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Application of Automated Physiotherapeutic Devices in the Rehabilitation of Patients with Degenerative-Dystrophic Diseases of the Spine and Vertebrogenic Pain Syndrome

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Abstract. ***Background:*** Degenerative-dystrophic diseases of the spine (DDDS) are prevalent, relating to muscle conditions linked to persistent pain, neurological impairments, functional limitations, and issues with postural stability. Spinal osteochondrosis is a common feature of DDDS and often plays a significant role in the development of vertebrogenic pain syndrome. Therapeutic exercise programs aimed at enhancing the strength and stability of the trunk and improving mobility are extensively acknowledged as a highly effective method for the prevention and management of chronic pain conditions.

Materials and Methods: This pilot randomized controlled trial included 20 patients aged 25 to 36 years diagnosed with DDDS and vertebrogenic pain syndrome who underwent a 4-week course of physical rehabilitation, consisting of 30-minute sessions three times a week. The experimental group trained on the interactive platform *Huber 360 Evolution* ("*LPG Systems*", France), while the control group performed standard physical exercises. Ethical approval was obtained, and written informed consent was secured from all participants. Postural control was assessed by using center-of-pressure parameters (X-COP, Y-COP, trajectory length [L], sway area [S], and mean velocity [V]), whereas functional capacity was measured with the Oswestry Disability Index (ODI).

Results: The findings revealed that, initially, participants predominantly depended on visual cues. This was clearly demonstrated by the longer trajectory length (L), larger sway area (S), greater center-of-pressure displacement (X-COP, Y-COP), and higher mean velocity (V) recorded under eyes-closed conditions, thus indicating a reduction in postural stability. After a 4-week rehabilitation program using the *Huber 360 Evolution*, the experimental group demonstrated notable decreases in L and S during eyes-closed trials, signifying improved non-visual postural control. Meanwhile, X-COP, Y-COP, and V remained relatively stable. The comparative analysis reveals more substantial improvements in L and S in the experimental group compared to controls, and ODI scores decreased significantly, indicating improved functional capacity. Additionally, ODI scores showed a significant decline, reflecting enhanced functional capacity.

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Conclusions: The *Huber 360 Evolution* training significantly enhances non-visual postural control and functional capabilities in young adults suffering from vertebrogenic pain syndrome, delivering better results compared to conventional exercise therapy.

Keywords: rehabilitation, postural control, balance, stabilometry, Huber 360 Evolution, Oswestry Disability Index.

Automatizuotų fizioterapijos prietaisų naudojimas pacientų, sergančių stuburo degeneracinėmis-distrofinėmis ligomis ir vertebrogeniniu skausmo sindromu, reabilitacijai

Santrauka. ***Įvadas:*** Degeneracinės-distrofinės stuburo ligos (DDDS) yra plačiai paplitusios ir susijusios su raumenų sutrikimais, kurie lemia nuolatinį skausmą, neurologinius sutrikimus, funkcinius apribojimus bei laikysenos stabilumo sunkumus. Stuburo osteochondrozė yra dažnas DDDS požymis ir dažnai vaidina svarbų vaidmenį vertebrogeniniam skausmo sindromui išsivystyti. Terapinės mankštos programos, skirtos liemens jėgai ir stabilumui didinti bei judrumui gerinti, yra plačiai pripažįstamos kaip labai veiksmingas metodas lėtinio skausmo būklių prevencijai ir valdymui.

Medžiagos ir metodai: Šiame bandomajame atsitiktinių imčių kontroliuojamame tyrime dalyvavo 20 pacientų, kurių amžius buvo nuo 25 iki 36 metų, jiems buvo diagnozuota DDDS ir vertebrogeninis skausmo sindromas; jie dalyvavo 4 savaičių fizinės reabilitacijos kurse, susidedančiame iš 30 minučių užsiėmimų tris kartus per savaitę. Eksperimentinė grupė treniravosi naudodamasi interaktyviąja platforma „Huber 360 Evolution“ („LPG Systems“, Prancūzija), o kontrolinė grupė atliko standartinius fizinius pratimus. Buvo gautas etikos komiteto pritarimas, o iš visų dalyvių – raštiškas informuotas sutikimas. Laikysenos kontrolė buvo vertinama naudojant slėgio centro parametrus (X-COP, Y-COP, trajektorijos ilgį [L], svyravimo plotą [S] ir vidutinį greitį [V]), o funkcinis pajėgumas buvo matuojamas pagal Oswestry negalios indeksą (ODI).

