

## Artificial Intelligence Identifies Gait Subgroups in Low Back Pain Patients: Implications for Individualized Interventions

Felipe Fernandes Gonzalez<sup>1</sup>, Leonardo Metsavaht<sup>2</sup>, Eliane Celina Guadagnin, Talissa Oliveira Generoso, Dino Samartzis<sup>3</sup>, Jorge A Chahla, Marcus Vinicius Malheiros Luzo<sup>4</sup>, Gustavo Leporace<sup>2</sup>

<sup>1</sup>Orthopedic Surgery, Rush University Medical Center, <sup>2</sup>Department of Biomechanics Research, <sup>3</sup>Rush University Medical Center, <sup>4</sup>Department of Orthopedics and Trauma (DOT)

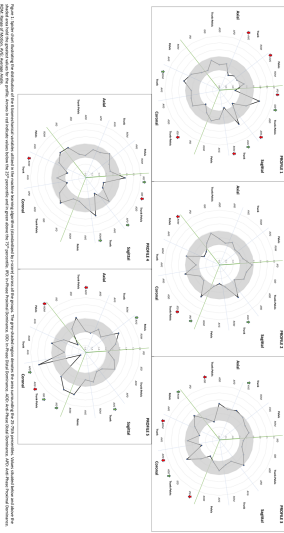
**INTRODUCTION:** Low back pain (LBP) is the world's most disabling condition, with tenuous treatment outcomes necessitating deep phenotyping via artificial intelligence (AI) solutions for more "personalized" management. Recent studies have highlighted the potential of gait analysis to reflect the underlying mechanisms and adaptations of LBP. Identifying gait subgroups based on trunk and pelvis motion/coordination could inform individualized interventions. Utilizing AI, our study aimed to identify different gait profiles in LBP patients and assess their clinical characteristics.

**METHODS:** Three-dimensional gait kinematics of 111 individuals with LBP (acute and chronic) were analyzed using an optoelectronic system. Mean angles, range of motion (ROM) and coordination of the trunk and pelvis across three planes were evaluated. Principal component analysis, self-organizing maps, and K-means clustering techniques were used to identify distinct gait profiles. Clinical characteristics (e.g. demographics, hip and trunk ROM, hip strength) were compared across profiles using the Kruskal-Wallis test with Bonferroni adjustment, at a 5% significance level. The 25th and 75th percentiles were used as reference for clinical interpretation.

### RESULTS:

Five distinct gait profiles were identified ( $p < 0.05$ ) (**Figure 1**). Profile 1 was mainly characterized by increased lateral trunk ROM and flexed trunk ( $4.1^\circ$ ;  $5.2^\circ$ ;  $p < 0.05$ ) (**Table 1**). Profile 2 featured trunk flexion and posterior pelvic tilt ( $3.4^\circ$ ;  $7.2^\circ$ ;  $p < 0.05$ ). Profile 3 presented excessive pelvic inclination and ROM and maximum angle in the coronal plane ( $2.9^\circ$  and  $11.1^\circ$ ;  $p < 0.05$ ) and pelvic anterior tilt ( $12.2^\circ$ ;  $p < 0.05$ ). Profile 4 showed trunk extension, and excessive trunk axial ROM ( $-3.0^\circ$ ;  $7.1^\circ$ ;  $p < 0.05$ ). Profile 5 featured a prominent pelvis-trunk in-phase component in the coronal and axial planes with pelvic predominance (20.2%; 45.6%;  $p < 0.01$ ). Profiles 1 and 2 predominantly consisted of males with higher body mass ( $>77.3\%$ ;  $>76.8\text{kg}$ ;  $p < 0.00$ ), while profiles 3 and 4, females with lower body mass ( $>86.2\%$ ;  $<65\text{kg}$   $p < 0.00$ ) (**Table 2**). Profile 4 displayed increased hip passive ROM and profile 5 decreased ( $p < 0.05$ ). No significant differences were found in hip strength and trunk ROM ( $p > 0.05$ ).

**DISCUSSION AND CONCLUSION:** This study successfully identified five distinct gait profiles associated with LBP utilizing a non-supervised machine learning algorithm. Each demonstrates unique differences in pelvis and trunk coordination, positioning, range of motion, and demographic characteristics that can inform targeted, personalized interventions. Profile 1 has gait and physical characteristics that potentially exacerbate loads on intervertebral discs and facet joints. Profile 2 exhibited lumbar rectification, which can impair the distribution of shear forces by the spine and its ability to withstand gravitational force. This characteristic may increase the risk of medical attention. Profile 3 was marked by significant pelvic alterations, which may be associated with hip pathology. This association underscores the importance of integrated hip and spine assessments in the diagnostic process for patients with similar gait abnormalities. Profile 4 featured characteristics that antagonize profile 1. This profile presented a combination of trunk extension and excessive rotation, potentially imposing additional loads on facet joints and elevating the risk of facet joint pathology. Profile 5 was characterized by a tight motor control in the axial plane, which could be the consequence of stiff hips. This gait profile suggests that enhancing hip mobility could be critical in alleviating compensatory spinal mechanisms and improving overall movement patterns. Each profile presented unique kinematic and physical characteristics, providing meaningful insights into clinical implications, associated pathologies, anatomical structures at risk, and management.



