Robotic-assisted rehabilitation for balance in stroke patients (ROAR-S): effects of cognitive, motor and functional outcomes

L. CASTELLI[1], C. IACOVELLI[2], C. LORETI[2], A.M. MALIZIA[3], I. BARONE RICCIARDELLI[3], A. TOMAINO[4], A. FUSCO[1], L. BISCOTTI[5], L. PADUA[1,3], S. GIOVANNINI[3,4]

[1]UOC Neuroriabilitazione ad Alta Intensità, Fondazione Policlinico Universitario A. Gemelli IRCCS, Rome, Italy
[2]Department of Emergency, Anaesthesiology and Intensive Care Medicine, Fondazione Policlinico Universitario A. Gemelli IRCCS, Rome, Italy
[3]Department of Geriatrics and Orthopaedics, Università Cattolica del Sacro Cuore, Rome, Italy
[4]UOS Riabilitazione Post-Acuzie, Fondazione Policlinico Universitario A. Gemelli IRCCS, Rome, Italy
[5]Università Cattolica del Sacro Cuore, Rome, Italy

Abstract. – OBJECTIVE: Due to the aging population, the incidence of stroke is steadily increasing. In patients with stroke outcomes, sensory, motor and cognitive problems limit the performance of activities of daily living. The development of new technologies in rehabilitation is improving the quality and efficiency of functional recovery. Hunova robotic platform (Movendo Technology, srl, Genoa, Italy) is a robotic device for functional assessment and rehabilitation of balance.

The purpose of this study is to evaluate the effects of rehabilitation with Hunova on cognitive function and balance in older adults with stroke.

PATIENTS AND METHODS: This is a randomized, controlled, single-blind study. Twenty-four older adults with stroke outcomes were randomized into the Hunova group (HuG), which performed a specific rehabilitation program for balance using Hunova for 12 sessions in addition to conventional rehabilitation, and the control group (CoG), which performed only conventional rehabilitation. All patients underwent a clinical cognitive, balance, quality of life and fatigue assessment, and an instrumental balance assessment with Hunova at the beginning and end of treatment.

RESULTS: Statistical analysis showed significant improvements in most clinical scales in both groups. Comparing the groups, HuG showed greater improvements in executive functions, speed of information processing, attention and discrimination of multiple stimuli, static and dynamic balance and autonomy in daily activities, standing postural sway, and trunk control in static and dynamic conditions.

CONCLUSIONS: Data analysis showed that elderly with stroke who underwent balance technology treatment with Hunova in combination with conventional treatment had a greater improvement in cognitive functions, balance and reduced risk of falling.

Key Words:
Postural Balance, Stroke, Elderly, Hunova, Rehabilitation, Personalized medicine.

Introduction

The World Health Organization[1] has defined stroke as "a clinical phenomenon characterized by the sudden onset of signs and/or symptoms referable to focal and/or global deficits in brain function lasting more than 24 hours or with an inauspicious outcome, which cannot be attributed to any other cause than cerebral vasculopathy".

Stroke is the second leading cause of death and the third leading cause of disability worldwide, as well as the third leading cause of death and disability combined[2]. Since 1990, the prevalence of stroke has been progressively increasing: the most recent data[3], referring to the year 2020, indicate a global prevalence of 10% for ischemic stroke and 3% for hemorrhagic stroke. In Italy, the global prevalence of stroke is 6.5%[4].

From 1990 to 2019, the number of strokes and stroke-related deaths increased, but there is a substantial reduction in age-standardized rates, especially among people older than 70 years[5].

Beyond endogenous factors[6,7], risk factors are well known: high blood pressure, smoking, overweight, pollution, etc. Stroke is sensitive to lifestyle: dietary, environmental, physical activity, and physiological factors impact health.

The reduction in the burden of stroke in older adults reflects the awareness of this new generation of "successful elderly", with an increased focus on the quality of life and healthy lifestyle.

Corresponding Author: Silvia Giovannini, MD, Ph.D; e-mail: silvia.giovannini@unicatt.it

Stroke prevention is a very important topic that affects quality of life and the healthcare system as direct and indirect costs (including caregivers' engagement). For one dollar invested in stroke and other cardiovascular disease prevention, there is a return on investment of 10.9 dollars[8].

Several pieces of evidence[9,10] reported the effectiveness of pre-rehabilitation (prehabilitation) in cardiovascular diseases and healthy lifestyle habits could prevent cerebrovascular accidents by reducing risk factors.

Unfortunately, the incidence of stroke is very high, so rehabilitation plays a key role. In fact, rehabilitation after a stroke is a fundamental step in preventing disability and mortality, especially in older adults.

In patients with stroke outcomes, problems with sensory, motor and cognitive function are limiting factors in performing activities of daily living. Some authors[11] have shown that cognitive impairments are present in about 83% of patients three months after the acute event, especially in visuospatial and executive functions.

Visuospatial functions include the ability to identify and interpret visual information, the ability to organize movement in space, and the perception of time[12]. At the same time, executive functions are involved in planning and executing a movement as well as in problem-solving[13].

Some authors[14,15] have pointed out the connection between cognitive impairment and functional performance in stroke patients. Other authors[16] have also highlighted the relationship between, among other things, executive functions and balance and activity performance in the acute or subacute phase of stroke.

The concomitant presence of cognitive and motor deficits may lead to a reduction in the performance of daily activities in stroke patients. In most cases, this condition requires the use of strategies that involve performing two or more tasks simultaneously. Impairment of this capacity may also lead to an increase in falls[17-19].

In the last decade, the effectiveness of robotic-assisted rehabilitation has been demonstrated in post-stroke treatment for upper[20] and lower limbs[21]. Robotic-assisted therapy presents a great impact on recovery, especially in motor function[22] in stroke patients.

Several pieces of evidence[23,24] in the literature suggest that robotic treatment should be performed in combination with conventional physical therapy to maximize its effectiveness. Furthermore, given the inter-relationship between motor and cognitive recovery, motor-cognitive technological rehabilitation should be studied to better understand the benefits of robotic therapy[25]. Dual-task training has presented interesting results, encouraging technological treatment[26] in stroke patients.