Rezultatai: Tyrimo duomenys parodė, kad iš pradžių dalyviai daugiausia rėmėsi regimaisiais signalais. Tai aiškiai patvirtino ilgesnis trajektorijos ilgis (L), didesnis svyravimo plotas (S), didesnis slėgio centro poslinkis (X-COP, Y-COP) ir didesnis vidutinis greitis (V), užfiksuoti užsimerkus, o tai rodo laikysenos stabilumo sumažėjimą. Po 4 savaičių reabilitacijos programos, kurioje buvo naudojama „Huber 360 Evolution“, eksperimentinės grupės tiriamųjų užsimerkus atliktų bandymų metu pastebimai sumažėjo L ir S rodikliai, o tai reiškia, kad pagerėjo neregimasis laikysenos valdymas. Tuo tarpu X-COP, Y-COP ir V rodikliai išliko palyginti stabilūs. Lyginamoji analizė rodo, kad eksperimentinės grupės, palyginti su kontroline grupe, L ir S rodikliai pagerėjo žymiai labiau, o ODI balai reikšmingai sumažėjo, o tai yra pagerėjusio funkcinio pajėgumo rodmuo. Be to, ODI balai kur kas sumažėjo, o tai rodo pagerėjusį funkcinį pajėgumą.

***Išvados*:** Treniruotės su „Huber 360 Evolution“ labai pagerina nevizualinę laikysenos kontrolę ir funkcinį pajėgumą jaunų suaugusiųjų, kenčiančių nuo vertebrogeninio skausmo sindromo, ir leidžia pasiekti geresnių rezultatų, palyginti su tradicine mankštos terapija.

Raktiniai žodžiai: reabilitacija, laikysenos kontrolė, pusiausvyra, stabilometrija, „Huber 360 Evolution“, Oswestry negalios indeksas.

Introduction

Degenerative spine disease (DDS) is one of the most frequent pathological disorders affecting the human population. Annual epidemiological studies show that approximately 266 million people, accounting for 3.63% of the world's population, have *Degenerative-Dystrophic Disc Diseases* (DDDD). The prevalence reached 5.7% in Europe and 2.4% in Africa [1]. In the functional spinal unit, numerous components are affected, including (but not limited to) intervertebral discs, vertebral bodies, facet joints, ligamenta flava, and longitudinal ligaments. From a clinical and radiologic perspective, DDS will manifest as disc dehydration, disc calcification, gas accumulation in the disc (vacuum phenomenon), disc bulging, and intervertebral disc herniation [2]. Degeneration-induced changes in

