applied sciences

MDPI

Review

Devices for Gait and Balance Rehabilitation: General Classification and a Narrative Review of End Effector-Based Manipulators

Paul Diego *, Saioa Herrero, Erik Macho, Javier Corral, Mikel Diez, Francisco J. Campa and Charles Pinto

Bilbao School of Engineering, University of the Basque Country (UPV/EHU), Plaza Ingeniero Torres Quevedo 1, 48013 Bilbao, Spain; saioa.herrero@ehu.eus (S.H.); erik.macho@ehu.eus (E.M.); j.corral@ehu.eus (J.C.); mikel.diez@ehu.eus (M.D.); fran.campa@ehu.eus (F.J.C.); charles.pinto@ehu.eus (C.P.)

* Correspondence: paul.diego@ehu.eus

Abstract: Gait and balance have a direct impact on patients' independence and quality of life. Due to a higher life expectancy, the number of patients suffering neurological disorders has increased exponentially, with gait and balance impairments being the main side effects. In this context, the use of rehabilitation robotic devices arises as an effective and complementary tool to recover gait and balance functions. Among rehabilitation devices, end effectors present some advantages and have shown encouraging outcomes. The objective of this study is twofold: to propose a general classification of devices for gait and balance rehabilitation and to provide a review of the existing end effectors for such purposes. We classified the devices into five groups: treadmills, exoskeletons, patient-guided systems, perturbation platforms, and end effectors. Overall, 55 end effectors were identified in the literature, of which 16 were commercialized. We found a disproportionate number of end effectors capable of providing both types of rehabilitation (2/55) and those focused on either balance (21/55) or gait (32/55). The analysis of their features from a mechanical standpoint (degrees of freedom, topology, and training mode) allowed us to identify the potential of parallel manipulators as driving mechanisms of end effector devices and to suggest several future research directions.

Keywords: rehabilitation; balance; gait; end effectors; neurological disorders; parallel manipulators

check for updates

Citation: Diego, P.; Herrero, S.; Macho, E.; Corral, J.; Diez, M.; Campa, F.J.; Pinto, C. Devices for Gait and Balance Rehabilitation: General Classification and a Narrative Review of End Effector-Based Manipulators. *Appl. Sci.* **2024**, *14*, 4147. https://doi.org/10.3390/app14104147

Academic Editors: Andoni Carrasco-Uribarren, Sara Cabanillas-Barea and Portela Alejandro

Received: 15 April 2024
Revised: 11 May 2024
Accepted: 12 May 2024
Published: 14 May 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Among neurological disorders that affect the central nervous system (CNS), stroke is the one with the strongest impact around the world [1,2]. Stroke occurs when blood vessels feeding the brain are either blocked or leak, depriving the brain of blood and therefore of the oxygen that the brain cells need to survive [3].

Around the world, there are 12.2 million new strokes per year, one every 3 s [4], and with an annual rate of 6.5 million cases, it is the second-leading cause of death after ischemic heart disease [5]. Due to technological advances, the stroke incidence and mortality percentages per population have decreased substantially in high-income countries [6]. However, the total burden of stroke in terms of number of stroke cases, deaths, and economic cost has increased worldwide as a result of population growth and a higher life expectancy [7,8]. It is also considered a major cause of disability, since after a stroke, one third of patients die, another third recover either completely or with minimal residual disability, and the rest recover with residual disability [9]. In fact, among adults, stroke is the most common cause of new disability leading to more than one impairment that could affect communication, cognition, vision, and motor functions like gait and balance functions [10,11].

Besides stroke, other CNS disorders, such as multiple sclerosis (MS) and Parkinson's disease (PD), lead to balance and gait function impairment [12,13]. These impairments are highly related to activities of daily life (ADLs) such as sitting, standing, and walking, and hence they have a direct effect on the independence and the quality of life of the patients [14,15]. According to a study carried out by Rudberg et al. [16], imbalance and walking difficulties are the main impairments that matter most to people affected by stroke in terms of being able to cope with ADLs.

1.1. Advantages of Robotic-Assisted Rehabilitation Compared to Conventional Therapy

Nowadays, rehabilitation is the main treatment for the recovery of gait and balance functions. Several studies proved that repetition, high-intensity, and task-oriented rehabilitation play a key role in neuroplasticity phenomena and the outcomes of the rehabilitation [17]. However, conventional therapy is time- and energy-consuming for therapists, and thus it is difficult for them to provide a high-dosage and high-intensity rehabilitation. Furthermore, current assessments in gait [18] and balance [19] rehabilitation are based on subjective and qualitative clinical scales, which limits the possibility of tailoring the rehabilitation to individual needs.

Robot-assisted therapy uses robotic devices as a therapeutic approach for treating neurological injuries and assisting in rehabilitation training by automating the rehabilitation therapy process [20]. Robotic devices can supply repetitive, intensive, and task-oriented training [21], which frees up therapists from physically demanding tasks and allows them to supervise more than one patient simultaneously. Moreover, they are able to carry out more complex rehabilitation exercises and provide feedback to the patients in a motivating environment, which stimulates functional recovery and promotes neuroplasticity phenomena [22]. Hence, the use of robotic devices in therapy can overcome the limitations of conventional therapy and enhance the rehabilitation conditions. Also, robot-assisted therapy can be equipped with sensors that provide unbiased data and allow objective assessment of the patient's progress in terms of gait and balance [23] and propose a more effective tailored rehabilitation [24].

Despite the evidence of less efficacy quantifying gait [25], subjective and observer's experience-based conventional therapy continues to be predominant among clinicians, mainly due to its inherent simplicity, availability, and low cost [26]. However, even if this conventional therapy may be useful for an initial overall evaluation of some balance and gait parameters, it is not adequate for analyzing the multifaceted aspects of gait variability and complexity [27].

The skepticism and fear of rehabilitation team members to be replaced by robots may be another reason that hinders the application of robot-assisted rehabilitation in a clinical setting. Nonetheless, in rehabilitation, it is necessary to optimize the trade-off between the number of people treated, the intensity and duration of the treatment, and the associated health-care costs [28]. In this context, robotic devices do not make physiotherapists redundant: they support them with the more physically challenging tasks [29] to increase the intensity, duration, and number of patients treated in a cost-effective way.

There is evidence that robot-assisted rehabilitation can improve balance function [30] and help patients to achieve independent walking and a higher walking speed [31]. However, the superiority, in terms of balance and gait outcomes, of robot-assisted rehabilitation compared to conventional therapy is still unclear. In fact, some Cochrane reviews showed no difference between robotic and conventional gait therapy in promoting motor recovery in patients with neurological disorders [32]. Although there is a lack of clear evidence to support the robotic approach over conventional therapy, different studies proved that a combination of both approaches led to better gait [33,34] and balance function [35] outcomes than the use of just conventional training without robotic devices. These findings suggest that robot-assisted therapy may be a complementary approach for gait and balance function rehabilitation.

1.2. Aim of the Article

Due to the aforementioned advantages and the importance of balance and gait in ADLs, a wide range of rehabilitation robots has been developed during the last few decades [36]. However, the current literature on rehabilitation robotics often provides limited information about the characteristics of available prototypes, and this lack of information makes the classification of robotic devices challenging [37]. Some review articles attempted to pave the way toward a standard classification [38], but the proposed classifications are focused on gait rehabilitation systems and do not consider those devices for balance rehabilitation [39,40]. Hence, there is a need to provide a classification that takes into account both balance and gait rehabilitation devices.

From the available reviews and studies on lower-limb rehabilitation robots [41,42], four general types of rehabilitation devices can be distinguished: treadmill-based robots, wearable exoskeletons, end effectors, and overground rehabilitation robots. Specific reviews of treadmill-based robots [43], wearable exoskeletons [44], and overground rehabilitation robots [45] can be found in the literature. In contrast, the information available about end effectors for gait and balance rehabilitation is scarce, too general (i.e., limited to a few commercially available end effectors and well-known prototypes), and mainly focused on gait rehabilitation [46]. Therefore, there exists an information gap, and different end effector-based robots that could be promising for gait and balance rehabilitation are scattered in the literature.

Compared to other types of rehabilitation robots, end effectors present some advantages (e.g., easily adjustable to different patients, reduced setup time, and promoting active patient participation), and different studies highlighted their suitability for rehabilitation [47]. Thus, it may be interesting for the scientific community to carry out a thorough review to identify and analyze the end effectors covered in the literature.

Consequently, this article has two main objectives: to propose a classification of rehabilitation robots for gait and balance functions and to provide a comprehensive overview of end effector robots in the literature. The key points of these two objectives are shown in Figure 1.

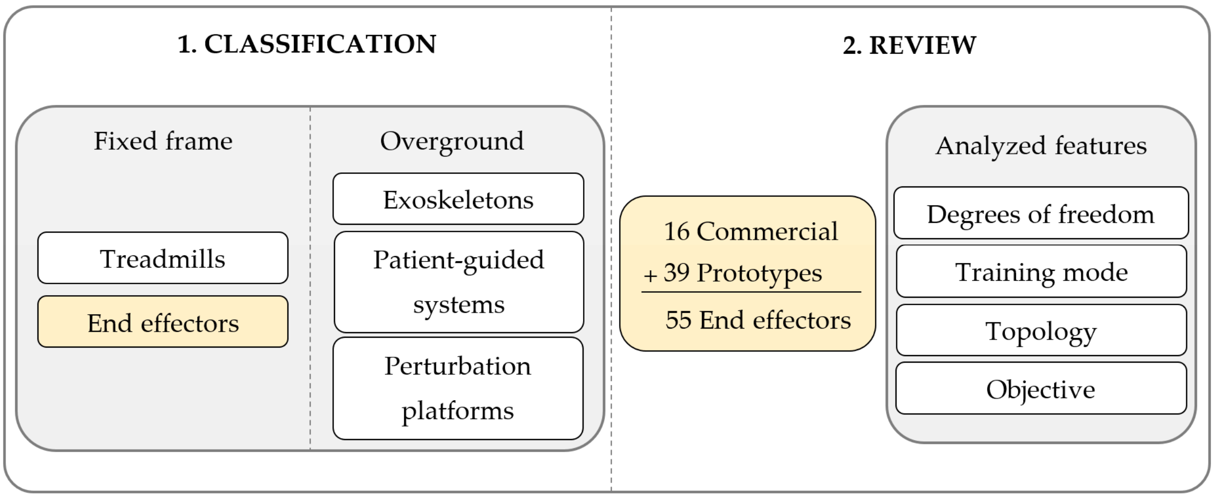

Figure 1. The two main objectives of this article and their corresponding key points.