On that basis, the hypothesis behind the study is that robotic balance treatment in combination with conventional rehabilitation may be more effective than conventional rehabilitation alone, enabling a more timely recovery.

The purpose of this study is to evaluate the effectiveness of a technological rehabilitation treatment with a robotic platform to improve cognitive function, balance, and gait in older adults with stroke outcomes.

Patients and Methods

This is a single-blind, non-inferiority, randomized, interventional, control-group study. Patients admitted to the post-acute rehabilitation unit from February to October 2022 were included in the study.

The inclusion criteria were: (i) age ≥55 years; (ii) outcome of ischemic or hemorrhagic stroke, documented through neuroimaging techniques (MRI or computed tomography); (iii) stroke occurred within the previous 6 months; (iv) presence of sufficient cognitive ability to understand the physical therapist's instruction and execute simple orders, as assessed through the Token Test (score ≥26.5); (v) ability to walk independently or with minimal assistance; (vi) ability to understand and sign informed consent. Instead, the exclusion criteria were as follows: (i) patients with systemic, neurological, or cardiac conditions that make walking dangerous or cause motor deficits; (ii) presence of orthopedic or postural problems; (iii) presence of plantar ulcers; (iv) presence of partial or total amputations of foot segments.

Patients included in the study were divided into two groups using a randomization algorithm according to the random sorting procedure. The sequence of assignment to the two groups was generated through the PASS2019 [Power Analysis and Sample Size Software (NCSS, LLC. Kaysville, UT, USA)] software.

Patients were divided into the Hunova Group (HuG, the experimental group) or the Conventional Group (CoG, the control group). Patients in the HuG group, in addition to the rehabilitation treatment prescribed by clinical practice, underwent specific rehabilitation for balance disorders using the robotic platform 3 times a week. Patients in the CoG group underwent only the conventional treatment prescribed by clinical practice.

The HuG patients were treated with the Hunova robotic platform (Movendo Technology srl, Genoa, Italy) according to the methods and procedures described by Giovannini et al[27] (Figure 1).

Hunova is a robotic platform used for the evaluation and treatment of the trunk and lower extremities. It consists of two sensorized electromechanical platforms, one located under the feet and the other under the seat, which allow assessment and treatment in both standing and sitting positions[28]. All patients, regardless of the randomization group, underwent the same amount of rehabilitation treatment as determined in the individual rehabilitation plan.

Assessment

All patients, after being considered eligible for the study and after signing informed consent, were evaluated at the beginning of the study (baseline, T0) and after 4 weeks (T1). For the clinical evaluation, cognitive, balance, motility and walking, autonomy, quality of life and fatigue assessments were performed.

For assessment of cognitive performance, the Frontal Assessment Battery (FAB), Stroop Colour Word Test (SCWT), Symbol Digit Modalities Test (SDMT), Digits Cancellation Test (DCT) and Trial Making Test (TMT) were administered. For balance assessment, the Berg Balance Scale (BBS), the Short Physical Performance Battery (SPPB) and the Timed Up&Go (TUG) were used. For the assessment of walking, the Ambulation Index (AI), Walking Handicap Scale (WHS) and Functional Ambulation Classification (FAC) were performed. For the assessment of autonomy in activities of daily living, the modified Barthel Index (mBI) was used; for the assessment of quality of life, the EuroQoL5D (EQ-5D) and for fatigue the Modified Fatigue Impact Scale (MFIS) and the Fatigue Scale for Motor and Cognitive Function (FSMC) were used.

The FAB is a brief instrument that can be used to help discriminate between dementia with a frontotemporal dysexecutive phenotype and Alzheimer's-type dementia[29]. SCWT is a test used to assess the ability to inhibit cognitive interference[30]. SDMT is a tool used to assess divided attention and information processing speed[31]. The DCT is an instrument that assesses executive functions, the speed of information processing and the ability to focus attention[32]. The TMT measures flexibility of thinking on a visual-motor sequencing task[33]. The BBS is used to objectively determine a patient's ability (or inability) to safely balance during a series of predetermined tasks[34]. The SPPB measures balance, lower limb strength and functional capacity in older adults; it consists of three domains, including balance, habitual or self-selected gait speed and lower limb strength[35]. The TUG is a test used to assess mobility. It evaluates static and dynamic balance and measures the risk of falls in the elderly population[36]. AI, FAC and WHS are three different tools used to assess the gait ability[37-39]. The mBI and EQ-5D are instruments used to assess independence during activities of daily living[40] and quality of life[41]. The MFIS and the FSMC are two questionnaires that assess the impact of fatigue on activities of daily living[42,43].

With regard to the instrumental balance assessment, was performed using the Hunova robotic platform in two different modes. First, the static standing balance was performed with open-eyes (OE) and closed-eyes (CE); secondly, the dynamic balance was assessed with OE.

Statistical Analysis

Since this is a study of a specific subgroup of patients, on whom the actual usefulness of reha-

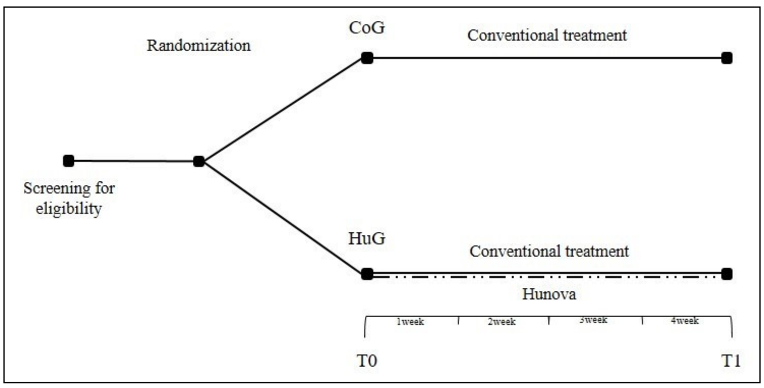

Figure 1. Study design.

bilitative treatment with Hunova has not yet been studied in the literature, a minimum sample size was not formally estimated. However, based on Julious' rules[44], twenty-four subjects were included in the study, evaluated and treated, and randomized into two groups of equal size.