vertebral bodies involve structural and compositional alterations at the levels of the vertebral tissue, and frequently result in the generation of osteophytes or the progression of erosive osteochondrosis that impairs vertebral endplates [3]. Resnick (1985) introduced a systematic six-stage framework for vertebral osteochondrosis, which he designated as vertebral osteochondrosis. This process encompasses the following stages: intervertebral disc thinning combined with hyaline degeneration, the occurrence of chondral microfractures, the activation of chondroblasts, subchondral reactive neovascularization, demineralization of bony trabeculae, and the development of osteosclerosis [4]. Chronic low back pain is the most obvious clinical feature of spinal degeneration. This symptom is highly dependent on inflammatory mediators, such as tumor necrosis factor-alpha (TNF-α), and it is associated with an overstimulation of substance P. A notable characteristic of discogenic pain is the infiltration of nociceptive nerve fibers and microvasculature into the usually aneural and avascular intervertebral disc tissue [5]. Neuromuscular disturbances driven by pain have the potential to impact motor control, with symptoms of postural instability and erratic trunk motion commonly affecting movement during physical activities. These findings highlight the importance of neuromuscular system physiology to promote the integration of movement and balance of the posture in conjunction with the rehabilitation and highlight the importance of precise rehabilitation programs [6,7]. Several rehabilitation strategies have been implemented to tackle these deficits. One of the common approaches involves performing sensorimotor exercises on unstable platforms. These exercises are designed to enhance trunk endurance, improve stability, and build both endurance and resistance by focusing on limb stabilization while working on the unstable surface. Moreover, dynamic exercises enable the restoration of coordination and motor control through proprioceptive training. Cognitive-behavioral therapy and educational approaches which address psychological and social aspects of chronic pain provides additional support to clients. More modern therapeutic concepts are now employing advanced devices such as the *Huber 360 Evolution* system. This device combines strength training with postural control work to engage the deep spinal stabilizer muscles that underpin segmental stability, and precise movement. Studies have demonstrated that these methods are effective in enhancing proprioception, improving neuromuscular coordination, and reducing pain severity [8,9]. The aim of this pilot randomized controlled study was to evaluate the preliminary effects of a rehabilitation program incorporating the *Huber 360 Evolution* system on postural control and functional disability compared with conventional floor-based stabilization exercises in patients with degenerative-dystrophic spinal disorders and vertebrogenic pain syndrome.

Materials and Methods

Study Design and Participants

This pilot randomized controlled trial was conducted between June and July 2025 at a rehabilitation center in Ukraine. The study included patients aged 25–36 years diagnosed with degenerative-dystrophic spine disease and vertebrogenic pain syndrome. The inclusion criteria were as follows: (1) clinically and/or radiologically confirmed degenerative-dystrophic spine disease; (2) vertebrogenic pain lasting ≥4 weeks; (3) a stable neurological status without progressive deficits; (4) ability to stand independently for postural assessment; (5) ability to complete a 4-week rehabilitation program (three sessions per week); and (6) agreement to refrain from additional physiotherapy during the study period. Exclusion criteria included: acute exacerbation of spinal pathology; progressive neurological deficits; previous spinal surgery; severe musculoskeletal disorders (fractures, inflammatory rheumatologic diseases, significant scoliosis); vestibular disorders; and uncontrolled cardiovascular, respiratory, or metabolic diseases. Twenty participants were randomly allocated (1:1) to the

experimental group (n = 10) or control group (n = 10) by using a computer-generated randomization sequence. Randomization was performed by an independent researcher not involved in the intervention. Due to the nature of the intervention, allocation concealment was not implemented, and neither the participants nor the therapists were blinded to group assignment, which may introduce performance bias.

Ethical Considerations

The study protocol was approved by the Kyiv Medical University ethics committee (Protocol No. 27, May 2025). All participants provided written informed consent prior to enrollment. The study was conducted in accordance with the Declaration of Helsinki.

Outcome Measures

Functional Assessment

The *Oswestry Disability Index* (ODI) served as a measure to evaluate the disability associated with low back pain. This assessment tool focuses on an individual's capacity to carry out daily activities such as walking, sitting, lifting, and other routine tasks. Evaluations were conducted both prior to and following the intervention.

Postural Control Assessment

Static and dynamic postural control were evaluated by using the *Huber 360 Evolution* system (*LPG Systems*, France). Static postural control was evaluated via the Romberg test on the *Huber 360* platform, performed first with eyes open, followed by eyes closed. Dynamic postural control was assessed by using platform-based tasks on the *Huber 360 Evolution* system. The following center-of-pressure (COP) parameters were recorded: lateral displacement (X-COP, mm), anterior–posterior displacement (Y-COP, mm), total COP trajectory length (L, mm), sway area (S, mm^2), and mean COP velocity (V, mm/s).

Primary and Secondary Outcomes

To improve the interpretability and reduce the risk of multiple comparisons, outcomes were categorized as primary and secondary.

The primary outcome of this study was the change in the center-of-pressure (COP) trajectory length (L) under eyes-closed (EC) conditions, as this parameter reflects postural stability in the absence of visual input.