The article is organized as follows. In Section 2, the currently available rehabilitation devices for gait and balance training are explained and classified. As seen in Figure 1, we classified them into five general groups depending on the type of rehabilitation workspace (i.e., fixed frame or overground). Section 3 highlights the advantages of the end effector-based robots, presents all the identified designs, and discusses future directions pursue to tackle the shortcomings of current end effectors. In total, 55 end effectors were identified (16 commercial devices and 39 prototypes), and we analyzed their most relevant features from a mechanical point of view. Finally, in Section 4, the conclusions of this review article are drawn.

2. Gait and Balance Rehabilitation

In this section, we describe the different approaches, training modes, and robotic devices for gait and balance training, and a classification of the currently available rehabilitation robotic devices for such functions is proposed.

2.1. Rehabilitation Approaches and Training Modes

Nowadays, two main rehabilitation approaches can be distinguished in the literature: bottom-up and top-down approaches. Bottom-up approaches are based on the mechanism of neural plasticity, and the idea is to act on the physical level (bottom) and expect changes at the central neural system level (top). In contrast, top-down approaches consist of defining the rehabilitation therapies based on the state of the brain after a neurological disorder [48].

Functional electrical stimulation (FES), brain–computer interfaces (BCIs), and robotic devices are potentially powerful tools for top-down neurorehabilitation. FES refers to the use of electrical stimulation of lower-motor neurons to cause muscle contraction and to accomplish functional tasks such as standing or walking [49], whereas BCIs are systems that record, decode, and translate measurable neurophysiological signals into an effector action or behavior [50]. Hence, BCI systems can be combined with robotic devices or with FES to promote rehabilitation according to the patient's intention directly decoded from the brain activity. Although many robotic devices have potential for top-down approaches, in this review article we focus on the application of robotic devices for direct bottom-up rehabilitation (see Figure 2).

- Top-down approach
- **Bottom-up approach**
  - Assistive
  - **Therapy** (**Active–passive–hybrid**)
    - Upper limbs
    - **Lower limbs**
      - Stationary trainers
      - **Standing/walking type**
        - **Gait** (**G**)
        - **Balance** (**B**)

Figure 2. General classification of the devices used in the rehabilitation field. Categories further considered in this article are represented in bold.

Robotic systems can aid in rehabilitation as assistive robotic devices and as therapy robotic devices [51]. Assistive robotic devices do not generate exercises for the affected limbs, and their objective is to assist the patients in performing ADLs. Wheelchairs, crutches, and walkers are examples of assistive devices. In contrast, therapy robotic devices mimic the task of a physiotherapist and can generate rehabilitation exercises that are useful for regaining essential functionalities such as balance and walking. Therapy robotic devices can be classified based on the training mode and thus according to human–robot interaction control strategies. Different training modes and control strategies have been proposed in the literature for therapy robots [52], and although the terms may vary among different works, the main principle behind them is similar. In this review, we classify therapy robotic devices as active, passive, and hybrid, as in [40].

- **Active robotic** devices provide **passive training**. That is, the device helps the patient to follow rehabilitation trajectories predefined by the physiotherapists. Studies report that passive exercises (from the patient's point of view) with active rehabilitation devices increase the range of motion of lower-limb joints and reduce muscle atrophy [53]. This type of training mode is suitable for early-stage rehabilitation where the patient still does not have enough muscle strength.

- **Passive robotic** devices promote **active training**. These devices are used at intermediate–advanced rehabilitation stages when patients can perform their own movements. In this training mode, the participation of the patient is necessary, and the robot can assist the patients to complete the rehabilitation trajectory or provide resistance force to make the exercise more challenging. It has been observed that the active participation of the patients promotes neuroplasticity and improves the rehabilitation results [54,55].
- **Hybrid robotic** devices are a combination of the previous two. They provide **hybrid training**, where the device can interact with the patient during the rehabilitation trajectory or just follow the patient motion. From now on, the terms "therapy devices" and "rehabilitation devices" are going to be used indistinctly.

2.2. Classification of Robotic Devices for Gait and Balance Functions

Therapy or rehabilitation robotic devices can be further classified according to different criteria, such as the rehabilitation objective, their suitability for different therapy stages, the position of the patient during the rehabilitation, and the human–machine mechanical interface.

In general, rehabilitation robots can be divided into upper- or lower-limb rehabilitation devices depending on the body functioning that they aim to rehabilitate [56]. Despite several studies showing that there exists a neuronal coupling between upper limbs and lower limbs during locomotion and balance [57,58], in this article, we focus only on lower-limb rehabilitation robots. Among lower-limb rehabilitation robots, some are mainly used for the rehabilitation of specific joints (e.g., ankle, knee, etc.) and muscle strengthening, while others are used for functional rehabilitation, that is, for gait and balance rehabilitation.

The interconnection between balance and gait [59,60] makes it difficult to distinguish whether a robotic device is only for gait rehabilitation or for both gait and balance rehabilitation. In fact, in accordance with the results of some studies [61,62] that reported a balance improvement as an outcome of gait rehabilitation, Lorusso et al. concluded that balance function can be rehabilitated directly or indirectly (as a side effect of gait training) [63]. Thus, devices suitable for gait rehabilitation can indirectly rehabilitate balance function. In the classification for lower-limb rehabilitation devices proposed in this section (see Figure 3), we distinguish between devices for gait (G) rehabilitation, those for direct balance (DB) rehabilitation, and those for indirect balance (IB) rehabilitation.

Fixed frame	Treadmills	With BWS	(G-IB)
		With BWS + exoskeleton	(G-IB)
		Perturbation treadmills	(G and DB)
	End effectors	Unique footplate	(DB)
		Double footplates	(G-IB)
Overground	Perturbation platforms	Above ground	(DB)
		Ground level	(DB)
	Exoskeletons	Wearable	(G-IB)
		Platform-mounted	(G-IB)
	Patient-guided systems	Mobile robotic platform	(G and DB)
		Suspension robots	(G-IB)

Figure 3. Overview of the classification of currently available lower-limb rehabilitation devices for gait and balance functions. G stands for gait rehabilitation, DB for direct balance rehabilitation, and IB for indirect balance rehabilitation.

Overall, lower-limb rehabilitation robots can be divided into two main groups according to the position of the patient during the rehabilitation process: sitting- or lying-type rehabilitation devices, also known as stationary trainers, and standing- or walking-type rehabilitation devices.

2.2.1. Sitting/Lying-Type Rehabilitation Devices (Stationary Trainers)

Recent works have stated that rehabilitation is more effective in the early stage after neurological damage occurs [64]. However, in the initial rehabilitation stage, patients may not be able to maintain their balance when standing by themselves or using a body weight support (BWS) system. Thus, the rehabilitation devices that require patients to be in a standing position are not suitable for them. In this context, stationary trainers are used. Stationary trainers are rehabilitation systems in which the patient is in a resting position (sitting or lying) next to the robotic device. Since the patient is in a resting position, these kinds of systems cannot provide direct gait rehabilitation, but they can prepare the patient for future gait and dynamic balance rehabilitation by strengthening lower-limb muscles as well as increasing joint mobility and movement coordination [41].

Stationary trainers can be grouped into two types depending on the human–machine mechanical interface. On the one hand, there exist end effector-type stationary trainers, in which the connection between the patient and the rehabilitation system takes place at the distal segment of the patient (the foot). Lambda [65], NEUROBike [66], the design proposed by Wang et at. [67], and the commercialized elliptical trainer MOTOmed® (RECK Group, Betzenweiler, Germany) are examples of footplate-based end effectors. In these systems, the objective is to rehabilitate the whole lower limb by increasing the muscle activity and hip—knee–ankle joint mobility. There also exist platform-based end effectors for exercising and restoring specific joints such as the human ankle [68] and knee [69]. Furthermore, end effector-type stationary systems like the Erigo®-Tilt Table (Hocoma, Volketswil, Switzerland) have also been developed for early-stage mobilization of the lower limbs and to gradually help the patient to maintain an upright position.

On the other hand, there are stationary trainers based on exoskeletons or active orthosis. In these systems, the exoskeleton is attached to a stationary frame and guides the patient's leg according to a preprogrammed motion. The exoskeleton-based stationary trainers covered in the literature include Physiotherabot [70], MotionMaker [71], Supine [72], and iLeg [73]. Even though these robotic systems are not appropriate for gait or balance rehabilitation, as end effector-based stationary trainers, they provide an efficient strengthening of the lower-limb muscles.

Finally, there also exist stationary trainers that combine footplate-based end effectors with passive orthoses. While the passive orthosis provides a proper support to the lower limbs and guides hip, knee, and ankle rotation, the footplate-based end effectors carry out rehabilitation trajectories. The ANKUR-LL II [74] and the mechanism proposed by Sunilkumar et al. [75] are examples of this type of trainer found in the literature.

2.2.2. Standing/Walking-Type Rehabilitation Devices

Unlike the stationary trainers, the main aim of standing/walking rehabilitation devices is to correct the gait pattern and the balance function in similar conditions to ADLs. The patients rehabilitate in a standing position, and even though these types of devices are usually provided with a BWS system, patients must have a certain level of physical ability to maintain the vertical position [74]. Hence, these systems are feasible for intermediate-to-advanced stages of rehabilitation.

Standing/walking-type lower-limb rehabilitation devices can be classified into two groups depending on the type of rehabilitation workspace: fixed-frame devices and overground devices. The former cannot move around in the environment and the patient performs the rehabilitation in a fixed and confined area, while the latter can move in the environment, allowing the patient to walk overground around the clinical facility.

Fixed-Frame Devices

The currently available fixed-frame devices for gait and balance rehabilitation can be subclassified into two categories: treadmill-based and end effector-based robotic devices.

Treadmills

Treadmills systems are suitable for gait and balance rehabilitation, being one of the most commonly used systems for conventional therapy [43].