The sample was described in its clinical and demographic variables using descriptive statistical techniques. Quantitative variables were summarized with mean and standard deviation (SD), median and interquartile range (IQR) where appropriate.

Qualitative variables were presented through absolute and percentage frequency tables.

The Shapiro-Wilk probability test was used to assess the normality of the distributions.

The within-group analysis was based on the application of the Wilcoxon Signed Rank test for each clinical, cognitive and balance outcome registered at T0 and T1.

The between-group differences were analyzed by comparing the percentage increase of each outcome, defined as:

$$\Delta S = \frac{(s(T1)-s(T0))}{(s(T0))}$$

where S is one of the clinical or balance outcomes employed in the study (except for BBS, SPPB, FAC, AI and mBI and the cognitive performance variables), and $S(T0)$ and $S(T1)$ are the S scores at T0 and T1, respectively.

The between-group analysis of BBS, SPPB, FAC, AI and mBI scales and cognitive performance assessment (FAB, SCWT, SDMT, DCT and TMT) were conducted by considering the differences between the scores, $S(T1)$-$S(T0)$, because the minimal value of these scales is 0 and normalization was not thus possible.

The Mann-Whitney U test was applied to compare the percentage increase calculated for each group. Statistical significance for each test was set at 0.05.

Statistical analysis was performed with SPSS 25 (IBM Corp., Armonk, NY, USA).

Results

Twenty-four patients admitted to the rehabilitation unit between February and October 2022 were included in the study. The two groups did not differ in terms of clinical and demographic characteristics, as shown in Table I.

Concerning the assessment of cognitive performance, the intra-group analysis showed a statistically significant improvement between T0 and T1 in most of the scales for both groups, with the exception of the TMT (p=0.182) for HuG and the SDMT (p=0.173) and TMT (p=0.862) for CoG (Table II).

In contrast, the inter-group comparison showed a statistically significant improvement in FAB (p=0.021), SDMT (p=0.025), DCT (p=0.021) and SCWT (p=0.028) (Figure 2).

Regarding motor assessments, intragroup analysis showed statistically significant improvements in most clinical scales in both groups. In particular, HuG patients showed statistically significant improvement at T1 compared with T0 for all measures, except FAC (p=0.221). In CoG, on the other hand, statistically significant improvements were observed in the motricity index-lower limb (MI-LL) affected side (p=0.005), TUG (p=0.012) SPPB walking subscore (p=0.008), SPPB sit-to-stand subscore (p=0.014), SPPB total score (p=0.018), FAC (p=0.046) and WHS (p=0.006) (Table II). As for the intergroup comparison of clinical scales, however, a statistically si-

Table I. Clinical and demographical characteristics of the sample at baseline.

		HuG N=12	CoG N=12	*p*-value
Gender, %	Male	58.33%	58.33%	1.000
	Female	41.67%	41.67%	
Age, years	Mean±DS	77.1±11.25	76.6±8.87	0.713
Latency, days	Mean±DS	6±1.70	9±3.87	0.160
Aetiology, %	Ischemic	58.33%	75.00%	
	Hemorrhagic	41.67%	25.00%	0.514
Affected size, %	Left	66.67%	58.33%	
	Right	33.33%	41.67%	0.755

Table II. Intra-group and inter-group analysis of cognitive, motor, balance, gait and fatigue, autonomy and quality of life scales.

	HuG			**CoG**			
	T0 Median (IQR)	**T1 Median (IQR)**	***p*-value**	**T0 Median (IQR)**	**T1 Median (IQR)**	***p*-value**	***p*-value HuG *vs.* CoG**
Cognitive Functions							
FAB	9 (7.75-9.25)	13 (12-13.25)	***p*=0.003**	8 (6-9)	11 (8-11)	***p*=0.002**	***p*=0.021**
SDMT	21 (17-29)	33 (22-39.5)	***p*=0.002**	14 (11.75-23)	21 (17-34)	*p*=0.059	*p*=0.173
DCT	23 (17.5-31.25)	39 (29.25-43.25)	***p*=0.002**	29 (13.75-32)	33 (22.52-36.25)	***p*=0.003**	***p*=0.025**
TMT	25 (21.55-30.60)	15 (13.25-35.54)	*p*=0.182	23 (16-29.5)	16 (9.08-27)	*p*=0.129	*p*=0.862
SCWT	92 (73.95-127.83)	75 (62.07-93.75)	***p*=0.002**	88 (85.15-103.51)	80 (76.32-93.25)	***p*=0.002**	***p*=0.028**
Motor Functions							
MI-LL affected side	58 (58-64)	81 (76-92)	***p*=0.002**	64 (62-72)	76 (75-78)	***p*=0.005**	***p*=0.034**
MI-LL non affected side	88 (76-100)	96 (92-100)	***p*=0.026**	100 (88-100)	100 (90-100)	*p*=0.102	*p*=0.084
TUG	27 (21-31)	20 (15-25)	***p*=0.003**	30 (21-31)	27 (19-29)	***p*=0.012**	***p*=0.004**
BBS	33 (24-38)	48 (39-49)	***p*=0.003**	40 (28-43)	42.5 (28-49)	*p*=0.119	***p*<0.001**
SPPB_B	2 (2-2)	3 (3-3)	***p*=0.008**	2 (2-2)	2 (1-3)	*p*=0.655	***p*=0.008**
SPPB_W	1.5 (1-2)	2.5 (2-3)	***p*=0.008**	1 (1-1.25)	2 (1-2)	***p*=0.008**	*p*=0.398
SPPB _STS1	(1-1.25)	2 (2-2)	***p*=0.007**	1 (1-1.25)	2 (1-2)	***p*=0.014**	*p*=0.324
SPPB _TOT5	(4-5)	8 (7-9)	***p*=0.005**	4 (4-4.5)	6 (3-7)	***p*=0.018**	***p*=0.033**
AI	3.5 (3-4)	2 (1-4)	***p*=0.015**	3.5 (3-4)	3 (2-4)	*p*=0.480	*p*=0.073
FAC	2 (2-2.25)	3 (1-3.25)	*p*=0.221	1.5 (1-3)	3 (1-3)	***p*=0.046**	*p*=0.880
WHS	2 (2-3)	4 (3.75-5)	***p*=0.003**	2.5 (2-4)	4 (3-5)	***p*=0.006**	*p*=0.198
Fatigue, autonomy, and quality of life							
MFIS	47 (44-53)	30 (28.5-34)	***p*=0.002**	56 (51-57.75)	48 (43-53.75)	***p*=0.002**	*p*=0.002
MFIS _PHY	22 (19.5-24.25)	16 (12.75-17.5)	***p*=0.002**	23 (20.75-30)	20 (19-28)	***p*=0.003**	*p*=0.002
MFIS _COG	21 (19-24)	13 (11.75-15)	***p*=0.002**	26 (23.25-27)	22 (19-24)	***p*=0.003**	*p*=0.007
MFIS _PSY	4 (4-6)	2 (1-3.25)	***p*=0.002**	6 (4-7.25)	5 (2-6)	***p*=0.002**	*p*=0.003
FSMC	50 (42.75-59.5)	39 (30.75-45)	***p*=0.006**	54 (47.75-63)	51 (36.25-59)	***p*=0.011**	*p*=0.071
FSMC _PHY	25 (19.75-29)	18 (16.25-20.75)	***p*=0.003**	25 (17-32)	24 (14.5-27)	***p*=0.016**	*p*=0.010
FSMC _COG	25 (22.5-27.5)	21 (20-23.75)	***p*=0.034**	30 (27-31.25)	27 (22.5-29)	***p*=0.011**	*p*=0.468
mBI	20 (18-24.75)	85 (80.5-92)	***p*=0.002**	23 (21-24.5)	68 (62.75-77)	***p*=0.002**	***p*=0.010**
EQ-5D	12 (11-12.5)	7 (6.75-9)	***p*=0.005**	11 (8.75-11)	9 (7-10)	***p*=0.010**	***p*=0.012**
EQ-5D VAS	45 (40-55)	83 (68.75-90)	***p*=0.002**	50 (45-60)	75 (60-80)	***p*=0.002**	***p*=0.014**