Secondary outcomes included sway area (S, mm^2), mean COP velocity (V, mm/s), lateral displacement (X-COP, mm), anterior–posterior displacement (Y-COP, mm), and Oswestry Disability Index (ODI) scores.

Intervention

Both groups participated in a 4-week rehabilitation program consisting of 30-minute sessions, held three times per week. The control group performed floor-based core stabilization exercises targeting the multifidus and transversus abdominis muscles. The program included front and side planks and modified push-up variations (with or without a ball), performed in three sets of 10 repetitions, with 1–2 minutes of rest between the sets. The experimental group underwent training with the *Huber 360 Evolution* system, a motorized platform providing rotational and oscillatory movements with an adjustable amplitude and speed. The sessions included mobility, stretching, and strengthening com-

ponents. Mobility exercises involved controlled trunk and pelvic movements in forward, backward, lateral, and rotational directions. Each mobilization lasted 15–20 seconds, followed by 10 seconds of active recovery with a reduced amplitude, repeated 5 times per region. Stretching exercises primarily targeted the lumbar spine, thoracic spine, and lower limbs. Each stretch lasted 20 seconds, followed by 10 seconds of passive recovery, with 10–12 repetitions per muscle group. Isometric and dynamic contractions were included in the strength training. During the first week, isometric exercises were performed at 30–40% of maximum voluntary contraction, with 5–10 repetitions per exercise, each held for 20–25 seconds, and 10–15 seconds of passive recovery.

Statistical Analysis

Statistical analysis was performed by using *Statistica v.14.0.0.1* (*TIBCO Software Inc.*, USA). Data distribution was assessed by using the Shapiro–Wilk test. Given the small sample size, however, the ability of normality testing to reliably characterize the underlying distributions was limited. Stabilometric parameters were therefore analyzed primarily by using non-parametric methods and are presented as the median and the interquartile range (IQR). Within-group changes in stabilometric parameters were assessed by using the Wilcoxon signed-rank test, whereas between-group comparisons were performed by using the Mann–Whitney U test. Whereas, the ODI scores showed an approximately normal distribution and are presented as mean ± standard deviation (SD). Within-group changes in the ODI scores were analyzed by using paired-samples t-tests. Effect sizes for within-group ODI changes were expressed as Cohen's d. Given the exploratory nature of this pilot study, no formal adjustment for multiple comparisons was applied. Therefore, secondary outcome analyses should be interpreted as exploratory, and the possibility of Type I error due to multiple testing cannot be excluded. A p-value of < 0.05 was considered statistically significant.

Results

At baseline, stabilometric assessments using the *Huber 360 Evolution* system revealed a pronounced reliance on the visual input for postural control. Under eyes-open (EO) conditions, the center-of-pressure (COP) displacement remained relatively stable, whereas eyes-closed (EC) conditions resulted in an increased trajectory length (L), whereas the surface area (S) and mean COP velocity (V) were elevated; see Table 1.

Table 1. Baseline stabilometric parameters at the onset of rehabilitation

Clinical measures	E	E
X-COP (mm)	0.08[-4.92; 3.88]	-0.21 [-5.99; 3.80]
Y-COP (mm)	1.83 [-4.42; 14.98]	1.06 [-2.90; 28.17]
L (mm)	576.70 [515.40; 760.00]	990.80 [876.00; 1210.71]
S (mm^2)	198.30 [152.00; 305.60]	579.49 [376.50; 674.82]
V (mm/s)	11.91 [10.40; 15.25]	19.82 [16.79; 24.21]

Note: Data are presented as median (Me) and interquartile range (25th–75th percentiles).

Following the completion of the rehabilitation program, analysis of stabilometric parameters in the experimental group demonstrated statistically significant reductions only for the trajectory length (L) and surface area (S) under EC conditions. No statistically significant changes were detected in X-COP, Y-COP, trajectory length (L), surface area (S), or mean COP velocity (V) under eyes-open (EO) conditions, as shown in Table 2.