**Table 1:** Gait Characteristics of Low Back Pain Individuals by Subgroup. Data are presented as median.

	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	p-value
<b>3D Kinematics - Sagittal</b>						
Pelvis-Torso		34.4°	25.5°		26.1°	<0.001
Coordination IPD				24.3°	30.7	<0.001
Pelvis-Torso	48.8°	33.8	29.1°			<0.001
Coordination IPD				10.8°	18.8°	<0.001
Pelvis-Torso	16.4°	13.2	17.8°			<0.001
Coordination APD		13.5°	23.2°			<0.001
Pelvis-Torso	18.1°			20.9°		<0.001
Coordination APD					12.3	<0.001
Trunk Angle - Average (°)	4.1°	3.4°	-0.4°	-0.9°	-1.7°	<0.001
Trunk Angle - ROM (°)	27°	3.2°	3.1°	4.0°	3.3°	<0.001
Pelvis Angle - Average (°)	10.1°	7.4°	12.1°	9.1	10.1	<0.001
Pelvis Angle - ROM (°)	3.7°	2.6°	2.4°	2.9°	4.4°	0.001
<b>3D Kinematics - Coronal</b>						
Pelvis-Torso	5.6°	10.7°	2.3°	5.5°	11.7°	<0.001
Coordination IPD					20.2°	<0.001
Pelvis-Torso	18.6°	8.1°	14.0	19.3°	26.2°	<0.001
Coordination APD				68.9°		<0.001
Pelvis-Torso	75.1°	62.4°	79.3°		48.4°	<0.001
Coordination APD						<0.001
Pelvis-Torso	13.1°	18.8°	8.4°	8.7°	21.9°	<0.001
Coordination APD						<0.001
Trunk Angle - Average (°)	-0.7	-1.7	0.0	-0.1	-2.1	0.001
Trunk Angle - ROM (°)	8.3°	3.7°	3.8°	3.4°	4.8°	<0.001
Pelvis Angle - Average (°)	0.9°	-0.5°	0.2	0.9°	0.7	<0.001
Pelvis Angle - ROM (°)	8.8°	7.8°	11.8°	10.7°	8.2°	<0.001
<b>2D Kinematics - Axial</b>						
Pelvis-Torso	16.8	17.1	19.9	23.8	20.7	0.11
Coordination IPD						
Pelvis-Torso	41.8°	46.4°	38.1°	34.9	45.6°	0.001
Coordination APD						
Pelvis-Torso	19.8°	20.2°	27.8°	19.2°	18.0°	0.001
Coordination APD						
Pelvis-Torso	16.8	13.5	17.7°	17.9	14.1°	0.01
Coordination APD						
Trunk Angle - Average (°)	-4.1°	1.0	3.1°	1.2	0.7	0.001
Trunk Angle - ROM (°)	4.7°	2.5°	7.1°	7.3°	6.4°	0.001
Pelvis Angle - Average (°)	-0.5°	0.5°	0.9	0.7	2.5°	<0.001
Trunk Angle - ROM (°)	9.2	7.8	10.8	9.1	8.4	0.32

