulation momentum (°/s)

The analysis of scoliosis location comparison of the strength of the left and right limb in TSB condition between control (blue) and the other groups (major thoracic, major lumbar and double major) shows no significant difference except for the double major subgroup in comparison of the left limb’s strength with control group (on table 3 and graph 2 indicated by “³).

To add, subjects with major-thoracic, subjects with major-lumbar scoliosis and subjects with double major scoliosis showed a stronger right and left leg strength response than the control group.

Statistical analysis showed no significant difference in means of strength symmetry between the different groups (angle subgroups and location subgroups) nor in the different conditions.

III.4. Latency

Neither in the comparison for left limb’s latency and right limb’s latency based on scoliosis angles nor location was shown any significant difference.

The analysis of normality of the leg latency symmetry showed no Gaussian distribution. A non-parametric Kruskal-Wallis's test showed no significant difference between the different groups nor in angle groups' comparisons nor in location subgroups comparisons. There appears to be no difference in the symmetry of the leg response latency between the different groups.

IV. Discussion

The aim of this study was to highlight the different motor responses in dynamic balance in healthy subjects compared with scoliotic subjects and between different scoliotic groups according to the angle and location of their major curve. First, the scoliotic group was classified and compared based on their Cobb angle (Cobb≤20°, 20°<Cobb<40°, Cobb ≥40°) with control group. Second, the scoliotic group was classified and compared by their curve location (major thoracic, major lumbar and double major curve) with control group.

IV.1. Limits of this study

About the values obtained with the MCT protocol, no standards have been established in the literature for children or adolescents previously. Feber-Viart et al. (2007) determined norms for children with the Equitest®, but only for the SOT protocol. Subsequently, a study establishing reference values for the MCT test can be pursued to compare our values for the scoliotic group as well as to verify the values for the control group.

Besides, the small number of subjects recruited leads to a lack of power in the statistical results, large standard deviations and wide confidence intervals in inter-group comparisons. Indeed, scoliotic subjects are classified into different types of curve (angle and location), which means that samples are small, confidence intervals are wide, and a ceiling effect is not reached in inter-group comparisons. Ideally, there should be a minimum of 35 subjects per subgroup for this type of study calculated by using a formula (https://statorials.org/taille-de-lechantillon/).

In terms of height, weight, age, sex and Risser score, the data of our sample seems to be large. These factors need to be considered in the balance control assessment of children (Sinno et al., 2021). Gouleme et al. (2014) looked at the progression of balance control linked to the development of the sensorimotor system during growth. The study reports that the proprioceptive system is developed at the age of 7.5 years except for adaptative processes that develop later in childhood at age of 7-11, the visual and vestibular system is identical to that of an adult at the age of 15-16 years. The difference in average age of 2 years (11 years for the control subjects versus 13 years for the scoliotic subjects) could have an influence on the development of the sensorimotor system of the recruited subjects. More, there was

a difference of 19 cm and 17 kg between the control and double major groups. On the one hand, this may be explained by the small sample size of the double major group, which is not representative. On the other hand, weight and height data were not recorded for some subjects in the control group when measurements were taken in 2011. Sinno et al. (2021) concluded that age and gender affect the changes in sensory weighting strategies, while height and BMI influence balance control in children.

IV.2. Results summary and interpretation

To summarize the results, there was no significant difference between the different subgroups (angle and location) in terms of **weight symmetry**. Filipovic et al. (2006) suggested that AIS could be functionally compensated with a neuroplasticity of the central nervous system, at least for a Cobb angle up to 42° keeping a symmetry of weight. According to the systematic review by Paramento et al (2024), studies are fairly divided concerning static postural control. Leteneur et al. (2021) found a correlation between the trunk inclination and several standing parameters in AIS subjects while other authors (Kaviyani et al., 2020) found no significant difference between AIS and control subjects in static balance control. In terms of dynamic balance, studies have been conducted on walking behaviour of AIS subjects. Yang et al. (2013) described asymmetric movements of the trunk and ankles in the frontal and transverse planes during walking. These 2 parameters should be analysed in greater detail because they could compensate each other and show weight symmetry as a result. Gur et al. (2015) showed that there was no asymmetrical body mass in AIS patients using weight-bearing squat test of Equitest®. This study concluded that weight is symmetrically distributed to the lower extremities with knees flexed at different angles. Another study observed that brace use in AIS patients has no positive effect on weight-bearing symmetry (Yilmaz et al., 2023). This is why, wearing brace would improve balance control in terms of proprioception but not weight symmetry, which would not be influenced by scoliosis (Gur et al., 2015; Yilmaz et al., 2023). In general, there was a tendency in the Cobb≥40° subgroup to put more weight on the left leg compared with the other angle subgroups. The severity of scoliosis could be related to an increase in the sensory integration disorder (Baulieu et al., 2009), which could influence weight asymmetry in the Cobb≥40° subgroup.