Table 2. Stabilometric parameters in the experimental group

Clinical measures	Condition	Before	After	Wilcoxon signed-rank test (p)
X-COP (mm)	EO	-2.00 [-3.30;4.00]	-5.10 [-9.90; 6.20]	0.84
	EC	1.30 [-6.60; 4.00]	-2.10 [-5.30; 3.20]	0.92
Y-COP (mm)	EO	9.80 [0.70; 13.30]	10.90 [4.80; 15.70]	0.69
	EC	10.90 [-2.80; 31.97]	10.40 [5.80; 32.60]	0.84
L (mm)	EO	595.80 [546.90; 681.50]	573.40 [541.40; 682.80]	0.37
	EC	1039.60 [919.70; 1242.10]	618.90 [539,20; 692.50]	0.01*
S (mm^2)	EO	275.60 [152.40; 355.36]	289.30 [175.10; 353.70]	0.49
	EC	579.51 [431.10; 879.10]	200.60 [156.20; 228.60]	0.01*
V (mm/s)	EO	12.30 [11.20; 13.60]	11.40 [10.80; 13.60]	0.27
	EC	20.80 [17.50; 24.80]	23.00 [14.80; 30.40]	0.49

Note: * indicates $p < 0.05$.

In the control group, statistically significant reductions in the trajectory length (L) and surface area (S) were observed under eyes-open (EO) conditions. However, no significant changes were identified in either the trajectory length (L) or the surface area (S) under eyes-closed (EC) conditions. Additionally, displacement along the frontal (X-COP) and sagittal (Y-COP) axes, along with the mean COP velocity (V), showed no statistically significant differences before and after rehabilitation, as presented in Table 3.

Table 3. Results of the Wilcoxon signed-rank test in the control group before and after rehabilitation

Clinical measures	Condition	Before	After	Wilcoxon signed-rank test (p)
X-COP (mm)	EO	0.71 [-5.98; 3.20]	1.20 [-5.70; 3.20]	0.90
	EC	-2.30 [-5.60; 2.70]	-1.30 [-5.60; 2.70]	0.50
Y-COP (mm)	EO	-0.70 [-6.85; 13.04]	-1.30 [-6.80; 13.50]	0.67
	EC	0.12 [-4.61; 6.51]	0.60 [-4.80; 16.60]	0.68
L (mm)	EO	537.30 [478.60; 974.00]	451.90 [320.70; 634.10]	0.01*
	EC	915.80 [769.70; 995.20]	933.60 [789.70; 998.00]	0.28
S (mm^2)	EO	173.50 [153.90; 229.60]	169.70 [143.50; 229.60]	< 0.01*
	EC	554.10 [274.20; 656.30]	395.10 [208.90; 512.80]	0.09
V (mm/s)	EO	10.70 [9.50; 19.40]	11.40 [9.50; 19.70]	0.10
	EC	18.30 [15.70; 21.40]	19.60 [15.70; 27.70]	0.25

Note: * indicates $p < 0.05$.

Between-group comparison of stabilometric parameters is presented in Table 4. Displacement on the frontal (X-COP) and sagittal (Y-COP) axes was similar in both groups under eyes-open (EO) and eyes-closed (EC) conditions. For the trajectory length (L), the values were significantly lower in the control group under EO conditions, whereas, under EC conditions, they were significantly lower in the experimental group. The surface area (S) was significantly lower in the experimental group under EC conditions. The mean COP velocity (V) showed no significant differences between the two groups under either visual condition.

Table 4. Results of the Mann-Whitney U test comparing experimental and control group after rehabilitation

Clinical measures	Condition	Experimental (n = 10)	Control (n = 10)	Mann–Whitney U test (p)
X-COP (mm)	EO	-5.12 [-9.97; 6.20]	1.21 [-5.73; 3.21]	0.95
	EC	-2.15 [-5.32; 3.29]	-1.30 [-5.60; 2.70]	0.95
Y-COP (mm)	EO	10.90 [4.80; 15.70]	-1.30 [-6.80; 13.51]	0.38
	EC	10.40 [5.80; 32.60]	0.60 [-4.80; 16.60]	0.24
L (mm)	EO	573.40 [541.40; 682.80]	451.90 [320.70; 634.10]	0.01*
	EC	618.90 [539,20; 692.50]	933.60 [789.70; 998.00]	0.01*
S (mm^2)	EO	289.30 [175.10; 353.72]	169.70 [143.50; 229.60]	0.38
	EC	200.60 [156.23; 228.60]	395.10 [208.90; 512.80]	0.01*
V (mm/s)	EO	11.40 [10.80; 13.60]	11.40 [9.50;19.70]	0.89
	EC	23.00 [14.80; 30.40]	19.60 [15.70; 27.70]	0.72

Note: * indicates $p < 0.05$.