0.1, 0.5, 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 230, 240, 250, 260, 270, 280, 290, 300, 310, 320, 330, 340, 350, 360, 370, 380, 390, 400, 410, 420, 430, 440, 450, 460, 470, 480, 490, 500, 510, 520, 530, 540, 550, 560, 570, 580, 590, 600, 610, 620, 630, 640, 650, 660, 670, 680, 690, 700, 710, 720, 730, 740, 750, 760, 770, 780, 790, 800, 810, 820, 830, 840, 850, 860, 870, 880, 890, 900, 910, 920, 930, 940, 950, 960, 970, 980, 990, 1000, 1010, 1020, 1030, 1040, 1050, 1060, 1070, 1080, 1090, 1100, 1110, 1120, 1130, 1140, 1150, 1160, 1170, 1180, 1190, 1200, 1210, 1220, 1230, 1240, 1250, 1260, 1270, 1280, 1290, 1300, 1310, 1320, 1330, 1340, 1350, 1360, 1370, 1380, 1390, 1400, 1410, 1420, 1430, 1440, 1450, 1460, 1470, 1480, 1490, 1500, 1510, 1520, 1530, 1540, 1550, 1560, 1570, 1580, 1590, 1600, 1610, 1620, 1630, 1640, 1650, 1660, 1670, 1680, 1690, 1700, 1710, 1720, 1730, 1740, 1750, 1760, 1770, 1780, 1790, 1800, 1810, 1820, 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6810, 6820, 6830, 6840, 6850, 6860, 6870, 6880, 6890, 6900, 6910, 6920, 6930, 6940, 6950, 6960, 6970, 6980, 6990, 7000, 7010, 7020, 7030, 7040, 7050, 7060, 7070, 7080, 7090, 7100, 7110, 7120, 7130, 7140, 7150, 7160, 7170, 7180, 7190, 7200, 7210, 7220, 7230, 7240, 7250, 7260, 7270, 7280, 7290, 7300, 7310, 7320, 7330, 7340, 7350, 7360, 7370, 7380, 7390, 7400, 7410, 7420, 7430, 7440, 7450, 7460, 7470, 7480, 7490, 7500, 7510, 7520, 7530, 7540, 7550, 7560, 7570, 7580, 7590, 7600, 7610, 7620, 7630, 7640, 7650, 7660, 7670, 7680, 7690, 7700, 7710, 7720, 7730, 7740, 7750, 7760, 7770, 7780, 7790, 7800, 7810, 7820, 7830, 7840, 7850, 7860, 7870, 7880, 7890, 7900, 7910, 7920, 7930, 7940, 7950, 7960, 7970, 7980, 7990, 8000, 8010, 8020, 8030, 8040, 8050, 8060, 8070, 8080, 8090, 8100, 8110, 8120, 8130, 8140, 8150, 8160, 8170, 8180, 8190, 8200, 8210, 8220, 8230, 8240, 8250, 8260, 8270, 8280, 8290, 8300, 8310, 8320, 8330, 8340, 8350, 8360, 8370, 8380, 8390, 8400, 8410, 8420, 8430, 8440, 8450, 8460, 8470, 8480, 8490, 8500, 8510, 8520, 8530, 8540, 8550, 8560, 8570, 8580, 8590, 8600, 8610, 8620, 8630, 8640, 8650, 8660, 8670, 8680, 8690, 8700, 8710, 8720, 8730, 8740, 8750, 8760, 8770, 8780, 8790, 8800, 8810, 8820, 8830, 8840, 8850, 8860, 8870, 8880, 8890, 8900, 8910, 8920, 8930, 8940, 8950, 8960, 8970, 8980, 8990, 9000, 9010, 9020, 9030, 9040, 9050, 9060, 9070, 9080, 9090, 9100, 9110, 9120, 9130, 9140, 9150, 9160, 9170, 9180, 9190, 9200, 9210, 9220, 9230, 9240, 9250, 9260, 9270, 9280, 9290, 9300, 9310, 9320, 9330, 9340, 9350, 9360, 9370, 9380, 9390, 9400, 9410, 9420, 9430, 9440, 9450, 9460, 9470, 9480, 9490, 9500, 9510, 9520, 9530, 9540, 9550, 9560, 9570, 9580, 9590, 9600, 9610, 9620, 9630, 9640, 9650, 9660, 9670, 9680, 9690, 9700, 9710, 9720, 9730, 9740, 9750, 9760, 9770, 9780, 9790, 9800, 9810, 9820, 9830, 9840, 9850, 9860, 9870, 9880, 9890, 9900, 9910, 9920, 9930, 9940, 9950, 9960, 9970, 9980, 9990, 10000.

3D: Three-dimensional; IPD: In-Plane Distal Distance; ROM: Range of Motion; APD: Anterior-Posterior Distal Distance; ROM: Range of Motion; IR: Internal Rotation; IR: Internal Rotation; Pelvis and trunk angles in sagittal plane (°) values indicate anteroposterior flexion. Pelvis and trunk angles in coronal plane (°) values indicate ipsilateral spread inclination. Pelvis and trunk angles in axial plane (°) values indicate ipsilateral forward rotation. Thomas test.

**Table 2:** Demographic and Clinical Characteristics of Low Back Pain Individuals by Subgroup. Data are presented as median (25<sup>th</sup> and 75<sup>th</sup> percentile).