The currently available treadmill-based devices for gait rehabilitation can be divided into two types: treadmills with BWS system, and treadmills-based exoskeletons. Treadmills with BWS consist of a unidirectional treadmill combined with a suspension system that supports part of the patient's weight. While the patient is walking on the treadmill, two to three therapists manually assist the legs and hip to correct the gait patterns [43]. RehaWalk® (zebris Medical GmbH, Isny, Germany), C-Mill (Motek Medical, Houten, The Netherlands) and the LokoStation (Woodway Inc., Waukesha, WI, USA) are commercial examples of this gait rehabilitation system. One major limitation of the treadmills with BWS is the number of therapists that are needed and their labor intensiveness. To overcome this problem, treadmills-based exoskeletons were proposed. This type of treadmills consists of a BWS and a bilateral lower limb exoskeleton (or active leg orthoses) attached to the patient's leg while he/she is walking on a treadmill frame [53]. The exoskeletons are mechatronic devices, usually serial robot architectures, that move in parallel to the skeleton of the patient and they adjust the motion of the lower limb joints through a preprogrammed physiological gait pattern. The Lokomat® (Hocoma, Volketswil, Switzerland) was one of the first treadmill-based exoskeleton to be commercialized [76], being ALEX [77], LOPES [78] and the ReoAmbulator™ (Motorika Medical Ltd., Caesarea, Israel) other well-known devices.

With respect to direct balance rehabilitation, some treadmills can act as a balance perturbation source for the patient. The MIT-Skywalker is an example of this [79]. It consists of a double treadmill (one for each foot) that besides rehabilitate gait, through a rhythmic and discrete training, it has the capacity to tilt the surface of the treadmills in the medio-lateral direction and thus to provide balance training. There also exist bidirectional treadmills [80] and treadmills mounted on movable platforms [81] that can generate slip and trip-like perturbations by changing the belt acceleration (e.g., sudden starts), by reversing the rotation and by lateral shifts. The BalanceTutor (MediTouch Ltd., Tnuvot, Israel) is a commercialized example of these perturbation systems. There are also devices that combine treadmills with push/pull mechanisms to assess how patients maintain their balance during perturbed walking, that is, walking in the presence of perturbations with different magnitudes and directions [82,83].

End effectors

End effector devices are robotic systems that consist of one or two footplates on which the patients place their feet. In contrast to systems with exoskeletons, where the human-machine mechanical interface involves the entire limb, in end effector systems the human-robot interaction occurs at the distal segments (feet) and thus no alignment between the patient and the robot joints is required. Hence, leg movements are controlled just by the trajectory of a unique footplate or bilaterally placed footplates. These types of devices are suitable for both gait and balance rehabilitation.

For gait rehabilitation, the end effectors usually consist of two footplates that simulate different phases of natural gait (i.e., swing and stance). Based on the trajectory generated [38], two types of end effectors can be distinguished: end effectors with fixed trajectories and end effectors with adjustable trajectories. In the former ones, the trajectory of the footplates can only be adjusted by changing the size of the mechanism components that transfer the movement to the footplates. Crank-rocker mechanisms, such as the Gait Trainer-GT I [84] and the LOKOIRAN [85], and the five-linkage and six-linkage mechanism proposed by Kim et al. [86] and Shao et al. [87] are examples of end effectors with fixed trajectories. In contrast, in the end effector with adjustable trajectories, the trajectory is not predefined and it can be adjusted by programmable systems to generate different types of human gait patterns (e.g., stair climbing and flat walking). HapticWalker [88] and G-EO [89] systems are the most common examples of end effectors with adjustable trajectories.

The end effector systems for balance rehabilitation usually consist of a unique standing footplate. This standing surface can challenge the standing balance of the patients by tilt movements or, in general, by ground perturbations. Hunova® [90] and the Balance System™ SD (Biodex Medical Systems Inc., Shirley, NY, USA) are examples of end effectors for standing balance. Besides, it is possible to combine these perturbation footplates with a treadmill, to assess and rehabilitate the balance function of the patients in walking conditions [91].

Overground Type Devices

Regarding overground type robots, three different family of devices can be distinguished: perturbation platforms, overground exoskeletons, and patient-guided systems.

Perturbation platforms

Perturbation platforms are devices mainly focused on balance rehabilitation. The Balance Training Assist developed by Toyota Motor Corporation is an example of this type of device. It consists of a standing platform mounted on two wheels, with an upright handgrip, that can self-balance [92]. It can provide sagittal perturbations to the patient, to challenge standing balance, by rotating or by moving forward/backward the standing platform.

The perturbation platform proposed by Van-Doornik et al. [93] and the SLIP-FALL movable ground platform designed by Robinson et al. [94] are other examples of this type of devices that challenge the balance function during walking (i.e., gait stability). In particular, the 4 degrees-of-freedom perturbation platform presented by Van Doornik et al. was designed to check the balance of the patients by applying multidirectional perturbations during the stance phase of walking, whereas the SLIP-FALL movable platform can simulate slippery ground and thus provide controllable slip-like perturbations to the patient. In contrast to the Balance Training Assist platform developed by Toyota, these two perturbation platforms are located at ground level.

Exoskeletons

In last decades, various overground exoskeletons have been developed and commercialized for lower limb rehabilitation. These robotic devices actuate over one or more leg joints, and their main objective is to rehabilitate locomotor function [95]. However, they can also be used to assess the balance function of the patients in the anterior-posterior direction [96]. It is possible to distinguish two types of overground exoskeletons depending on who (the patient or the robotic system) has to carry the weight of the exoskeleton. There exist fully wearable exoskeletons, such as the currently commercial Hybrid Assistive Limb (HAL) [97], ReWalk™ (ReWalk Robotics Inc., Marlborough, MA, USA) and EksoNR (Ekso Bionics, San Rafael, CA, USA) exoskeletons, in which the patient supports the weight of the exoskeleton. There are also mobile-platform mounted exoskeletons, such as Gable CORE™ (Gable Systems BV, Hengelo, The Netherlands) and NaTUre-gaits [98], where the exoskeleton is mounted on a mobile wheeled platform that supports the weight of the device.

Patient-guided systems

Patient-guided systems are the last type of overground devices. From a biomechanical standpoint, patients using these devices rehabilitate in an environment that is very close to the one in ADLs and thus they reach a higher level of independent walking compared to BWS treadmill training [45]. Nonetheless, they are mainly designed for the rehabilitation of partially recovered patients who have regained sufficient strength to walk overground and thus, for patients in their intermediate-advanced rehabilitation stage. Two types of patient-guided robotic systems can be distinguished in the literature: mobile robotic platforms and suspension robotic systems.

Mobile robotic platforms are robots especially designed for gait training. They consist of an overground omnidirectional wheeled frame, which is inherently stable, and a BWS (harness or a trunk/pelvic support) connected to it, that provides the user with safety and freedom to initiate and carry out the walking movement [99]. The robotic components can be the support system (active BWS) and/or the wheeled frame, which provides automated navigation or actively follows the patients by measuring their intention [96]. KineAssist [100], Andago® (Hocoma, Volketswil, Switzerland), WHERE-I and WHERE-II [101] are examples of mobile robotic platforms. Besides these examples, Olensek et al. proposed a novel robot, which combines the balance assessment robot (BAR) developed by University Rehabilitation Institute of Ljubljana (Slovenia) and a mobile platform. It is capable of providing controlled push-like perturbation to promote balance training during overground walking [102].

Overground suspension robots are active BWS systems similar to those used to support training on treadmills and end effectors, but with the difference that they must be capable of following the patient around the clinical environment, while they provide safety and vertical supportive force. These robots are usually connected to a rail-mechanism on the ceiling, such as in the ZeroG® (Aretech, Sterling, VA, USA) and the FLOAT (Reha-Stim Medtec, Zürich, Switzerland). These systems are generally for gait training and they cannot provide direct balance rehabilitation without using additional robotic devices. Since overground suspension robots are above the patient, there are no barriers between the patient and therapist. Hence, rehabilitation takes place in a more accessible and controlled environment.

3. End Effector-Based Devices for Gait and Balance Rehabilitation

3.1. Advantages of End Effector-Type Rehabilitation Devices

Among the previously explained rehabilitation devices for gait and balance, end effector-based robots present encouraging results. This is mainly due to their advantages with respect to other robotic devices, such as exoskeletons and treadmills.

If we compare them with treadmill-based devices and overground exoskeletons, end effector devices are easier to set-up [35]. In fact, their minimal preparation time and low operating costs have made them attractive for rehabilitation and increased the number of commercially available end effectors for gait training [103]. Since no alignment between patient and robot joints is required in end effectors, they can be easily adjusted to different sizes and patients. However, it is challenging to adapt the exoskeletons to different patients, since the lengths of the robot segments and the joints must be perfectly aligned with the anatomical limbs and joints [103].

Even though exoskeleton-type robots can directly control individual joints (hip, knee, and ankle) and avoid abnormal leg movement patterns, it has been proved that the free motion of the knee and hip joints provided by end effectors promotes "destabilization training" [104]. This training can reinforce the neuronal circuit and contribute to postural control and sensory integration [105]. Furthermore, active patient participation in rehabilitation appears to be a promising method of locomotor rehabilitation [106], and according to some studies, it may be considered one of the most important features of any training [107]. In this regard, exoskeletons may produce the opposite effect, that is, make the patient more passive, since they are affixed to the entire lower limb.

From a rehabilitation movement standpoint, end effectors are more suitable than treadmill-based robots and exoskeletons when different types of terrain and human gait patterns need to be simulated, like climbing up/down stairs [108]. End effectors can generate movements that are not constrained only to one anatomical plane (i.e., the sagittal plane), and consequently they can increase the patient's influence on the walking trajectory and provide meaningful balance training [46]. In connection with this, end effector robots can provide perturbations in the anterior–posterior or mediolateral directions, as well as a combination thereof. In contrast, the current generation of exoskeletons can only apply perturbation in the sagittal plane, which is a strong limitation, considering that perturbations in everyday life are not restricted to this plane [96].

Despite evidence of encouraging results (e.g., higher rates of independent walking) of end effectors compared to exoskeletons [109], there is still a lack of a clinical consensus on which type of device should be used for patients with neurological disorders [110]. Nonetheless, the number of studies that support and highlight the suitability of end effector-type robots for the improvement of gait and balance in patients with neurological disorders is considerable. As an example, Gandolfi et al. concluded that end effector robot-assisted gait training enhances walking and balance functions in patients with multiple sclerosis [111]. Mazzoleni et al. underlined the efficacy of end effector-based training on gait, balance, and coordination in chronic stroke patients [112], and Maranesi et al. conducted a systematic review that evidenced improvements in overall mobility, gait speed, and functional ambulation with the use of end effector gait trainers in stroke patients also [113].