Changes in the COP path length before and after rehabilitation in both groups under EO and EC conditions are illustrated in Figure 1.

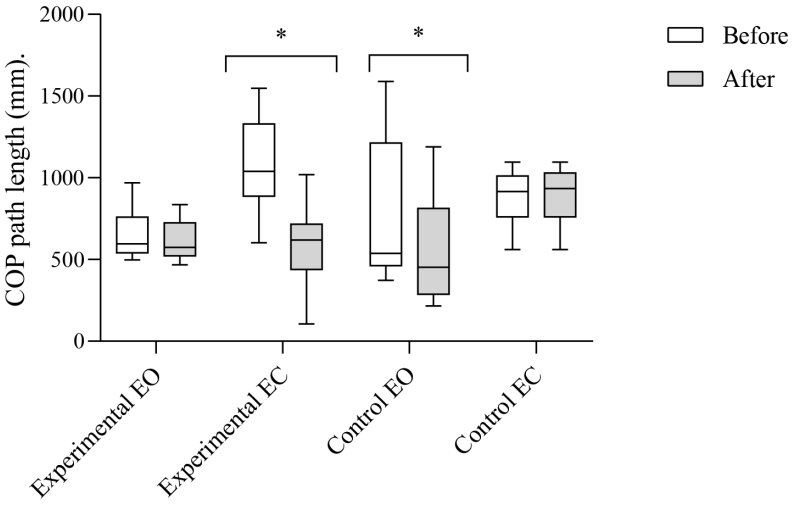

Figure 1. Changes in the center of pressure (COP) path length before and after rehabilitation in the experimental and control groups under eyes-open (EO) and eyes-closed (EC) conditions. Data are presented as the median (Me) and the interquartile range (25th–75th percentiles). * $p < 0.05$ for within-group pre–post comparisons

In the experimental group, the mean ODI score decreased from 3.50 ± 0.50 to 2.20 ± 0.40 (t(9) = −5.00, $p < 0.01$). Similarly, in the control group, the mean ODI score decreased from 2.40 ± 0.70 to 1.50 ± 0.60 (t(9) = −3.20, $p = 0.01$) (see Table 5; Figure 2).

Table 5. Changes in Oswestry Disability Index scores before and after rehabilitation

Group	Before (mean ± SD)	After (mean ± SD)	Mean difference (95% CI)	t (9)	p	Cohen's d
Experimental group	3.50 ± 0.50	2.20 ± 0.40	−1.30 (−1.80 to −0.80)	−5.00	<0.01	1.20
Control group	2.40 ±0.70	1.50 ± 0.60	−0.90 (−1.50 to −0.30)	-3.20	0.01	0.85

Note: ODI scores were normally distributed and are presented as mean ± SD.

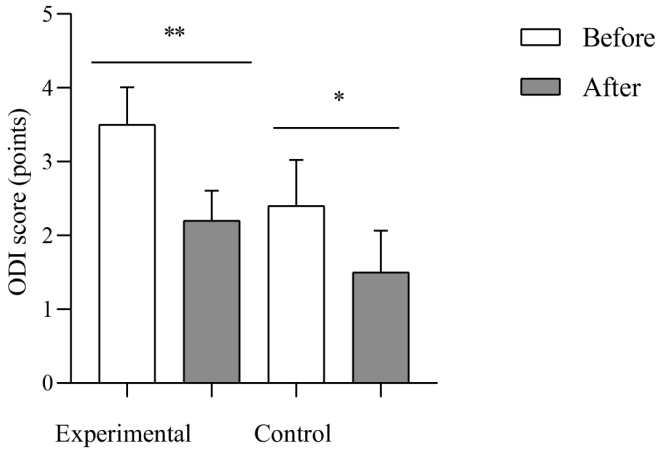

Figure 2. Changes in the Oswestry Disability Index (ODI) scores before and after rehabilitation in the experimental and control groups. Values are presented as mean ± SD. *$p < 0.05$; **$p < 0.01$