HuG: Hunova Group; CoG: Conventional Group; FAB: Frontal Assessment Battery; SDMT: Symbol Digit Modalities Test; DCT: Digit Cancellation Test; TMT: Trial Making Test; SCWT: Stroop Colour Word Test; MI-LL: Motricity Index-Lower Limb; TUG: Timed Up&Go; BBS: Berg Balance Scale; SPPB_B: Short Physical Performance Battery_Balance subscore; SPPB_W: Short Physical Performance Battery_Walking subscore; SPPB_STS: Short Physical Performance Battery_Sit-to-stand subscore; SPPB_TOT: Short Physical Performance Battery_Total score; AI: Ambulation Index; FAC: Functional Ambulation Classification; WHS: Walking Handicap Scale; MFIS: Modified Fatigue Impact Scale; MFIS_PHY: Modified Fatigue Impact Scale_Physical; MFIS_COG: Modified Fatigue Impact Scale_Cognitive; MFIS_PSY: Modified Fatigue Impact Scale_Psychosocial; FSMC: Fatigue Scale for Motor and Cognitive Functions; FSMC_PHY: Fatigue Scale for Motor and Cognitive Functions_Physical; FSMC_COG: Fatigue Scale for Motor and Cognitive Functions_Cognitive; mBI: modified Barthel Index; EQ-5D: EuroQoL-5D. Values of $p<0.05$ are considered statistically significant and are in bold.

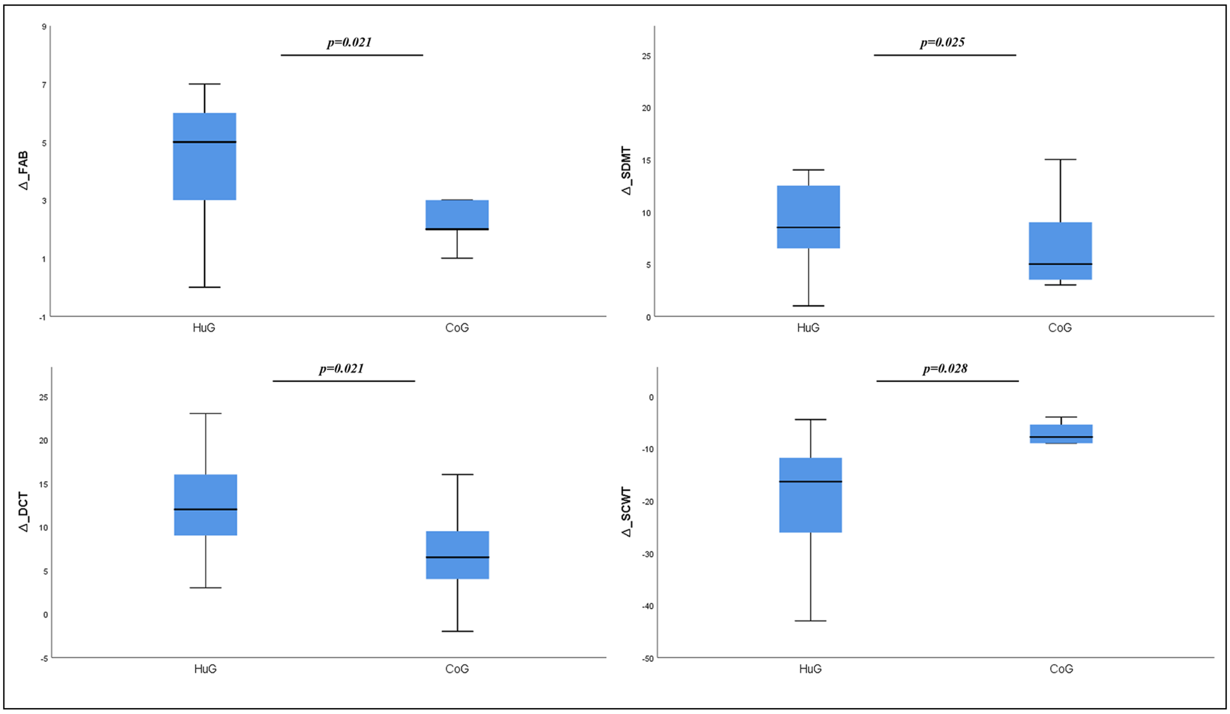

Figure 2. Inter-group comparison of cognitive scales.

gnificant difference was found in MI-LL affected side (p=0.034), TUG (p=0.004), BBS (p<0.001), SPPB balance subscore (p=0.008) and SPPB total score (p=0.033).