Several research and review articles have collated information about end effectors already available for gait and balance rehabilitation [36,46]. However, most of these are part of a classification study that includes other type of rehabilitation devices (exoskeletons, treadmills, stationary trainers, etc.), and thus the information provided about end effectors is limited and does not cover a wide range of the prototypes covered in the literature. In the following subsection, we provide information about the identified end effectors for gait and balance rehabilitation.

3.2. Review of End Effectors

In this section, we present and analyze existing end effector-based devices for the rehabilitation of gait and balance functions. To identify the end effectors covered in the literature, we searched for scientific publications in four online databases: Web of Science, Scopus, PubMed, and IEEE Xplore. The search was conducted for articles published from 1998 to 2023. We only considered English written articles discussing end effector systems for gait and/or balance rehabilitation in which the patient(s) performed the rehabilitation process in a standing position. Hence, those end effectors for lower limbs that provide rehabilitation motions while the patient is seated or in a lying position (i.e., stationary trainers) and those focused on joint-specific rehabilitation (e.g., ankle and knee rehabilitation) are not included in this review.

3.2.1. Commercially Available End Effectors

In total, 55 end effectors were found in the literature. Among them, only 16 are commercially available, whereas the rest are designs or prototypes used for research purposes. The different commercially available end effectors, together with some of their most important features, are presented in Table 1.

Most of the commercialized end effectors for gait rehabilitation, such as the Gait Trainer (Reha-Stim, Berlin, Germany) and Lyra (THERA-Trainer, Hochdorf, Germany), consist of two 1-degree of freedom (DOF) footplates that move each foot of the patient according to a fixed trajectory. However, devices such as the G-EO system (REHA Technology, Olten, Switzerland) and Morning Walk (CUREXO Inc., Seoul, South Korea) can simulate more complex movements (e.g., stair climbing) due to the use of two 3-DOF footplates. In general, hybrid training mode is used for gait function recovery, and depending on patient condition, the device supports gait movements completely or partially.

Regarding direct balance rehabilitation, a great majority of the commercialized end effectors consist of a unique footplate with two rotational DOFs around the mediolateral and anterior–posterior directions (e.g., Balance System™ SD). However, there are also end effectors such as DynSTABLE (Motek Medical, Houten, The Netherlands) and EquiTest® (NeuroCom International Inc., Clackamas, OR, USA), which have the capacity to introduce translational perturbations. In contrast to gait rehabilitation devices, passive rehabilitation is the predominant training approach provided by balance rehabilitation end effectors.

From the control strategy point of view, balance rehabilitation end effectors are simpler in comparison with the gait rehabilitation ones.

Table 1. Commercialized end effector-based devices for gait and balance rehabilitation.

Device	Ref	DOFs	Objective	Training Mode	Company
Gait Trainer-GT I	[114]	1×2	Gait	Hybrid	Reha-Stim (Germany)
Gait Trainer-GT II	[115]	1×2	Gait	Hybrid	Reha-Stim Medtec (Switzerland)
LEXO®	[116]	1×2	Gait	Hybrid	Tyromotion (Austria)
Lyra	[117]	1×2	Gait	Passive	THERA-Trainer (Germany)
Morning Walk	[118]	3×2	Gait	Hybrid	CUREXO, Inc. (South Korea)
G-EO system	[119]	3×2	Gait	Hybrid	REHA Technology (Switzerland)
Hunova®	[120]	2×2	Balance	Hybrid	Movendo Technology (Italy)
Balance System™ SD	[121]	2	Balance	Active	Biodex Medical Systems, Inc. (USA)
DynSTABLE	[122]	2	Balance	Passive	Motek Medical (The Netherlands)
Huber 360®	[123]	2	Balance	Passive	LPG Systems (France)
GeaHD	[124]	2	Balance	Passive	Vertigomed (Italy)
PROPRIO® 5000	[125]	2	Balance	Passive	Perry Dynamics, Inc. (USA)
Smart EquiTest®	[126]	2	Balance	Passive	NeuroCom International, Inc. (USA)
ProKin	[127]	2	Balance	Active	TecnoBody® (Italy)
MultiTest Equilibre	[128]	6	Balance	Active	FRAMIRAL (France)
CAREN	[129]	6	Both	Passive	Motek Medical (The Netherlands)

DOFs, degrees of freedom ($\times 2$ = two footplates). The training mode is from the patient's point of view, that is, "active" means that the patient takes part in to generate movement of the footplates, whereas "passive" means that the device moves the footplates without the collaboration of the patient.

There also exist other commercialized end effectors, such as the CAREN (computer-assisted rehabilitation environment) developed by Motek Medical, which are suitable for both gait and balance rehabilitation. The CAREN consists of a 6-DOF platform (Gough–Stewart platform) with a dual-belt treadmill mounted on top [91]. Therefore, patients can walk on the treadmill while ground perturbations introduced by the Stewart platform challenge their stability during gait.

Although the well-known LokoHelp® (Woodway Inc., Waukesha, WI, USA), which is an electromechanical gait device designed to be placed on a treadmill, can be considered an end effector, its motion generation depends mainly on a treadmill. Hence, unlike the CAREN, where the motion of the treadmill and the end effector are decoupled, we are not considering it as an end effector. Likewise with the MRG-P100 (HIWIN Technologies Corp., Taichung, Taiwan), where the movement transmitted to the lower limbs is generated by an end effector, but with the help of an exoskeleton. According to our classification, these devices can be considered hybrid designs.

3.2.2. Non-Commercially Available End Effectors

Compared to the number of the aforementioned commercialized devices, a significant number of prototypes and theoretical designs of end effectors were found in the literature. Namely, 39 end effectors were proposed among different research groups and authors. Depending on the type of mechanism that they use for moving the footplates and thus to generate the rehabilitation movements, these end effectors can be divided into two groups: those that use parallel kinematic manipulators (PKMs), and those using another kind of mechanisms (e.g., slider-crank and serial robots).

-**Driven by PKM**. The non-commercially available end effectors driven by PKMs are presented in Table 2. All of them have the advantages of parallel mechanisms, such as excellent positioning accuracy, high stiffness, compactness, and a high payload/mass ratio [130]. Moreover, the entire mechanism can be confined below the footplates, avoiding possible collisions with the patients, and the actuators can be placed on the fixed frame, which reduces the inertia of the device (lower energy consumption).

Table 2. PKM-driven end effectors for gait and balance rehabilitation.

Authors	Ref	Topology	DOFs	Objective	Training Mode
2023, Risk-Mora et al.	[131]	2-$\underline{\mathrm{P}}$RR	(2T) × 2	Gait	Passive
2021, Kose et al.	[132]	$\underline{\mathrm{P}}$-$\underline{\mathrm{R}}$PRR-$\underline{\mathrm{R}}$RR	(1T1R + T) × 2	Gait	Passive
2020, Xie et al.	[133]	2-$\underline{\mathrm{P}}$SS-(2-$\underline{\mathrm{P}}$RR-PR)R	(1T2R) × 2	Gait	Passive
2019, Wang et al.	[134]	$\underline{\mathrm{P}}$-2-$\underline{\mathrm{P}}$SS-(2-$\underline{\mathrm{R}}$RR-PR)R	(1T2R + T) × 2	Gait	Passive
2018, Zhang et al.	[135]	3-$\underline{\mathrm{P}}$RR	(2T1R) × 2	Gait	Passive
2018, Azcaray et al.	[136]	2-$\underline{\mathrm{PR}}$R	(2T1R) ×2	Gait	Passive
2017, Maddalena et al.	[137]	$\underline{\mathrm{P}}$-3-U$\underline{\mathrm{P}}$S-$\underline{\mathrm{P}}$S	(1T3R + T) × 2	Gait	Passive
2016, Rastegarpanah et al.	[138]	6-U$\underline{\mathrm{C}}$U (Stewart)	(3T3R) × 2	Gait	Passive
2016, Azar et al.	[139]	6-U$\underline{\mathrm{P}}$S (Stewart)	(3T3R) × 2	Gait	Passive
2015, Elias	[140]	6-U$\underline{\mathrm{P}}$S (Stewart)	(3T3R) × 2	Gait	Passive
2013, Mao et al.	[141]	$\underline{\mathrm{P}}$-6-U$\underline{\mathrm{C}}$U (Stewart)	(3T3R + T) × 2	Gait	Passive
2010, Yoon et al.	[142]	$\underline{\mathrm{P}}$-($\underline{\mathrm{P}}$R-$\underline{\mathrm{P}}$RP)	(1T1R + T) × 2	Gait	Hybrid
2006, Yoon et al.	[143]	3-$\underline{\mathrm{R}}$RR + ($\underline{\mathrm{P}}$SPP + $\underline{\mathrm{PR}}$P)	(2T1R + 1T2R) × 2	Gait	Hybrid
2004, Boian et al.	[144]	6-U$\underline{\mathrm{C}}$U (Stewart)	(3T3R) × 2	Gait	Passive
2003, Yoon et al.	[145]	3-$\underline{\mathrm{R}}$RR + (2-$\underline{\mathrm{P}}$R-2-$\underline{\mathrm{P}}$RP)	(2T1R + 1T3R) × 2 + R	Gait	Passive
2003, Yano et al.	[146]	2-$\underline{\mathrm{P}}$RR$_\mathrm{p}$R	(2T) × 2	Gait	Passive
2000, Yano et al.	[147]	$\underline{\mathrm{R}}$-(3-U$\underline{\mathrm{C}}$U-PPP)-R	(2T2R) × 2	Gait	Active
2019, Summa et al.	[148]	$\underline{\mathrm{R}}$-6-U$\underline{\mathrm{C}}$U (Stewart)	3T3R + R	Both	Passive
2023_Zermane et al.	[149]	3-$\underline{\mathrm{P}}$RS	1T2R	Balance	Passive
2023, Ersoy et al.	[150]	3-R$\underline{\mathrm{P}}$S	1T2R	Balance	Hybrid
2022, Ishizaki et al.	[151]	4-R$\underline{\mathrm{C}}$U/U	2R	Balance	Passive
2021, Rivera et al.	[152]	2-$\underline{\mathrm{R}}$SS/U	2R	Balance	Hybrid
2020, Baselizadeh et al.	[153]	2-$\underline{\mathrm{R}}$SS/U	2R	Balance	Passive
2011, Patanè et al.	[154]	3-$\underline{\mathrm{P}}$SS/S	3R	Balance	Passive

Topology column represents the nature of the parallel kinematic manipulator's chains, where P, R, S, U, and C stand for prismatic, revolute, spherical, universal, and cylindrical joints, respectively. Underlined letters indicate the actuated kinematic joints. $\mathrm{R_p}$ stands for a shared revolute joint in a pantograph. DOFs column indicates the number and type of each degree of freedom: translation (T) and rotation (R).

