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

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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^{o}; 5.2^{o}; $p<0.05$) **(Table 1).** Profile 2 featured trunk flexion and posterior pelvic tilt (3.4^{o}; 7.2^{o}; $p<0.05$). Profile 3 presented excessive pelvic inclination and ROM and maximum angle in the coronal plane (2.9^{o} and 11.1^{o}; $p<0.05$) and pelvic anterior tilt (12.2^{o}; $p<0.05$). Profile 4 showed trunk extension, and excessive trunk axial ROM (-3.0^{o}; 7.1^{o}; $p<0.05$). 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%; >76.8kg; $p<0.00$), while profiles 3 and 4, females with lower body mass (>86.2%; <65kg $p<0.00$) **(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 LPB 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.

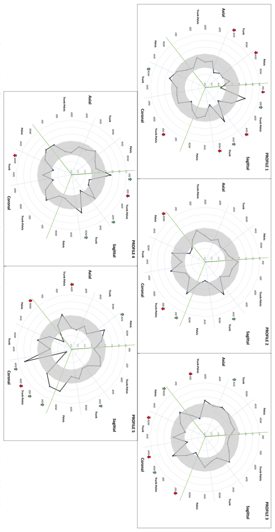

Figure 1: Spider chart illustrating the distribution of the 6 biomechanical variables utilized in the machine learning algorithm (standardized by z-score) across all the groups. The grey-shaded region denotes the area surrounding the 25-75th percentiles. Values situated below and above the shaded area hold the greatest values for the profile. Arrows in red indicate values below the 25th percentile and in green above the 75th percentile. IPD: In-Phase Proximal Dominance. IDD: In-Phase Distal Dominance. ADD: Anti-Phase Distal Dominance. APD: Anti-Phase Proximal Dominance. ROM: Range of Motion. AVG: Average Angle.

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
3D Kinematics - Sagittal						
Pelvis-Trunk Coordination IPD	**18.0** $^{@\#}$	34.4 $^{\#}$	25.7 $^{@}$	**40.3** $^{@}$	26.1 $^{@}$	< 0.00
Pelvis-Trunk Coordination IDD	**48.8** $^{\#}$	33.8	29.7 $^{\#}$	**24.3** $^{\#}$	38.7	< 0.00
Pelvis-Trunk Coordination ADD	16.4 $^{\#}$	13.2	17.0 $^{\#}$	10.9 $^{\#}$	**19.8** $^{\#}$	<0.00
Pelvis-Trunk Coordination APD	**10.1** $^{\#}$	13.3 $^{@}$	25.2 $^{\#@}$	**20.9** $^{\#}$	12.5	< 0.00
Trunk Angle - Average (°)	**4.1** $^{@}$	**3.4 #**	-0.6 $^{@\#}$	**-3.0** $^{@\#}$	-1.7 $^{@\#}$	< 0.00
Trunk Angle - ROM (°)	**2.7** $^{\#@}$	3.2 $^{\#}$	3.1 $^{\#}$	**4.0** $^{\#}$	3.3 $^{@}$	< 0.00
Pelvis Angle - Average (°)	10.5 $^{@}$	7.4 $^{@}$	**12.2** $^{@}$	9.9	10.8	<0.01
Pelvis Angle - ROM (°)	3.3 $^{\#}$	2.5 $^{@}$	2.6 $^{@\#}$	2.9 $^{@}$	4.6 $^{@}$	0.00
3D Kinematics - Coronal						
Pelvis-Trunk Coordination IPD	5.6 $^{@}$	**10.2** $^{\#}$	**2.3** $^{@\#}$	5.5 $^{@\#}$	**11.7** $^{@}$	< 0.00
Pelvis-Trunk Coordination IDD	**10.6** $^{\#}$	**9.1** $^{@}$	14.0	**19.3** $^{\#@}$	**20.2** $^{\#@}$	< 0.00
Pelvis-Trunk Coordination ADD	73.4 $^{@}$	62.4 $^{\#}$	79.3 $^{@\#}$	68.9 $^{@}$	**40.4** $^{@}$	< 0.00
Pelvis-Trunk Coordination APD	13.1 $^{\#@!}$	18.0 $^{\#@}$	**5.4** $^{\#}$	**5.7** $^{@}$	**27.7** $^{\#@!}$	< 0.00
Trunk Angle - Average (°)	-0.7	-1.7	0.0	-0.3	-2.1	0.09
Trunk Angle – ROM (°)	**5.2** $^{\#@}$	3.7 $^{\#@}$	**2.9** $^{@}$	**2.6** $^{\#}$	**4.5** $^{\#@}$	< 0.00
Pelvis Angle - Average (°)	0.9 $^{@}$	-0.5 $^{@}$	0.2	0.9 $^{@}$	0.7	<0.00
Pelvis Angle - ROM (°)	8.8 $^{@}$	**7.2** $^{\#}$	**11.1** $^{@\#}$	10.7 $^{@\#}$	**5.2** $^{@}$	< 0.00
3D Kinematics - Axial						
Pelvis-Trunk Coordination IPD	16.8	17.1	19.9	23.8	20.7	0.11
Pelvis-Trunk Coordination IDD	44.8 $^{@}$	46.4 $^{@}$	**30.1** $^{@}$	34.9	**45.6** $^{@}$	0.00
Pelvis-Trunk Coordination ADD	19.8 $^{@}$	20.2 $^{@}$	27.8 $^{@}$	19.2 $^{@}$	**18.0** $^{@}$	0.00
Pelvis-Trunk Coordination APD	16.8	13.5	17.7 $^{@}$	17.9	14.1 $^{@}$	0.01
Trunk Angle – Average (°)	**-1.1** $^{@}$	1.0	**3.1** $^{@}$	1.2	0.7	0.00
Trunk Angle – ROM (°)	4.7 $^{@\#}$	5.3 $^{@}$	7.3 $^{@}$	**7.1** $^{\#}$	5.6 $^{@}$	0.00
Pelvis Angle – Average (°)	**-0.6** $^{@}$	0.5 $^{@}$	0.9	0.7	**2.5** $^{@}$	<0.00
Pelvis Angle – ROM (°)	9.2	7.8	10.6	9.1	8.4	0.32

@, #, %, !, $: The pairs of symbols indicate statistically significant differences between the groups.