Comparison between T0 and T1 in both groups showed statistically significant improvement in MFIS, FSMC and EQ-5D. In contrast, when considering the between-group comparison, there was a statistically significant difference in the MFIS (p=0.002) and its subscales motor (p=0.002), cognitive (p=0.007) and psychosocial (p=0.003). Regarding mBI, all patients showed statistically significant improvement regardless of the randomization group: intergroup comparison showed that HuG patients showed greater improvement than CoG patients (p=0.010).

The same results were obtained by intergroup comparison for total EQ-5D score (p=0.012) and pain-related score (EQ-5D VAS, p=0.014), as shown in Table II. As for the instrumental evaluation under static conditions, the intragroup analysis showed for HuG a statistically significant improvement in Mean-Distance-RMS under EO condition (p=0.041), the range of anteroposterior (AP) center of pressure (COP) oscillations with OE (p=0.006) and mean COP AP velocity with OE (p=0.041). For CoG, however, statistical analysis showed an improvement in the area with OE (p=0.042) and Romberg Index (p=0.042) (Table III).

Comparing the groups, however, a statistically significant difference emerged for the area with CE (p=0.050), in Mean Distance-RMS-CE (p=0.039), in mid-lateral (ML) trunk swing amplitude with OE (p=0.045) and COP AP swing amplitude with CE (p=0.039).

Regarding instrumental assessment under dynamic conditions, the intragroup analysis showed a statistically significant improvement only in HuG, whereas for CoG, there was no statistically significant change at T1 (Table III); the same results were obtained in the intergroup comparison for COP (Figure 3) and trunk (Figure 4).

Discussion

Balance maintenance can be considered the product of many components, including postural control, predictive and reactive strategies, somatosensory integration, musculoskeletal system integrity, nervous system integrity, static and dynamic stability, and cognitive functions[45].

Several studies[14] have demonstrated an association between cognitive impairments and activity performance at different stages of stroke. Further-

Table III. Intra-group and inter-group analysis of instrumental assessment in static condition and dynamic condition of whole sample.

	HuG			CoG			
	T0 Median	T1 Median (IQR)	*p*-value (IQR)	T0 Median	T1 Median (IQR)	*p*-value (IQR)	*p*-value HuG *vs.* CoG
Static Condition							
Area-EC [cm²]	5.12 (3.62-7.96)	4.41 (2.48-6.25)	*p*=0.099	6.74 (4.22-12.62)	7.16 (4.14-13.95)	*p*=0.223	***p*=0.050**
Area-EO [cm²]	2.81 (1.6-4.77)	2.11 (1.39-3.02)	*p*=0.272	3.99 (2.36-5.34)	3.46 (2.26-4.15)	***p*=0.042**	*p*=0.319
Mean distance-RMS -EO [cm]	0.62 (0.45-0.76)	0.5 (0.41-0.59)	***p*=0.041**	0.73 (0.62-0.94)	0.69 (0.59-0.92)	*p*=0.078	*p*=0.089
Mean distance-RMS-EC [cm]	0.89 (0.78-0.99)	0.81 (0.52-0.91)	*p*=0.071	0.9 (0.71-1.16)	0.93 (0.71-1.28)	*p*=0.223	***p*=0.039**
Romberg Index	0.54 (0.29-0.93)	0.48 (0.29-0.93)	*p*=0.875	0.67 (0.33-1.33)	0.55 (0.33-0.7)	***p*=0.042**	*p*=0.977
COP path-EO [cm]	51.87 (45.64-78.54)	43.91 (41.34-50.11)	*p*=0.158	46.42 (37.35-62.86)	45.1 (39.52-59.61)	*p*=0.223	*p*=0.319
COP path-EC [cm]	85.58 (53.3-183.42)	84.6 (61.02-93.9)	*p*=0.117	77.84 (57.33-107.26)	77.84 (45.66-91.34)	*p*=0.223	*p*=0.291
Trunk movement-EO [deg/s²]	0.05 (0.05-0.06)	0.05 (0.04-0.07)	*p*=0.239	0.06 (0.05-0.07)	0.06 (0.04-0.06)	*p*=0.684	*p*=0.347
Trunk movement -EC [deg/s²]	0.07 (0.05-0.12)	0.06 (0.05-0.08)	*p*=0.117	0.06 (0.04-0.09)	0.06 (0.04-0.08)	*p*=0.343	*p*=0.198
Trunk sway range AP-EO [deg]	3.57 (2.98-4.77)	3.27 (2.81-4.08)	*p*=0.695	3.96 (2.17-5.61)	4.91 (3.25-6.22)	*p*=0.223	*p*=0.128
Trunk sway range AP-EC [deg]	2.82 (2.08-4.35)	2.77 (2.54-4.16)	*p*=0.937	3.6 (3.12-5.41)	3.5 (2.83-6.26)	*p*=0.498	*p*=1.000
Trunk sway range ML-EO [deg]	1.33 (0.99-1.44)	0.78 (0.47-1)	*p*=0.084	1.76 (1.18-3.82)	1.47 (1.39-3.79)	*p*=0.684	***p*=0.045**
Trunk sway range ML-EC [deg]	1.46 (1.05-1.68)	1.14 (0.52-2.09)	*p*=0.530	1.82 (1.22-4.69)	1.96 (1.73-4.69)	*p*=0.136	*p*=0.128
COP sway range AP-EO [cm]	2.92 (1.94-3.46)	1.95 (1.73-2.46)	***p*=0.006**	3.12 (2.71-4.46)	3.02 (2.37-3.6)	*p*=0.684	*p*=1.000
COP sway range AP-EC [cm]	4.35 (3.18-4.88)	3.45 (2.49-4.71)	*p*=0.117	3.14 (2.63-3.5)	2.91 (1.79-3.96)	*p*=0.498	***p*=0.039**
COP sway range ML-EO [cm]	1.43 (1.22-2.17)	1.77 (1.43-1.95)	*p*=1.000	2.09 (1.36-3.33)	1.74 (1.28-2.61)	*p*=0.223	*p*=0.319
COP sway range ML-OC [cm]	1.82 (1.58-2.51)	1.87 (1.47-2.28)	*p*=0.875	3.1 (2.21-4.82)	3.48 (2.16-3.97)	*p*=0.892	*p*=1.000
Ratio of axes of the ellipse-EO [%]	48.4 (33.14-72.12)	62.05 (49.23-86.15)	*p*=0.084	54.64 (36.05-64.67)	43.65 (34.99-65.53)	*p*=0.498	*p*=0.101
Ratio of axes of the ellipse -EC [%]	49.12 (41.16-62.66)	48.23 (37.36-61.08)	*p*=0.583	59.72 (53.75-72.86)	61.62 (59.17-68.13)	*p*=0.892	*p*=0.410
Mean speed COP AP-EO [cm/s]	1.61 (1.26-2.46)	1.37 (1.28-1.45)	*p*=0.041	1.44 (1.08-1.56)	1.44 (1.03-1.48)	*p*=0.223	*p*=0.551
Mean speed COP AP-EC [cm/s]	2.61 (1.63-6.63)	2.58 (1.88-3.17)	*p*=0.136	2.29 (1.8-2.69)	2.32 (1.37-2.69)	*p*=0.498	*p*=0.347
Mean speed COP ML-EO [cm/s]	0.81 (0.75-1.12)	0.76 (0.64-0.9)	*p*=0.583	0.84 (0.62-1.12)	0.71 (0.62-0.97)	*p*=0.223	*p*=0.977
Mean speed COP ML-EC [cm/s]	1.23 (0.92-2.06)	0.94 (0.86-1.41)	*p*=0.272	0.98 (0.84-2.42)	0.9 (0.81-1.88)	*p*=0.223	*p*=0.843
Dynamic condition							
Area-EC [cm²]	41.5 (21.13-92.33)	14.06 (9.9-25.41)	***p*=0.010**	37.24 (22.39-55.32)	35.6 (28.43-41.44)	*p*=0.684	***p*=0.004**
Mean distance -RMS-EO [cm]	2.21 (1.62-3.27)	1.27 (1.14-1.69)	***p*=0.015**	2.5 (1.78-3.05)	2.21 (1.93-2.65)	*p*=0.684	***p*=0.004**
COP path-EO [cm]	90.75 (61.95-135.2)	57.42 (33.25-69.88)	***p*=0.010**	83.18 (60.19-101.15)	83.18 (46.88-92.64)	*p*=0.892	***p*=0.005**