However, one major drawback of using PKMs is their limited workspace. In particular, the size and shape of the workspace are critical for those end effectors with gait rehabilitation purposes, in which a sufficient step length/height must be achieved to mimic human gait trajectory. One of the most straightforward ways to tackle this problem is to increase the dimensions of the PKM, but this solution would lead to bulky designs. That is why some of the currently available prototypes, instead of increasing the size of the design, use a PKM with prismatic joints to overcome this problem, like in the 3-$\underline{\mathrm{P}}$RR proposed by Zhang et al. [135], where P and R stand for prismatic and revolute joints, respectively, while the underlined letter indicates the actuated kinematic joint. Another way to increase the workspace is to combine a linear guide serially with the PKM, i.e., connect the PKM, which moves each footplate, above a linear guide that allows displacement along the anterior–posterior (longitudinal) direction. The $\underline{\mathrm{P}}$-($\underline{\mathrm{P}}$R-$\underline{\mathrm{P}}$RP) PKM developed by Yoon et al. [142] is an example of the application of this strategy.

With respect to the end effectors driven by PKMs for balance rehabilitation, all of them consist of a unique platform that can provide at least two rotations around the two horizontal axes (mediolateral and anterior–posterior rotations). The amplitudes of the rehabilitation movements required for balance training are not as big as the ones for gait rehabilitation, and hence the workspace limitation of a PKM does not affect them. Despite this advantage, the number of end effectors driven by PKMs for balance rehabilitation is fewer than those for gait recovery.

Among different PKMs for gait rehabilitation, two Stewart platforms, one for each foot of the patient, are used. The main advantage of using Stewart platforms is that they provide 6 DOFs to each foot of the patient and thus they can introduce perturbations in any direction of the space. Overall, two kinds of Gough–Stewart platforms are examined in the literature: 6-U$\underline{\mathrm{P}}$S and 6-U$\underline{\mathrm{C}}$U, where U, C, and S, stand for universal, cylindrical, and spherical joints, respectively. As an example, the prototype presented by Boian et al. for walking simulation consists of two 6-UCU platforms [144], whereas the one proposed by Elias et al. consists of two 6-UPS platforms [140]. Moreover, different prototypes based on unique Stewart platforms were developed for balance rehabilitation. Examples are the design proposed by Summa et al. (DORIS) [148] and the CAREN platform already mentioned. The passive rehabilitation mode is the predominant training mode for PKM-driven end effectors for gait and balance training.

-**Not driven by PKMs.** In contrast, Table 3 summarizes the main features of currently available end effectors for gait and balance rehabilitation that are not driven by PKMs. The HapticWalker developed by Schmidt et al. [88] is a well-known example and one of the first end effector-based robots that enabled the simulation of stair climbing for rehabilitation. Serial robotic arms, slider-crank mechanisms, and five- and six-linkage mechanisms are in charge of generating the movement in these devices, and most of them offer hybrid rehabilitation.

Table 3. Non-PKM-driven end effectors for gait and balance rehabilitation.

Authors	Ref	DOFs	Objective	Training Mode
2005, Schmidt et al.	[88]	(2T1R) $\times$ 2	Gait	Passive
2010, Yano et al.	[155]	(2T) $\times$ 2	Gait	Hybrid
2015, Yano et al.	[156]	(2T) $\times$ 2	Gait	Passive
2018, Boehm et al.	[157]	(1T) $\times$ 2	Gait	Hybrid
2021, Ji et al.	[158]	(2T1R) $\times$ 2	Gait	Hybrid
2009, Chen et al.	[159]	(1T) $\times$ 2	Gait	Hybrid
2015, Vu et al.	[160]	(2T) $\times$ 2	Gait	Hybrid
2016, Shao	[87]	(1T) $\times$ 2	Gait	Hybrid
2020, Kim	[86]	1T	Gait	Hybrid
2014, Haslinger et al.	[161]	2R	Balance	Hybrid
2015, Kharboutly et al.	[162]	1T3R	Balance	Passive
2010, Ding et al.	[163]	2R	Balance	Hybrid
2016, Amritha et al.	[164]	2R	Balance	Active
2018, Retirado et al.	[165]	1R	Balance	Hybrid
2007, Mansfield et al.	[166]	2T	Balance	Passive

Comparing to the prototypes based on PKMs, these devices are simpler, mainly because they provide at most a total of 6 DOFs for gait rehabilitation and 4 DOFs for balance rehabilitation. Moreover, in some cases, the perturbations or trajectories generated are fixed [86,87] and cannot be modified unless the components of the prototype are changed by others with different dimensions.

3.3. Future Research Directions

Based on the results of this review, fewer than one third of the end effectors for gait and balance rehabilitation are commercially available. This small number of commercialized devices compared to the number of prototypes limited to research purposes makes it evident that the development of new devices has been surpassing the introduction of currently existing prototypes into the clinical setting. Although prototypes are important tools for preliminary evidence of usefulness in the rehabilitation process, they should be further validated through clinical trials. In agreement with Gandolfi et al. [37], we encourage the authors of the end effectors identified to undergo the process of obtaining FDA approval or a CE mark to transfer their inventions from applied research to the market, which would ensure the effectiveness of these designs in the rehabilitation of gait and balance.

We found that the number of DOFs in end effector-based devices for gait rehabilitation ranges from 1 to 15. More DOFs means more flexibility in designing rehabilitation exercises, but usually at the expense of increasing the device cost. Therefore, a trade-off between the number of DOFs and the ability to simulate different gait rehabilitation movements is necessary. Considering that during human gait, the lower limbs are mainly contained in the sagittal plane, at least 3 DOFs should be provided for each footplate. However, given that an extra DOF outside the sagittal plane allows the simulation of perturbations that arise during walking on uneven and irregular terrains, it seems reasonable to use end effectors with 4 DOFs for gait rehabilitation. Hence, we consider end effector-based devices with at least 6 DOFs (two 3-DOF footplates) and a maximum of 8 DOFs (two 4-DOF footplates) sufficiently suitable for cost-effective gait rehabilitation.

Regarding the end effectors identified for direct balance rehabilitation, the DOFs in these devices ranges from 1 to 7. From the authors' point of view, an end effector for balance rehabilitation should be able to introduce at least two rotational perturbations in the mediolateral and anterior–posterior directions, which are the most common rotations during ADLs.

On the other hand, prototype end effectors for direct balance rehabilitation are fewer than those for gait rehabilitation. The fact that some studies [63] considered balance rehabilitation as a side effect of gait training (indirect balance rehabilitation) may be one of the reasons for this lower number. Nonetheless, for patients that are in an earlier rehabilitation stage and are not able to stand during gait-like movements, direct balance rehabilitation devices are necessary.

Among the currently available devices, only CAREN and DORIS can provide independent and simultaneous gait and direct balance rehabilitation. However, both are based on a unique Stewart platform, and thus the option of guiding each foot independently during gait rehabilitation is not possible. In this context, it could be interesting as a future research line to design end effector-based devices with one footplate for each foot that can provide gait and direct balance rehabilitation independently and simultaneously. This type of device would reduce setup time, since both gait and direct balance functions can be tested with the same machine. In addition to providing more complete gait rehabilitation, the advantage of using two independent footplates for direct balance rehabilitation lies in the possibility of correcting possible asymmetric posture problems and delivering more realistic perturbations to challenge the balance.

According to [167], the vast majority of the rehabilitation end effectors that are driven by PKMs are used for ankle motion. Despite ankle rehabilitation being their predominant application, the use of PKMs is also widespread in functional (i.e., balance and gait) rehabilitation. In fact, in this review, 25 (including CAREN) end effectors driven by PKMs were identified. Certain features of PKMs make them attractive for balance and gait rehabilitation end effectors; however, a significant number of prototypes are driven by 6-DOF or redundantly actuated PKMs [136,151]. In order to take advantage of their features in a cost-effective way, we suggest the use of lower-mobility PKMs and the development of novel lower-mobility PKMs that could generate training movements for balance and gait rehabilitation end effectors. Recently, the authors in [168] proposed a synthesis method to design lower-mobility PKMs with potential for balance rehabilitation. Rehabilitation devices driven by these manipulators could be an interesting option.

Most of the selected studies focused on rehabilitation rather than on the assessment of gait and balance function. However, when developing new rehabilitation devices, assessment should be taken into account, in particular the type and location of the assessment tools. In the case of end effectors, sensors can be easily embedded in the footplates and baropodometric meshes or force plates in combination with a motion capture system that can be used to assess the recovery level of the patient in terms of gait and balance function. Instead of using different devices for assessment and rehabilitation, a single device for both rehabilitation and assessment is recommended. This would provide objective data about the state and recovery level of the patient and ease the task of the therapists. In addition, assessment tools are necessary for the proper selection of the rehabilitation mode (active, passive, or hybrid) and therefore to tailor the rehabilitation process according to each patient's need.

4. Conclusions

In this article, we provided a comprehensive overview of the currently available end effector-based devices for gait and balance rehabilitation. In addition, we proposed a classification of the existing different lower-limb devices that are suitable for the rehabilitation of gait and balance functions. In this classification, the difference between direct and indirect balance rehabilitation was highlighted, since we found that most of the studies considered balance rehabilitation a side effect of gait training devices, and thus there was a need to provide a classification that considers this small, although important, nuance.

Regarding the reviewed end effectors, most of them are prototypes and have not been clinically tested. Moreover, there exists a disproportion in the number of end effector-based prototypes for gait training and those for direct balance rehabilitation, being more for gait rehabilitation. Only two end effectors out of 55 are designed to provide gait and direct balance rehabilitation independently and simultaneously. By analyzing the different driving mechanisms, we realized that due to their attractive features, PKMs are extensively used in end effector-based devices to generate rehabilitation trajectories. However, the use of lower-mobility PKMs is still limited, and most of the designs tend to use full-mobility Stewart platforms.