Bold/Highlight green and red: Values higher than the 75th percentile and smaller than the 25th percentile when statistically significant difference between the groups.

3D: Three-dimensional. IPD: In-Phase Proximal Dominance. IDD: In-Phase Distal Dominance. ADD: Anti-Phase Distal Dominance. APD: Anti-Phase Proximal Dominance. ROM: Range of Motion. ER: External Rotation. IR: Internal Rotation. Pelvis and trunk angles in sagittal plane: (+) values indicate anteversion/flexion. Pelvis and trunk angles in coronal plane: (+) values indicate ipsilateral upward inclination. Pelvis and trunk angles in axial plane: (+) values indicate ipsilateral forward rotation.

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

	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	p-value
Demographic						
Number of patients	22	18	29	27	15	
Age (yrs)	44.0 (39.5-51.5)	44.0 (35.2-51.0)	48.0 (36.7-55.7)	45.0 (38.5-48.2)	49.0 (41.0-56.0)	0.34
Body mass (kg)	**83.2 (75.0-98.6)** $^{\#!}$	76.8 (72.2-93.0) $^{\%\$}$	65.0 (59.3-73.2) $^{\$!}$	**61.5 (56.6-69.1) @%#**	79.3 (63.5-98.5) $^{@}$	**0.00**
Height (cm)	175.6 (167.4-179.6) $^{\#@}$	**176.4 (173.2-181.6)** $^{\$\%}$	164.8 (161.4-168.9) $^{\#\$}$	**164.5 (158.4-171.6) @%**	173.4 (167.6-179.8)	**0.00**
BMI (kg/m²)	**26.7 (25.0-30.5)** $^{\$}$	25.6 (22.8-27.8)	24.1 (21.6-27.4)	**22.6 (21.5-24.0) #$**	25.6 (22.9-32.0) $^{\#}$	**<0.00**
Sex distribution (n / %)	5F (22.7) * 17M (77.3)	2F (11.1) * 16M (88.9)	25F (86.2) * 4M (13.8)	24F (88.9) * 3M (11.1)	7F (46.7) 8M (53.3)	**< 0.00**
Strength and ROM tests						
Hip Abduction Strength (%BW)	30.9 (23.5-39.2)	37.0 (27.4-46.0)	32.8 (19.8-42.6)	38.5 (27.0-52.2)	29.9 (20.2-41.2)	0.22
Hip ER Strength (%BW)	14.5 (10.4-17.2)	16.7 (12.6-22.2)	16.3 (12.6-20.4)	16.9 (12.0-18.7)	13.0 (11.9-16.7)	0.29
Lumbar Flexion (°)	41.0 (35.5-50.5)	41.0 (33.5-53.5)	48.0 (41.0-56.0)	48.0 (34.5-54.0)	31.5 (24.0-49.2)	0.74
Lumbar Extension (°)	20.0 (13.5-31.0)	15.0 (11.0-19.5)	16.0 (11.0-21.0)	16.0 (12.0-24.2)	13.5 (9.0-21.8)	0.37
Lumbar Lateral Flexion (°)	21.0 (18.0-24.5)	22.0 (15.5-31.5)	25.0 (18.0-27.0)	21.5 (18.0-32.0)	24.5 (17.0-28.2)	0.74
Lumbar Lateral Flexion (°)	22.0 (19.5-25.5)	22.0 (14.5-31.0)	24.0 (19.0-30.0)	25.0 (20.8-31.0)	19.0 (16.0-29.5)	0.23
Hip Flexion (°)	**70.0 (63.0-83.5) @**	79.0 (63.5-96.0)	80.0 (74.0-90.0)	**92.0 (72.8-111.0) @**	70.0 (59.8-90.0)	**0.01**
IR Hip (°)	24.0 (20.5-36.0) $^{\$!}$	34.0 (27.5-36.5)	40.0 (30.0-47.0) $^{@\$}$	**42.0 (32.8-49.2) #!**	**22.0 (12.0-37.5) @#**	**<0.00**
ER Hip (°)	**48.0 (39.0-55.00)@!**	**48.0 (42.0-51.00)#%**	**38.0 (34.0-45.00)@#**	46.0 (35.2-50.0)	**38.0 (32.0-46.25)!%**	**0.03**
Thomas (°)	-11.0 (-14.5-(-5.5)	-14.0 (-15.0-(-9.5)	-13.0 (-16.0-(-9.0)	-13.0 (-19.8-(-8.8)	-11.0 (-14.0-(-6.5)	0.52

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

@, #, %, !, $: The pairs of symbols indicate statistically significant differences between the groups.

Bold/Highligh green and red: Highest and smallest value when statistically significant difference between the groups.

BMI: Body Mass Index. 3D: Three-dimensional. ROM: Range of Motion. ER: External Rotation. IR: Internal Rotation. Pelvis and trunk angles in sagittal plane: (+) values indicate anteversion/flexion. Pelvis and trunk angles in coronal plane: (+) values indicate ipsilateral upward inclination. Pelvis and trunk angles in axial plane: (+) values indicate ipsilateral forward rotation. Thomas: (+) values indicate hip flexion and (-) hip extension during Thomas test.