Table continued

Table III *(Continued)*. Intra-group and inter-group analysis of instrumental assessment in static condition and dynamic condition of whole sample.

	HuG			CoG			
	T0 Median	T1 Median (IQR)	*p*-value (IQR)	T0 Median	T1 Median (IQR)	*p*-value (IQR)	*p*-value HuG *vs.* CoG
Trunk movement -EO [deg/s2]	0.11 (0.09-0.14)	0.07 (0.06-0.08)	***p*=0.008**	0.1 (0.07-0.17)	0.08 (0.07-0.11)	*p*=0.684	***p*=0.017**
Trunk sway range AP-EO [deg]	5.87 (4.82-7.19)	3.22 (2.38-4.41)	***p*=0.012**	6.16 (4.6-11.71)	7.69 (3.37-13.86)	*p*=0.892	***p*=0.010**
Trunk sway range ML-EO [deg]	3 (1.65-6)	1.9 (1.21-2.84)	***p*=0.002**	5.63 (2.74-7.01)	4.66 (3.07-6.3)	*p*=0.684	***p*<0.001**
COP sway range AP-EO [cm]	7.98 (5.5-8.47)	5.02 (4.12-5.65)	***p*=0.023**	8.56 (6.07-9.47)	8.6 (7.21-9.2)	*p*=0.684	***p*=0.045**
COP sway range ML-EO [cm]	6.82 (4.21-11.24)	445 (2.88-6.44)	***p*=0.034**	7.07 (5.77-9.98)	7.07 (6.11-8.86)	*p*=0.684	***p*=0.045**
Mean speed COP AP-EO [cm/s]	2.03 (1.65-3.49)	1.15 (0.77-1.69)	***p*=0.015**	2.03 (1.47-2.35)	2.03 (1.29-2.42)	*p*=0.892	***p*=0.005**
Mean speed COP ML-EO [cm/s]	1.38 (1.04-1.78)	0.81 (0.63-1.31)	*p*=0.028	1.52 (1.16-1.79)	1.58 (0.93-1.75)	*p*=0.684	*p*=0.089

HuG: Hunova Group; CoG: Conventional Group; EO: Eyes Open; EC: Eyes Closed; COP: Centre of Pressure; AP: Antero-Posterior; ML: Medio-Lateral. Values of $p<0.05$ are considered statistically significant and are in bold.

more, executive and visuospatial functions play a role in the recovery of balance up to one year after the acute event[16]. Precisely because of this multifactorial characteristic, the recovery of balance in a condition of nervous system distress is a considerable challenge[46].

The purpose of this study was to evaluate the influence of balance technology treatment combined with conventional physical therapy in older adults with stroke outcomes in different domains.

Data analysis showed that cognitive performance improved significantly in both groups, confirming the importance of rehabilitation after stroke and the interdependence of cognitive and motor function. In particular, HuG patients, treated with the Hunova robotic platform, showed an improvement in executive functions, speed of information processing, attention and discrimination of multiple stimuli.

The involvement of the cognitive component confirms the theory of brain adaptation. Plasticity has been considered a key feature explaining individual differences in coping with brain damage, depending on structural factors such as brain size and number of synapses[47]. The brain reserve is still considered a protective factor for many neurodegenerative pathologies that can also remain dormant for a long time due to the size and neural networks as in the threshold theory[48].