We conclude the article by suggesting some directions for future research, among which three are of particular interest to the rehabilitation field. On the one hand, we believe that the existing prototypes should be further improved to transfer them from research to a clinical setting. This would supply the health system with new and more effective tools for the rehabilitation process. On the other hand, future research should focus on the use of lower-mobility PKMs as the driving mechanisms for the end effectors, since their compelling features make the prototypes suitable for gait and balance rehabilitation while the number of actuators and the cost is reduced. Finally, efforts should be invested in the development of new end effectors capable of providing gait and direct balance rehabilitation independently and simultaneously. These double-purpose end effectors, in combination with assessment tools, can meet most research and clinical needs in a cost-effective way.

Author Contributions: All authors contributed to the conceptualization and methodology; writing—original draft preparation, P.D.; writing—review and editing, S.H. and E.M.; visualization, P.D., S.H., and E.M.; supervision, J.C., M.D., F.J.C., and C.P.; project administration, F.J.C. and C.P.; funding acquisition, F.J.C. and C.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received financial support for the project PID2019-105262RB-I00 funded by MCIN/AEI/10.13039/501100011033 and for the project PDC2022-133787-I00 funded by MCIN/AEI/10.13039/501100011033 and by the European Union Next Generation EU/PRTR. This research was also funded by the Basque Government for the project 2018222013 and PhD grant PRE_2023_2_0168.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Feigin, V.L.; Vos, T.; Nichols, E.; Owolabi, M.O.; Carroll, W.M.; Dichgans, M.; Deuschl, G.; Parmar, P.; Brainin, M.; Murray, C. The global burden of neurological disorders: Translating evidence into policy. *Lancet Neurol.* **2020**, *19*, 255–265. [CrossRef] [PubMed]
2. Katan, M.; Luft, A. Global Burden of Stroke. *Semin. Neurol.* **2018**, *38*, 208–211. [CrossRef]
3. Johnson, W.; Onuma, O.; Owolabi, M.; Sachdev, S. Stroke: A global response is needed. *Bull. World Health Organ.* **2016**, *94*, 634–634A. [CrossRef]

4. Feigin, V.L.; Brainin, M.; Norrving, B.; Martins, S.; Sacco, R.L.; Hacke, W.; Fisher, M.; Pandian, J.; Lindsay, P. World Stroke Organization (WSO): Global Stroke Fact Sheet 2022. *Int. J. Stroke* **2022**, *17*, 18–29. [CrossRef] [PubMed]
5. Feigin, V.L.; Stark, B.A.; Johnson, C.O.; Roth, G.A.; Bisignano, C.; Abady, G.G.; Abbasifard, M.; Abbasi-Kangevari, M.; Abd-Allah, F.; Abedi, V.; et al. Global, regional, and national burden of stroke and its risk factors, 1990–2019: A systematic analysis for the Global Burden of Disease Study 2019. *Lancet Neurol.* **2021**, *20*, 795–820. [CrossRef] [PubMed]
6. Lanas, F.; Seron, P. Facing the stroke burden worldwide. *Lancet Glob. Health* **2021**, *9*, e235–e236. [CrossRef] [PubMed]
7. Owolabi, M.O.; Thrift, A.G.; Mahal, A.; Ishida, M.; Martins, S.; Johnson, W.D.; Pandian, J.; Abd-Allah, F.; Yaria, J.; Phan, H.T.; et al. Primary stroke prevention worldwide: Translating evidence into action. *Lancet Public Health* **2022**, *7*, e74–e85. [CrossRef] [PubMed]
8. Rochmah, T.N.; Rahmawati, I.T.; Dahlui, M.; Budiarto, W.; Bilqis, N. Economic Burden of Stroke Disease: A Systematic Review. *Int. J. Environ. Res. Public Health* **2021**, *18*, 7552. [CrossRef] [PubMed]
9. Ingall, T. Stroke—Incidence, mortality, morbidity and risk. *J. Insur. Med. (N. Y.)* **2004**, *36*, 143–152.
10. Norrving, B.; Barrick, J.; Davalos, A.; Dichgans, M.; Cordonnier, C.; Guekht, A.; Kutluk, K.; Mikulik, R.; Wardlaw, J.; Richard, E.; et al. Action Plan for Stroke in Europe 2018–2030. *Eur. Stroke J.* **2018**, *3*, 309–336. [CrossRef]
11. Pollock, A.; St George, B.; Fenton, M.; Firkins, L. Top 10 Research Priorities Relating to Life after Stroke—Consensus from Stroke Survivors, Caregivers, and Health Professionals. *Int. J. Stroke* **2014**, *9*, 313–320. [CrossRef] [PubMed]
12. Cameron, M.H.; Nilsagard, Y. Balance, gait, and falls in multiple sclerosis. In *Handbook of Clinical Neurology*, 1st ed.; Elsevier B.V.: Amsterdam, The Netherlands, 2018; Volume 159, pp. 237–250. [CrossRef]
13. Chastan, N.; Do, M.C.; Bonneville, F.; Torny, F.; Bloch, F.; Westby, G.W.M.; Dormont, D.; Agid, Y.; Welter, M.-L. Gait and balance disorders in Parkinson's disease: Impaired active braking of the fall of centre of gravity. *Mov. Disord.* **2009**, *24*, 188–195. [CrossRef]
14. Tyson, S.F.; Hanley, M.; Chillala, J.; Selley, A.B.; Tallis, R.C. The Relationship Between Balance, Disability, and Recovery After Stroke: Predictive Validity of the Brunel Balance Assessment. *Neurorehabilit. Neural Repair* **2007**, *21*, 341–346. [CrossRef] [PubMed]
15. Preston, E.; Ada, L.; Dean, C.M.; Stanton, R.; Waddington, G. What is the Probability of Patients who are Nonambulatory after Stroke Regaining Independent Walking? a Systematic Review. *Int. J. Stroke* **2011**, *6*, 531–540. [CrossRef] [PubMed]
16. Rudberg, A.-S.; Berge, E.; Laska, A.-C.; Jutterström, S.; Näsman, P.; Sunnerhagen, K.S.; Lundström, E. Stroke survivors' priorities for research related to life after stroke. *Top. Stroke Rehabil.* **2021**, *28*, 153–158. [CrossRef] [PubMed]
17. Cramer, S.C.; Sur, M.; Dobkin, B.H.; O'Brien, C.; Sanger, T.D.; Trojanowski, J.Q.; Rumsey, J.M.; Hicks, R.; Cameron, J.; Chen, D.; et al. Harnessing neuroplasticity for clinical applications. *Brain* **2011**, *134*, 1591–1609. [CrossRef] [PubMed]
18. Geroin, C.; Zanga, C.; Gandolfi, M.; Smania, N.; Pistarini, C. The Assessment of Gait Disorders in Neurorehabilitation. *Biosyst. Biorobotics* **2018**, *19*, 69–82. [CrossRef]
19. Visser, J.E.; Carpenter, M.G.; van der Kooij, H.; Bloem, B.R. The clinical utility of posturography. *Clin. Neurophysiol.* **2008**, *119*, 2424–2436. [CrossRef] [PubMed]
20. Morone, G.; Paolucci, S.; Cherubini, A.; De Angelis, D.; Venturiero, V.; Coiro, P.; Iosa, M. Robot-assisted gait training for stroke patients: Current state of the art and perspectives of robotics. *Neuropsychiatr. Dis. Treat.* **2017**, *13*, 1303–1311. [CrossRef]
21. Poli, P.; Morone, G.; Rosati, G.; Masiero, S. Robotic Technologies and Rehabilitation: New Tools for Stroke Patients' Therapy. *BioMed Res. Int.* **2013**, *2013*, 1–8. [CrossRef]
22. Stanton, R.; Ada, L.; Dean, C.M.; Preston, E. Biofeedback improves activities of the lower limb after stroke: A systematic review. *J. Physiother.* **2011**, *57*, 145–155. [CrossRef] [PubMed]
23. Culhane, K.M.; O'Connor, M.; Lyons, D.; Lyons, G.M. Accelerometers in rehabilitation medicine for older adults. *Age Ageing* **2005**, *34*, 556–560. [CrossRef] [PubMed]
24. Maggioni, S.; Melendez-Calderon, A.; van Asseldonk, E.; Klamroth-Marganska, V.; Lünenburger, L.; Riener, R.; van der Kooij, H. Robot-aided assessment of lower extremity functions: A review. *J. NeuroEng. Rehabil.* **2016**, *13*, 72. [CrossRef]
25. Hulleck, A.A.; Menoth Mohan, D.; Abdallah, N.; El Rich, M.; Khalaf, K. Present and future of gait assessment in clinical practice: Towards the application of novel trends and technologies. *Front. Med. Technol.* **2022**, *4*, 901331. [CrossRef]
26. Wallmann, H.W. Introduction to Observational Gait Analysis. *Home Health Care Manag. Pract.* **2009**, *22*, 66–68. [CrossRef]
27. Mohan, D.M.; Khandoker, A.H.; Wasti, S.A.; Ismail Ibrahim Ismail Alali, S.; Jelinek, H.F.; Khalaf, K. Assessment Methods of Post-stroke Gait: A Scoping Review of Technology-Driven Approaches to Gait Characterization and Analysis. *Front. Neurol.* **2021**, *12*, 650024. [CrossRef] [PubMed]
28. Morone, G.; Iosa, M.; Paolucci, S. Rehabilitation Approach to Stroke. *Biosyst. Biorobotics* **2018**, *19*, 187–194. [CrossRef] [PubMed]
29. Freivogel, S.; Schmalohr, D.; Mehrholz, J. Improved walking ability and reduced therapeutic stress with an electromechanical gait device. *J. Rehabil. Med.* **2009**, *41*, 734–739. [CrossRef] [PubMed]
30. Swinnen, E.; Beckwée, D.; Meeusen, R.; Baeyens, J.-P.; Kerckhofs, E. Does Robot-Assisted Gait Rehabilitation Improve Balance in Stroke Patients? A Systematic Review. *Top. Stroke Rehabil.* **2014**, *21*, 87–100. [CrossRef]
31. Bruni, M.F.; Melegari, C.; De Cola, M.C.; Bramanti, A.; Bramanti, P.; Calabrò, R.S. What does best evidence tell us about robotic gait rehabilitation in stroke patients: A systematic review and meta-analysis. *J. Clin. Neurosci.* **2018**, *48*, 11–17. [CrossRef]
32. Pollock, A.; Baer, G.; Campbell, P.; Choo, P.L.; Forster, A.; Morris, J.; Pomeroy, V.M.; Langhorne, P. Physical rehabilitation approaches for the recovery of function and mobility following stroke. *Cochrane Database Syst. Rev.* **2014**, *2014*, CD001920. [CrossRef] [PubMed]