	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	p-value
<b>Demographic</b>						
Number of patients	22	18	29	27	15	
Age (yr)	44.0 (39.5-44.0)	44.0 (38.5-44.0)	45.0 (38.5-44.0)	49.0 (41.0-49.0)	56.0	0.34
Body mass (kg)	83.2 (75.8-83.2)	76.8 (72.2-76.8)	65.0 (59.3-65.0)	61.5 (56.6-61.5)	79.1 (63.5-79.1)	0.001
Height (cm)	175.6 (167.4-175.6)	176.4 (173.2-176.4)	164.8 (161.4-164.8)	164.5 (158.4-164.5)	175.4 (167.6-175.4)	0.001
BMI (kg/m <sup>2</sup> )	26.7 (25.8-26.7)	25.6 (22.8-25.6)	24.1 (21.6-24.1)	22.6 (21.5-22.6)	25.6 (22.9-25.6)	<0.001
Sex distribution (n / %)	27 (22.7) *	27 (11.1) *	207 (86.2) *	247 (88.9) *	77 (46.7) *	<0.001
<b>Strength and ROM</b>						
<b>IRIS</b>						
Hip Abduction Strength (%BW)	30.9 (23.5-30.9)	37.0 (27.4-37.0)	32.8 (19.4-32.8)	39.5 (27.0-39.5)	20.9 (20.2-20.9)	0.22
Hip ER Strength (%BW)	14.5 (10.4-14.5)	16.7 (12.6-16.7)	16.3 (12.5-16.3)	16.9 (12.0-16.9)	13.0 (11.9-13.0)	0.29
Lumbar Flexion (°)	17.2 (17.2-17.2)	22.2 (22.2-22.2)	20.4 (18.7-20.4)	18.7 (18.7-18.7)	16.7 (16.7-16.7)	0.74
Lumbar Extension (°)	41.0 (35.5-41.0)	41.0 (35.5-41.0)	48.0 (44.0-48.0)	48.0 (44.0-48.0)	31.5 (28.0-31.5)	0.37
Lumbar Lateral Flexion (°)	20.0 (13.5-20.0)	15.0 (11.0-15.0)	16.0 (11.0-16.0)	16.0 (12.0-16.0)	13.5 (9.0-13.5)	0.74
Lumbar Lateral Flexion (°)	31.0 (31.0-31.0)	19.5 (19.5-19.5)	21.0 (18.0-21.0)	21.5 (18.0-21.5)	24.5 (17.0-24.5)	0.25
Hip Flexion (°)	70.8 (63.8-70.8)	70.8 (63.8-70.8)	80.0 (74.0-80.0)	82.0 (72.8-82.0)	70.0 (58.8-70.0)	0.01
Hip Extension (°)	83.0 (83.0-83.0)	83.0 (83.0-83.0)	90.0 (90.0-90.0)	111.0 (111.0-111.0)	90.0	<0.001
IR Hip (°)	24.0 (20.5-24.0)	34.0 (27.5-34.0)	40.0 (30.0-40.0)	42.0 (32.8-42.0)	22.0 (12.0-22.0)	<0.001
ER Hip (°)	48.0 (39.8-48.0)	48.0 (42.8-48.0)	38.0 (34.8-38.0)	38.0 (34.8-38.0)	46.25 (46.25-46.25)	0.03
Thomas (°)	-11.0 (-14.5-11.0)	-14.0 (-15.0-14.0)	-13.0 (-16.0-13.0)	-13.0 (-10.8-13.0)	-11.0 (-14.0-11.0)	0.52

\*Indicates statistically significant differences in sex distribution within the groups.

0.1, 0.5, 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 230, 240, 250, 260, 270, 280, 290, 300, 310, 320, 330, 340, 350, 360, 370, 380, 390, 400, 410, 420, 430, 440, 450, 460, 470, 480, 490, 500, 510, 520, 530, 540, 550, 560, 570, 580, 590, 600, 610, 620, 630, 640, 650, 660, 670, 680, 690, 700, 710, 720, 730, 740, 750, 760, 770, 780, 790, 800, 810, 820, 830, 840, 850, 860, 870, 880, 890, 900, 910, 920, 930, 940, 950, 960, 970, 980, 990, 1000, 1010, 1020, 1030, 1040, 1050, 1060, 1070, 1080, 1090, 1100, 1110, 1120, 1130, 1140, 1150, 1160, 1170, 1180, 1190, 1200, 1210, 1220, 1230, 1240, 1250, 1260, 1270, 1280, 1290, 1300, 1310, 1320, 1330, 1340, 1350, 1360, 1370, 1380, 1390, 1400, 1410, 1420, 1430, 1440, 1450, 1460, 1470, 1480, 1490, 1500, 1510, 1520, 1530, 1540, 1550, 1560, 1570, 1580, 1590, 1600, 1610, 1620, 1630, 1640, 1650, 1660, 1670, 1680, 1690, 1700, 1710, 1720, 1730, 1740, 1750, 1760, 1770, 1780, 1790, 1800, 1810, 1820, 1830, 1840,