Limitations

This study has several limitations that should be considered when interpreting the findings. First, the sample size was small (n = 20), and no *a priori* sample size calculation was performed because the study was designed as an exploratory pilot investigation. Consequently, the statistical estimates are imprecise, and the findings should be considered hypothesis-generating rather than confirmatory. Second, allocation concealment was not implemented, which may have introduced a risk of selection bias. Furthermore, the participants and therapists could not be blinded because of the evident differences between the interventions, potentially increasing the risk of performance and expectation bias. Third, the follow-up period was limited to four weeks, which precludes conclusions regarding the long-term sustainability of the observed effects. The study was also conducted at a single rehabilitation center, which may limit the generalizability of the findings to other clinical settings and patient populations. Fourth, multiple stabilometric and functional outcomes were analyzed without formal adjustment for multiple comparisons. Although the COP trajectory length under eyes-closed conditions was defined as the primary outcome, the analysis of several secondary outcomes increases the risk of Type I error. Therefore, statistically significant findings for secondary outcomes should be interpreted as exploratory and require confirmation in adequately powered studies. Finally, the experimental and control interventions differed not only in modality but also in complexity, sensory feedback, task characteristics, and neuromotor demands. Therefore, the observed differences between the groups cannot be attributed exclusively to the *Huber 360 Evolution* system itself, and may partly reflect broader differences in the training exposure and the intervention structure. Future studies should use larger samples, longer follow-up periods, improved allocation procedures, and comparator interventions more closely matched for the training intensity, complexity, and neuromotor demands.

Discussion

The present pilot randomized study suggests that a rehabilitation program incorporating the *Huber 360 Evolution* system may be associated with improvements in selected stabilometric parameters in patients with persistent low back pain related to degenerative spinal changes. Given the small sample size and the exploratory nature of the study, the findings should be interpreted as preliminary. At baseline, the patients showed a greater postural sway under eyes-closed conditions than under eyes-open conditions, thus suggesting reliance on the visual input for maintaining postural stability. These observations are consistent with previous studies suggesting a reduced ability to sustain balance when the visual input is removed in individuals with chronic low back pain [10,11].

Following the completion of the rehabilitation program, the experimental group demonstrated significant improvements in the postural control under eyes-closed conditions. In particular, reductions in the trajectory length and surface area were observed. Given that these parameters reflect the magnitude of the postural sway, their reduction may indicate an improved postural stability in the absence of any visual input. These findings are in agreement with previous studies reporting beneficial effects of platform-based and sensorimotor training on postural regulation under visually deprived conditions [12,13].

The control group demonstrated greater postural instability under eyes-closed conditions compared with eyes-open conditions both before and after the intervention, thus indicating a persistent reliance on the visual feedback. In contrast, the experimental group showed an improved control of the center of pressure under eyes-closed conditions. This pattern suggests a potentially greater improvement in the postural control under visually deprived conditions in the experimental group; however, given the small sample size and the exploratory design, this finding requires confirmation in adequately powered trials.

The between-group findings further indicate that the direction of post-intervention differences depended on the visual condition. After rehabilitation, the COP trajectory length was lower in the control group under eyes-open conditions, whereas under eyes-closed conditions it was lower in the experimental group. The sway area under eyes-closed conditions was also lower in the experimental group. This condition-dependent pattern does not indicate uniform superiority of either intervention across all stabilometric outcomes and should be interpreted cautiously given the small sample size and the exploratory nature of the study.

Although mediolateral and anteroposterior displacement parameters remained largely unchanged, the reductions in the trajectory length and the sway area observed in the experimental group under eyes-closed conditions may reflect an improved spatial control of the postural sway. The absence of significant changes in the mean COP velocity suggests that the observed effects were related primarily to the magnitude and spatial distribution of sway rather than to the speed of corrective responses.