Looking at the **strength** analysis, it can be noted that the 20°<Cobb<40° group required significantly more strength from both legs (right and left) than the control group in all translation conditions. In general, an increase in muscle strength at any AIS angle subgroup compared with control group is observed. In terms of strength as a function of the location of the major curve, we observed significantly greater strength in both legs in major lumbar scoliosis and in major thoracic scoliosis than in control group in all conditions except in TSB condition. Kuo et al. (2011) also showed that the AIS group had less balance control and to compensate AIS subjects had higher muscles strength (in multifidus, gluteus medius, and gastrocnemius) than control subjects under perturbation conditions on an unstable platform. The main action of the muscles of the trunk would be to correct medio-lateral perturbations, while the muscular activity of the legs would allow the correction of backward-forward disturbances (Kuo et al., 2011; Paramento et al., 2024). Park et al. (2013) observed this poorer dynamic balance control in AIS patients by grouping them according to the angle curve to evaluate left and right balance, forward and backward balance, and overall postural balance. There were no differences between the scoliosis groups but the scoliosis group's forward and backward balance and the scoliosis groups' left and right lateral balance were more unstable than the control group. There is a link between increased muscle strength and instability in balance control in AIS patients. Kuo et al. (2010) raised the hypothesis that they increased muscle activity to reduce the degree of freedom of movement, thereby facilitating balance control. They added that the foot primarily perceives platform movements, whereas the trunk assists in maintaining balance and interacts with movements of lower limb in dynamic standing balance (Kuo et al., 2010).

Symmetry of strength between the 2 legs showed no significant difference in any group (nor angle, nor location). The results seem to be fairly like those of the control group. Therefore, in this study, no correlation can be envisaged between the type of curve or the severity of the curve and an asymmetry of strength in the legs. Gauchard et al. (2001) determined effect of the type and location of AIS on global balance control using dynamic posturographic tests. This study suggests that the location of the major curve seems to influence lateral disequilibrium and vestibular symmetry. As reported by Gauchard, et al. (2001), scoliosis group with the best dynamic balance control is double major, then lumbar, then thoracolumbar and finally thoracic. This study also explains why dynamic balance control would be

more affected in patients with high major curves. It would be in relation to a less horizontal repositioning of the skull that induces vestibular asymmetry from lack of length to compensate above the major curve (Gauchard et al., 2001). In our results, the double major group seemed to have a higher strength in the left limb in backward translation and a higher force in the right limb in forward translation than the other groups. This could have something to do with the fact that they have a better control of balance as mentioned Gauchard et al. (2001). It could also be due to the small non-representative sample compared to the other groups.

Patients in this study with thoracic scoliosis have mainly right convex curve, whereas those with lumbar scoliosis have mainly left convex curve. In general, these convexities are most common in thoracic and lumbar scoliosis (Khouri et al., 2004). These observations are in line with the demographic data from our study. No correlation can be envisaged between the convex side of the scoliosis and an asymmetry of strength in the legs. However, the lumbar multifidus on the convex side seems to activate stronger than on the concave side during quick backward tilting and the contrary is observed for a slow anticipated postural perturbation with visual feedback (Kuo et al.,2011). More, Farahpour et al. (2014) observed that the EMG responses of the biceps femoris and erector spinae muscles in scoliosis group was asymmetrical in forward translation but symmetrical during backward translation. Patients had a greater EMG response of the biceps femoris in the same side of her convex curve. In the same study, all control group muscles presented right-left symmetrical activities during both tests similarly to our results. However, in AIS the leg muscles on the dominant side can activate stronger and earlier than on the non-dominant side (Kuo et al., 2011). This could be one of the reasons for the small variations in our results, in addition to the influence of height, weight, age and gender.