The brain reserve model is accompanied by an active one (cognitive reserve), in continuous movement and is less quantifiable. According to it, the variability in clinical manifestations reflects individual differences in the ability to use more flexible and efficient cognitive strategies, which can emerge from different life experiences[49].

Consistent with this model, the brain actively reacts to damage, exploiting previously learned cognitive processes or using compensatory approaches[50].

Research[51] has made great strides allowing us to observe the neural mechanisms underlying age-related cognitive decline and so-called successful aging. However, the relationship between the natural outcome of aging, brain structure, plasticity and activation, remains an open question.

Regarding the motor component, it is interesting to note that HuG patients showed symmetrical improvement in lower limb function, unlike CoG patients. In addition, HuG patients showed significant improvement in balance, an improvement that was not recorded for CoG patients.

Furthermore, considering the instrumental assessment, HuG patients showed a statistically significant improvement in the minimum mean OE error and, although not statistically significant, a decrease in minimum mean CE error values, which on the contrary, increases in CoG patients.

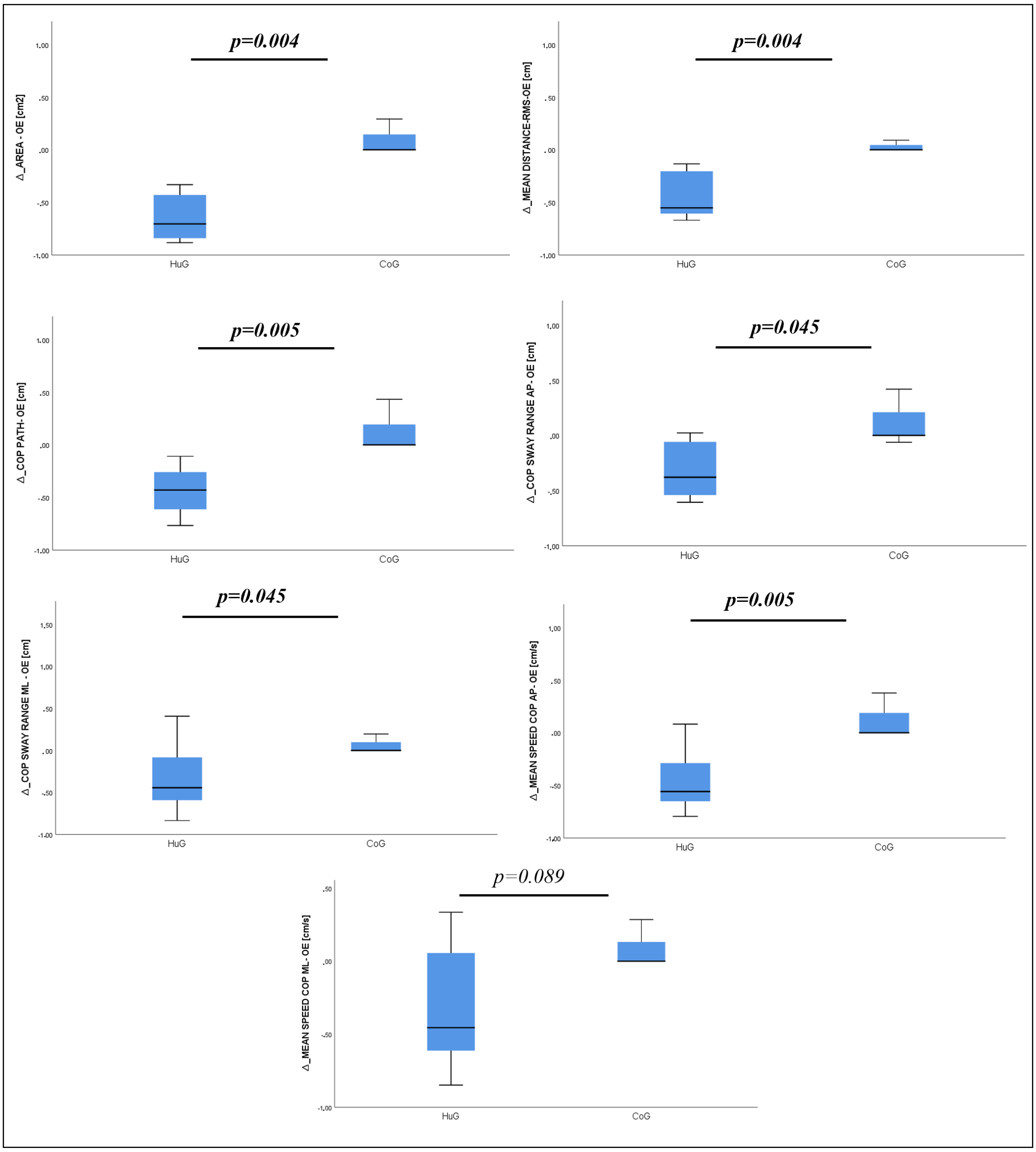

Figure 3. Comparison of Centre Of pressure (COP) displacement between the two groups.

Moreover, the difference between the two groups in ML trunk swing with eyes open and COP swing with eyes closed in AP was statistically significant, indicating greater trunk stability in HuG patients.

Based on the results of the clinical and instrumental assessments under static conditions, a concordance between the two assessments is present. However, this concordance is not maintained when considering the instrumental results of the dynamic assessment. In this case, only patients undergoing technological balance treatment achieved statistically significant improvement in all parameters considered.