It should be noted that while these findings are consistent with previous reports describing improvements in the postural control following sensorimotor and platform-based training [14–17], the underlying physiological mechanisms (such as changes in the proprioceptive or vestibular function) were not directly assessed in the present study. Therefore, any interpretation related to these mechanisms should be considered as a possible explanation rather than a confirmed effect.

Persistent low back pain is commonly associated with an impaired motor control, a reduced muscular endurance, and a decreased spinal stability, all of which contribute to functional disability. In this context, the evaluation of disability outcomes provides clinically relevant information regarding the functional impact of rehabilitation interventions. Both groups demonstrated statistically significant reductions in Oswestry Disability Index (ODI) scores following the intervention. The experimental group showed a mean reduction of 1.30 points, whereas the control group showed a reduction of 0.90 points, with large within-group effect sizes in both groups (Cohen's d = 1.20 and 0.85, respectively). However, these findings reflect within-group statistical changes and should not be interpreted as evidence of between-group superiority. Furthermore, the clinical significance of these changes remains uncertain. An MCID threshold was not predefined in the study protocol, and the relatively low baseline ODI scores may have limited the magnitude of possible improvement. Therefore, the observed changes should be interpreted as statistically significant improvements in self-reported disability rather than definitive evidence of clinically meaningful benefit. Future adequately powered studies should prespecify an appropriate MCID threshold and evaluate the proportion of participants achieving clinically meaningful improvement. It should also be acknowledged

that the experimental and control interventions differed not only in modality but also in complexity, sensory feedback, and neuromotor demands. The *Huber 360 Evolution* system integrates dynamic multiplanar movements with real-time feedback, whereas the control program consisted of conventional floor-based stabilization exercises. Therefore, the observed differences between the groups cannot be attributed exclusively to the *Huber 360 Evolution* system itself, and may partly reflect broader differences in the training exposure, task complexity, and neuromotor stimulation.

Conclusions

The findings of this pilot randomized study suggest that a rehabilitation program incorporating the *Huber 360 Evolution* system may be associated with improvements in selected parameters of the postural control in patients with degenerative-dystrophic spinal disorders and vertebrogenic pain syndrome. In the experimental group, significant reductions in the COP trajectory length and sway area were observed under eyes-closed conditions, whereas the control group demonstrated significant reductions in these parameters under eyes-open conditions. These findings suggest different patterns of postural adaptation between the interventions; however, given the small sample size and the exploratory nature of the study, these findings should be considered as preliminary.

Both groups demonstrated statistically significant reductions in the ODI scores following rehabilitation. Although the numerical reduction and the within-group effect size were greater in the experimental group, these findings should not be interpreted as evidence of between-group superiority. The clinical significance of the observed ODI changes remains uncertain because an MCID threshold was not predefined, and the baseline ODI scores were relatively low.

The findings should also be interpreted in the context of important methodological limitations, including the small sample size, a short intervention period, absence of allocation concealment, lack of adjustment for multiple comparisons, and differences between the interventions in complexity, sensory feedback, task characteristics, and neuromotor demands. Consequently, the observed effects cannot be attributed exclusively to the *Huber 360 Evolution* system itself.

Overall, this pilot study provides preliminary, hypothesis-generating evidence that rehabilitation incorporating the *Huber 360 Evolution* system may influence selected aspects of the postural control, particularly under conditions of visual deprivation. Larger adequately powered randomized studies with prespecified clinically relevant outcomes, comparator interventions more closely matched for the training intensity and complexity, and longer follow-up periods are required to confirm these findings and determine their clinical significance and long-term sustainability.

Author contributions

A. P.: Conceptualization, Methodology, Investigation, Supervision, Writing – Review & Editing.
D. P.: Software, Formal Analysis, Resources, Writing – Original Draft Preparation, Writing – Review & Editing, Visualization.
Both authors have read and approved the final version of the manuscript.

Conflict of Interest Statement

The authors declare that they have no conflicts of interest that could influence the results or interpretation of this study.

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