33. Moucheboeuf, G.; Griffier, R.; Gasq, D.; Glize, B.; Bouyer, L.; Dehail, P.; Cassoudesalle, H. Effects of robotic gait training after stroke: A meta-analysis. *Ann. Phys. Rehabil. Med.* **2020**, *63*, 518–534. [CrossRef] [PubMed]
34. Mehrholz, J.; Thomas, S.; Kugler, J.; Pohl, M.; Elsner, B. Electromechanical-assisted training for walking after stroke. *Cochrane Database Syst. Rev.* **2020**, *2020*, CD006185. [CrossRef] [PubMed]
35. Zheng, Q.-X.; Ge, L.; Wang, C.C.; Ma, Q.-S.; Liao, Y.-T.; Huang, P.-P.; Wang, G.-D.; Xie, Q.-L.; Rask, M. Robot-assisted therapy for balance function rehabilitation after stroke: A systematic review and meta-analysis. *Int. J. Nurs. Stud.* **2019**, *95*, 7–18. [CrossRef] [PubMed]
36. Valè, N.; Gandolfi, M.; Vignoli, L.; Botticelli, A.; Posteraro, F.; Morone, G.; Dell'Orco, A.; Dimitrova, E.; Gervasoni, E.; Goffredo, M.; et al. Electromechanical and Robotic Devices for Gait and Balance Rehabilitation of Children with Neurological Disability: A Systematic Review. *Appl. Sci.* **2021**, *11*, 12061. [CrossRef]
37. Gandolfi, M.; Valè, N.; Posteraro, F.; Morone, G.; Dell'orco, A.; Botticelli, A.; Dimitrova, E.; Gervasoni, E.; Goffredo, M.; Zenzeri, J.; et al. State of the art and challenges for the classification of studies on electromechanical and robotic devices in neurorehabilitation: A scoping review. *Eur. J. Phys. Rehabil. Med.* **2021**, *57*, 831–840. [CrossRef] [PubMed]
38. Ayad, S.; Ayad, M.; Megueni, A.; Spaich, E.G.; Struijk, L.N.S.A. Toward Standardizing the Classification of Robotic Gait Rehabilitation Systems. *IEEE Rev. Biomed. Eng.* **2019**, *12*, 138–153. [CrossRef] [PubMed]
39. Hobbs, B.; Artemiadis, P. A Review of Robot-Assisted Lower-Limb Stroke Therapy: Unexplored Paths and Future Directions in Gait Rehabilitation. *Front. Neurorobotics* **2020**, *14*, 19. [CrossRef]
40. Chaparro-Cárdenas, S.L.; Lozano-Guzmán, A.A.; Ramirez-Bautista, J.A.; Hernández-Zavala, A. A review in gait rehabilitation devices and applied control techniques. *Disabil. Rehabil. Assist. Technol.* **2018**, *13*, 819–834. [CrossRef]
41. Díaz, I.; Gil, J.J.; Sánchez, E. Lower-Limb Robotic Rehabilitation: Literature Review and Challenges. *J. Robot.* **2011**, *2011*, 1–11. [CrossRef]
42. Molteni, F.; Gasperini, G.; Cannaviello, G.; Guanziroli, E. Exoskeleton and End-Effector Robots for Upper and Lower Limbs Rehabilitation: Narrative Review. *PMR* **2018**, *10*, S174–S188. [CrossRef] [PubMed]
43. Hussain, S.; Xie, S.Q.; Liu, G. Robot assisted treadmill training: Mechanisms and training strategies. *Med. Eng. Phys.* **2011**, *33*, 527–533. [CrossRef] [PubMed]
44. Rodríguez-Fernández, A.; Lobo-Prat, J.; Font-Llagunes, J.M. Systematic review on wearable lower-limb exoskeletons for gait training in neuromuscular impairments. *J. NeuroEng. Rehabil.* **2021**, *18*, 22. [CrossRef]
45. Alias, N.A.; Huq, M.S.; Ibrahim, B.S.K.K.; Omar, R. The Efficacy of State of the Art Overground Gait Rehabilitation Robotics: A Bird's Eye View. *Procedia Comput. Sci.* **2017**, *105*, 365–370. [CrossRef]
46. Smania, N.; Geroin, C.; Valè, N.; Gandolfi, M. The End-Effector Device for Gait Rehabilitation. *Biosyst. Biorobotics* **2018**, *19*, 267–283. [CrossRef] [PubMed]
47. Hesse, S.; Schattat, N.; Mehrholz, J.; Werner, C. Evidence of end-effector based gait machines in gait rehabilitation after CNS lesion. *NeuroRehabilitation* **2013**, *33*, 77–84. [CrossRef] [PubMed]
48. Belda-Lois, J.-M.; Mena-del Horno, S.; Bermejo-Bosch, I.; Moreno, J.C.; Pons, J.L.; Farina, D.; Iosa, M.; Molinari, M.; Tamburella, F.; Ramos, A.; et al. Rehabilitation of gait after stroke: A review towards a top-down approach. *J. NeuroEng. Rehabil.* **2011**, *8*, 66. [CrossRef]
49. Moreno, J.C.; del Ama, A.J.; de los Reyes-Guzmán, A.; Gil-Agudo, Á.; Ceres, R.; Pons, J.L. Neurorobotic and hybrid management of lower limb motor disorders: A review. *Med. Biol. Eng. Comput.* **2011**, *49*, 1119–1130. [CrossRef] [PubMed]
50. Buch, E.; Weber, C.; Cohen, L.G.; Braun, C.; Dimyan, M.A.; Ard, T.; Mellinger, J.; Caria, A.; Soekadar, S.; Fourkas, A.; et al. Think to Move: A Neuromagnetic Brain-Computer Interface (BCI) System for Chronic Stroke. *Stroke* **2008**, *39*, 910–917. [CrossRef]
51. Senanayake, C.; Senanayake, S.M.N.A. Emerging robotics devices for therapeutic rehabilitation of the lower extremity. In Proceedings of the 2009 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, Singapore, 14–17 July 2009; pp. 1142–1147. [CrossRef]
52. Marchal-Crespo, L.; Reinkensmeyer, D.J. Review of control strategies for robotic movement training after neurologic injury. *J. NeuroEng. Rehabil.* **2009**, *6*, 20. [CrossRef]
53. Meng, W.; Liu, Q.; Zhou, Z.; Ai, Q.; Sheng, B.; Xie, S.S. Recent development of mechanisms and control strategies for robot-assisted lower limb rehabilitation. *Mechatronics* **2015**, *31*, 132–145. [CrossRef]
54. Lotze, M. Motor learning elicited by voluntary drive. *Brain* **2003**, *126*, 866–872. [CrossRef] [PubMed]
55. Hogan, N.; Krebs, H.I.; Rohrer, B.; Palazzolo, J.J.; Dipietro, L.; Fasoli, S.E.; Stein, J.; Hughs, R.; Frontera, W.R.; Lynch, D.; et al. Motions or muscles? Some behavioral factors underlying robotic assistance of motor recovery. *J. Rehabil. Res. Dev.* **2006**, *43*, 605. [CrossRef] [PubMed]
56. Iosa, M.; Morone, G.; Fusco, A.; Bragoni, M.; Coiro, P.; Multari, M.; Venturiero, V.; De Angelis, D.; Pratesi, L.; Paolucci, S. Seven Capital Devices for the Future of Stroke Rehabilitation. *Stroke Res. Treat.* **2012**, *2012*, 187965. [CrossRef] [PubMed]
57. Huang, H.J.; Ferris, D.P. Neural coupling between upper and lower limbs during recumbent stepping. *J. Appl. Physiol.* **2004**, *97*, 1299–1308. [CrossRef] [PubMed]
58. Smith, C.P.; Allsop, J.E.; Mistry, M.; Reynolds, R.F. Co-ordination of the upper and lower limbs for vestibular control of balance. *J. Physiol.* **2017**, *595*, 6771–6782. [CrossRef] [PubMed]
59. Hessam, M.; Salehi, R.; Yazdi, M.J.S.; Negahban, H.; Rafie, S.; Mehravar, M. Relationship between functional balance and walking ability in individuals with chronic stroke. *J. Phys. Ther. Sci.* **2018**, *30*, 993–996. [CrossRef]