Extremely interesting are the improvements achieved by HuG patients in substantially improving open-eye COP and trunk movements. In addition, the improvements recorded with both clinical scales and instrumental assessment reflect the developments achieved by patients in regai-

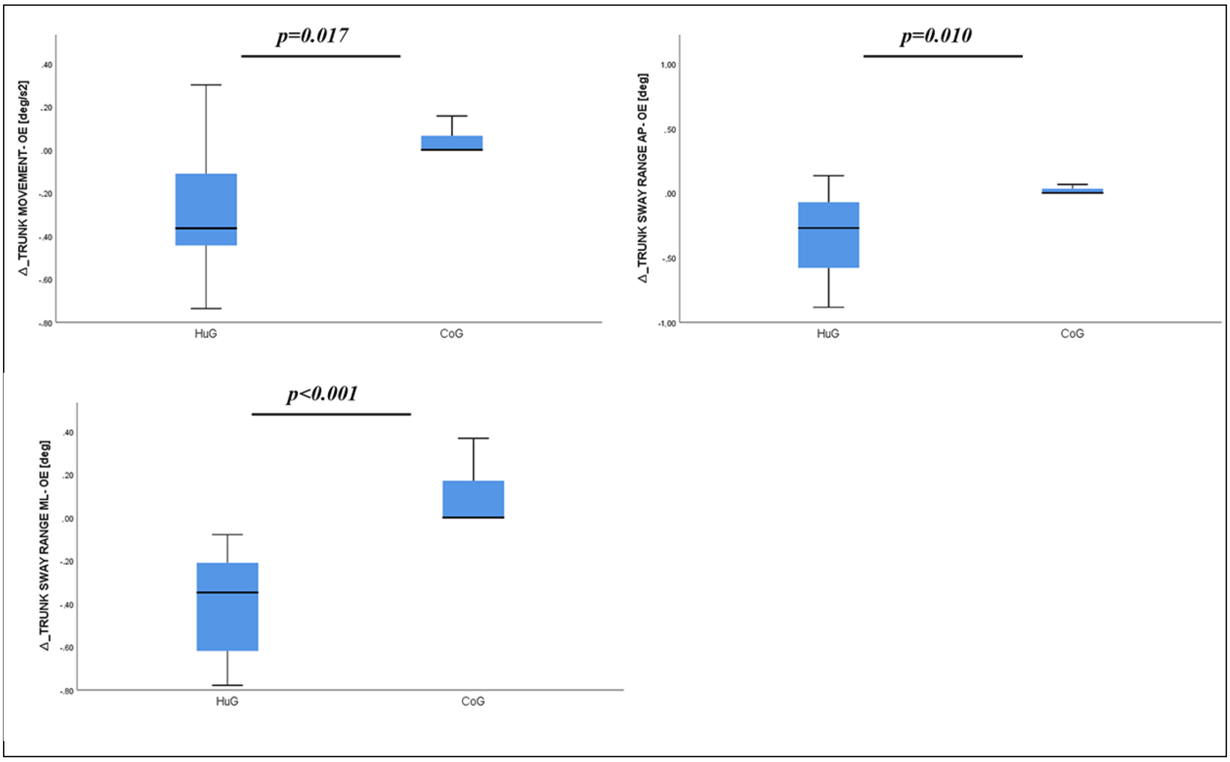

Figure 4. Comparison of trunk sway between the two groups.

ning autonomy in some activities of daily living, as documented by the mBI result.

These results agree with the work of Aprile et al[52] in which stroke patients treated with Hunova, in addition to conventional treatment, showed improvements in dynamic instrumental parameters at the end of treatment.

This study confirms the results of a recent review[53], in which the Hunova robotic platform appears to be one of the most effective robots for rehabilitation. In Parkinson's disease, the efficacy of treatment with Hunova in addition to conventional treatment has been demonstrated[54], while, to the authors' knowledge, the efficacy of robotic rehabilitation with Hunova in elderly patients with stroke outcomes has not yet been fully demonstrated.

The results of this study highlighted the importance of the ability to maintain balance in order to avoid the risk of falls and, consequently, to preserve individual self-sufficiency and maintain a functional, dignified, and rewarding lifestyle.

Balance, however, turns out to be one of the most impaired functions after the onset of a stroke, with negative consequences on global motor and cognitive function as well. Especially in older adults, attention should be paid to physical activity, sarcopenia, muscle strength[55,56] and drugs[57-59] on quality of life and mood.

This study aimed to demonstrate how general cognitive and motor conditions, balance, and walking could improve following the combination of robotic treatment performed by Hunova with conventional physiotherapy treatment. In fact, robotic rehabilitation allowed greater personalization of the rehabilitation intervention proposed to the patient, with objective improvements evidenced by the results obtained through clinical and instrumental assessments.

This rehabilitation approach has made it possible to take advantage of patients' residual functional abilities, reducing the risk of falling, the disability resulting from the event, and the autonomy of those affected. Moreover, the dual-task treatment allowed an improvement in patients' cognitive performance impacting the general quality of life and wellness.

While considering the results, some factors must be taken into consideration. Since these are preliminary results, in fact, further tests will be needed to confirm the initial hypothesis. The main limitation of the study is the sample size.

However, as described above, the inclusion of 12 subjects per group was estimated according to the Julious Practice Rules for Pilot Clinical Trials[44], for a total population of 24 subjects. Additionally, pilot study guidelines indicate that phase 2 pilot trials of motor and cognitive rehabilitation interventions can begin with a convenience sample of at least six participants[60]. Another limitation of the study is the lack of follow-up at the end of the protocol and at discharge. In fact, some longitudinal studies[61] suggest continued improvement in function even after discharge from rehabilitation.

Conclusions

These preliminary results provide an important starting point for further studies. Hunova could be considered an effective tool in improving the balance of older adults with stroke outcomes. This technological rehabilitation treatment is able to increase motor performance, cognitive functions, consciousness, and independence in daily living activities, consequently decreasing the risk of falling in older adults.

Ethics Approval

This study was conducted in accordance with specific national laws and the ethical standards outlined in the 1964 Declaration of Helsinki and its later amendments. The Institutional Ethics Committee of the Fondazione Policlinico Universitario" A. Gemelli" IRCCS approved the study protocol (Prot. 0003731/22). The study was registered on ClinicalTrials.gov (NCT05280587).

Informed Consent

An informed consent was obtained from each participant before any study procedure.

Availability of Data and Materials

Data supporting the results are not available.

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Conflicts of Interest

The author declares no conflict of interest.

ORCID ID

Letizia Castelli: 0000-0001-9455-3789
Chiara Iacovelli: 0000-0002-3547-6055
Claudia Loreti: 0000-0002-0835-4079
Augusto Fusco: 0000-0002-8528-7834
Lorenzo Biscotti: 0000-0003-1246-9546
Luca Padua: 0000-0003-2570-9326
Silvia Giovannini: 0000-0001-9125-752X

Authors' Contributions

All authors contributed, read and approved the final version of the manuscript.

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