Comparison of the **latency** of the motor responses of the different legs and symmetry showed no significant difference in any group. The results of this study are in line with Kuo et al. (2011) who found that AIS and normal subjects strongly coactivated bilateral leg and trunk muscles at similar latencies to maintain balance during sudden backward tilting,

The central nervous system may also have an impact in motor responses. Domenech et al. (2011) showed differences in activation patterns in motor-related cortical

areas between AIS and healthy subjects. The main impact on balance inputs was observed in the vestibular afferent system, so motor responses do not appear to be affected by the type of scoliosis (Paramento et al., 2024). Besides, the systematic review of Cortés-Pérez et al. (2022) investigates the relationship between vestibular system, morphological alterations and AIS, suggesting a potential association between vestibular changes and the development of spinal deformities. Studies mainly concentrates on alterations in the left side of the vestibular system, due to the higher occurrence of right curves. These alterations could influence the length, thickness, and angulation of the anterior and lateral semicircular canals on the left side, though the direction of change in canal verticality remains uncertain. However, it's unclear whether vestibular structural asymmetry precedes or results from spinal deformities in AIS, and no definitive link has been established between vestibular deformities and the specific characteristics of scoliotic curves or functional abnormalities observed in AIS patients. This is consistent with our results, which tend not to show a link between motor responses to dynamic balance and AIS nor classified per angle nor location of curvature; except for the strength applied by the legs, where the scoliotic subjects showed using a greater strength than the control group, and even more in the case of major lumbar scoliosis. Despite these uncertainties, the review underlines the importance of further research into vestibular abnormalities as a potential etiological factor in AIS.

To add, in term of dynamic balance control, asymmetries exist between the right and left lower limbs of AIS patient in gait. These asymmetries were observed in ground reaction force, step length, stance duration, and swing phases (Paramento et al., 2024).

V. Conclusion

The aim of this study was to analyze the motor responses of scoliotic subjects in dynamic balance at different levels of intensity as assessed by the Equitest. The analysis focused on weight symmetry, strength of the right and left leg, strength symmetry, response latency of the right and left leg and latency symmetry. It compared AIS subjects according to the angle and location of the major curve with control subjects. The results showed no significant differences for weight symmetry, strength symmetry, right and left leg latency or latency symmetry. The strength of the motor responses of the right and left leg seems to be greater in the AIS subjects of all groups than in the control subjects. The literature reports asymmetry of the trunk muscles in scoliotic subjects in both static and dynamic movements. However, in terms of the muscular chain of the lower limbs, the evidence remains unclear. This study provides evidence of a difference in the strength between control subjects and scoliotic subjects exerted on the force platforms in backward and forward translations. In this study, the visual system was not variable, so it would be interesting to see how the motor responses analysed in this study relate to the vestibular, proprioceptive and central nervous systems analysed in other studies of dynamic balance in scoliotic subjects.

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https://statorials.org/taille-de-lechantillon/

Objective: The aim of this study was to evaluate the motor responses during dynamic balance control of adolescents with idiopathic scoliosis, compared to healthy adolescents, using the Motor Control Test (MCT) with the Equitest® system.

Background: Adolescent idiopathic scoliosis (AIS) is the most prevalent form of scoliosis. AIS patients would present disturbances in balance control, involving impaired multisensory integration of vestibular, visual, and somatosensory inputs. Therefore, biomechanical aspects and sensorimotor issues contribute to a reorganization of static and dynamic balance control. No studies have looked at motor strategies in both legs in different scoliotic groups compared with a control group.

Materials and methods: 54 scoliotic patients and 54 control subjects participated in this study. The AIS patients were divided into three groups according to the Cobb angle curve: Cobb≤20° (n=14), 20°<Cobb<40° (n=34), Cobb ≥40° (n=6) and into three groups according to the location of the major curve: major thoracic (n=33), major lumbar (n=16), double major (n=5). This enabled the comparison of AIS patients with healthy adolescents, according to the severity of the scoliosis and according to the location of the scoliosis. A Computerized dynamic posturography, the Equitest®, was used to record postural responses in terms of weight symmetry, latency, and strength response. Therefore, only the Motor Control Test (MCT) was analyzed in this study including several perturbations, 3 backward translations and 3 forward translations with different magnitudes (small, medium, and large).

Results: Weight symmetry on the legs showed no significant difference between any groups or subgroups. Any significant difference was observed in the symmetry of the leg response latency between the different groups and in the comparison for left limb's latency and right limb's latency. There was no significant difference in strength symmetry analysis between the different groups. In the analysis of the strength of the right and left limb, AIS subjects of the group 20°<Cobb<40° was greater than in control groups. In this same analysis between AIS major thoracic, AIS major lumbar and control subjects, there are significant differences with control group in all conditions except for small translation backward.

Discussion: This study has some limits including the size of the samples, the homogeneity of the demographic data and there are no standard data for the MCT analysis of Equitest® for adolescents. Weight distribution is symmetrical, which could be explained by compensation in the central nervous system. As for the strength symmetry of the motor responses, back muscles could be compensated for by the muscular chain of the lower limbs. The greater force exerted by the right and left leg is consistent with previous studies showing greater muscle activity in scoliotic subjects. The central nervous system and vestibular afferent system appear to have an impact in motor responses.