60. Tamburella, F.; Scivoletto, G.; Molinari, M. Balance training improves static stability and gait in chronic incomplete spinal cord injury subjects: A pilot study. *Eur. J. Phys. Rehabil. Med.* **2013**, *49*, 353–364.
61. Baronchelli, F.; Zucchella, C.; Serrao, M.; Intiso, D.; Bartolo, M. The Effect of Robotic Assisted Gait Training With Lokomat® on Balance Control After Stroke: Systematic Review and Meta-Analysis. *Front. Neurol.* **2021**, *12*, 661815. [CrossRef]
62. Nindorera, F.; Nduwimana, I.; Thonnard, J.L.; Kossi, O. Effectiveness of walking training on balance, motor functions, activity, participation and quality of life in people with chronic stroke: A systematic review with meta-analysis and meta-regression of recent randomized controlled trials. *Disabil. Rehabil.* **2022**, *44*, 3760–3771. [CrossRef]
63. Lorusso, M.; Tagliamonte, N.L.; Tramontano, M.; Fresch, A.; Granelli, G.; Smania, N.; Tamburella, F. Technology-assisted balance assessment and rehabilitation in individuals with spinal cord injury: A systematic review. *NeuroRehabilitation* **2022**, *51*, 213–230. [CrossRef] [PubMed]
64. Coleman, E.R.; Moudgal, R.; Lang, K.; Hyacinth, H.I.; Awosika, O.O.; Kissela, B.M.; Feng, W. Early Rehabilitation After Stroke: A Narrative Review. *Curr. Atheroscler. Rep.* **2017**, *19*, 59. [CrossRef] [PubMed]
65. Bouri, M.; Le Gall, B.; Clavel, R. A new concept of parallel robot for rehabilitation and fitness: The Lambda. In Proceedings of the 2009 IEEE International Conference on Robotics and Biomimetics (ROBIO), Guilin, China, 19–23 December 2009; pp. 2503–2508. [CrossRef]
66. Monaco, V.; Galardi, G.; Coscia, M.; Martelli, D.; Micera, S. Design and Evaluation of NEUROBike: A Neurorehabilitative Platform for Bedridden Post-Stroke Patients. *IEEE Trans. Neural Syst. Rehabil. Eng.* **2012**, *20*, 845–852. [CrossRef]
67. Wang, W.; Hou, Z.-G.; Tong, L.; Zhang, F.; Chen, Y.; Tan, M. A novel leg orthosis for lower limb rehabilitation robots of the sitting/lying type. *Mech. Mach. Theory* **2014**, *74*, 337–353. [CrossRef]
68. Wang, C.; Fang, Y.; Guo, S.; Chen, Y. Design and Kinematical Performance Analysis of a 3-RUS/RRR Redundantly Actuated Parallel Mechanism for Ankle Rehabilitation. *J. Mech. Robot.* **2013**, *5*, 041003. [CrossRef]
69. Araujo-Gómez, P.; Mata, V.; Díaz-Rodríguez, M.; Valera, A.; Page, A. Design and Kinematic Analysis of a Novel 3UPS/RPU Parallel Kinematic Mechanism With 2T2R Motion for Knee Diagnosis and Rehabilitation Tasks. *J. Mech. Robot.* **2017**, *9*, 061004. [CrossRef]
70. Akdoğan, E.; Adli, M.A. The design and control of a therapeutic exercise robot for lower limb rehabilitation: Physiotherabot. *Mechatronics* **2011**, *21*, 509–522. [CrossRef]
71. Schmitt, C.; Métrailler, P.; Al-Khodairy, A.; Brodard, R.; Fournier, J.; Bouri, M.; Clavel, R. The Motion MakerTM: A Rehabilitation System Combining an Orthosis with Closed-Loop Electrical Muscle Stimulation. September 2004, pp. 117–120. Available online: https://scholar.google.com/scholar_lookup?journal=Proceedings+of+the+8th+Vienna+International+Workshop+on+Functional+Electrical+Stimulation&title=The+Motion+Maker%E2%84%A2:+A+Rehabilitation+System+Combining+an+Orthosis+with+Closed-Loop+Electrical+Muscle+Stimulation&author=C.+Schmitt&author=P.+M%C3%A9trailler&author=A.+AI-Khodairy&author=R.+Brodard&author=R.+Clavel&doi=10.1111/j.0954-6820.1953.tb14280.x& (accessed on 1 May 2024).
72. Lim, F.M.; Foong, R.; Yu, H. A supine gait training device for stroke rehabilitation. *J. Med. Devices Trans. ASME* **2014**, *8*, 020926. [CrossRef]
73. Zhang, F.; Hou, Z.G.; Cheng, L.; Wang, W.; Chen, Y.; Hu, J.; Peng, L.; Wang, H. ILeg-A Lower Limb Rehabilitation Robot: A Proof of Concept. *IEEE Trans. Hum. Mach. Syst.* **2016**, *46*, 761–768. [CrossRef]
74. Mohan, S.; Mohanta, J.K.; Kurtenbach, S.; Paris, J.; Corves, B.; Huesing, M. Design, development and control of a 2PRP-2PPR planar parallel manipulator for lower limb rehabilitation therapies. *Mech. Mach. Theory* **2017**, *112*, 272–294. [CrossRef]
75. Sunilkumar, P.; Mohan, S.; Mohanta, J.K.; Wenger, P.; Rybak, L. Design and motion control scheme of a new stationary trainer to perform lower limb rehabilitation therapies on hip and knee joints. *Int. J. Adv. Robot. Syst.* **2022**, *19*, 172988142210751. [CrossRef]
76. Colombo, G.; Joerg, M.; Schreier, R.; Dietz, V. Treadmill training of paraplegic patients using a robotic orthosis. *J. Rehabil. Res. Dev.* **2000**, *37*, 693–700. [PubMed]
77. Banala, S.K.; Agrawal, S.K.; Scholz, J.P. Active Leg Exoskeleton (ALEX) for Gait Rehabilitation of Motor-Impaired Patients. In Proceedings of the 2007 IEEE 10th International Conference on Rehabilitation Robotics, Noordwijk, The Netherlands, 13–15 June 2007; pp. 401–407. [CrossRef]
78. Veneman, J.F.; Kruidhof, R.; Hekman, E.E.G.; Ekkelenkamp, R.; Van Asseldonk, E.H.F.; van der Kooij, H. Design and Evaluation of the LOPES Exoskeleton Robot for Interactive Gait Rehabilitation. *IEEE Trans. Neural Syst. Rehabil. Eng.* **2007**, *15*, 379–386. [CrossRef] [PubMed]
79. Susko, T.; Swaminathan, K.; Krebs, H.I. MIT-Skywalker: A Novel Gait Neurorehabilitation Robot for Stroke and Cerebral Palsy. *IEEE Trans. Neural Syst. Rehabil. Eng.* **2016**, *24*, 1089–1099. [CrossRef] [PubMed]
80. Bassi Luciani, L.; Genovese, V.; Monaco, V.; Odetti, L.; Cattin, E.; Micera, S. Design and Evaluation of a new mechatronic platform for assessment and prevention of fall risks. *J. NeuroEng. Rehabil.* **2012**, *9*, 51. [CrossRef] [PubMed]
81. Shapiro, A.; Melzer, I. Balance perturbation system to improve balance compensatory responses during walking in old persons. *J. NeuroEng. Rehabil.* **2010**, *7*, 32. [CrossRef] [PubMed]
82. Vlutters, M.; Van Asseldonk, E.H.F.; Van der Kooij, H. Center of mass velocity based predictions in balance recovery following pelvis perturbations during human walking. *J. Exp. Biol.* **2016**, *219*, 1514–1523. [CrossRef]

83. Matjačić, Z.; Zadravec, M.; Goljar, N.; Olenšek, A. Dynamic Balance Assessment During Pathological Bipedal Walking. In *Converging Clinical and Engineering Research on Neurorehabilitation II*; Ibáñez, J., González-Vargas, J., Azorín, J.M., Akay, M., Pons, J.L., Eds.; Biosystems & Biorobotics; Springer International Publishing: Cham, Switzerland, 2017; Volume 15, pp. 1389–1392. [CrossRef]
84. Hesse, S.; Uhlenbrock, D. A mechanized gait trainer for restoration of gait. *J. Rehabil. Res. Dev.* **2000**, *37*, 701–708. [PubMed]
85. Taherifar, A.; Hadian, M.R.; Mousavi, M.; Rassaf, A.; Ghiasi, F. LOKOIRAN-A novel robot for rehabilitation of spinal cord injury and stroke patients. In Proceedings of the 2013 First RSI/ISM International Conference on Robotics and Mechatronics (ICRoM), Tehran, Iran, 13–15 February 2013; pp. 218–223. [CrossRef]
86. Kim, J.-Y.; Kim, J.-Y.; Kim, H.-S.; Park, K. Development and Evaluation of a Hybrid Walking Rehabilitation Robot, DDgo Pro. *Int. J. Precis. Eng. Manuf.* **2020**, *21*, 2105–2115. [CrossRef]
87. Shao, Y.; Xiang, Z.; Liu, H.; Li, L. Conceptual design and dimensional synthesis of cam-linkage mechanisms for gait rehabilitation. *Mech. Mach. Theory* **2016**, *104*, 31–42. [CrossRef]
88. Schmidt, H.; Hesse, S.; Bernhardt, R.; Krüger, J. Haptic Walker—A Novel Haptic Foot Device. *ACM Trans. Appl. Percept.* **2005**, *2*, 166–180. [CrossRef]
89. Hesse, S.; Waldner, A.; Tomelleri, C. Innovative gait robot for the repetitive practice of floor walking and stair climbing up and down in stroke patients. *J. NeuroEng. Rehabil.* **2010**, *7*, 30. [CrossRef]
90. Saglia, J.A.; De Luca, A.; Squeri, V.; Ciaccia, L.; Sanfilippo, C.; Ungaro, S.; Michieli, L. De Design and Development of a Novel Core, Balance and Lower Limb Rehabilitation Robot: Hunova®. In Proceedings of the 2019 IEEE 16th International Conference on Rehabilitation Robotics (ICORR), Toronto, ON, Canada, 24–28 June 2019; pp. 417–422. [CrossRef]
91. Sinitski, E.H.; Lemaire, E.D.; Baddour, N. Evaluation of motion platform embedded with force plate-instrumented treadmill. *J. Rehabil. Res. Dev.* **2015**, *52*, 221–234. [CrossRef]
92. Ozaki, K.; Kondo, I.; Hirano, S.; Kagaya, H.; Saitoh, E.; Osawa, A.; Fujinori, Y. Training with a balance exercise assist robot is more effective than conventional training for frail older adults. *Geriatr. Gerontol. Int.* **2017**, *17*, 1982–1990. [CrossRef]
93. Van Doornik, J.; Sinkjaer, T. Robotic Platform for Human Gait Analysis. *IEEE Trans. Biomed. Eng.* **2007**, *54*, 1696–1702. [CrossRef] [PubMed]
94. Robinson, C.J.; Purucker, M.C.; Faulkner, L.W. Design, control, and characterization of a sliding linear investigative platform for analyzing lower limb stability (SLIP-FALLS). *IEEE Trans. Rehabil. Eng.* **1998**, *6*, 334–350. [CrossRef]
95. Young, A.J.; Ferris, D.P. State of the Art and Future Directions for Lower Limb Robotic Exoskeletons. *IEEE Trans. Neural Syst. Rehabil. Eng.* **2017**, *25*, 171–182. [CrossRef] [PubMed]
96. Shirota, C.; van Asseldonk, E.; Matjačić, Z.; Vallery, H.; Barralon, P.; Maggioni, S.; Buurke, J.H.; Veneman, J.F. Robot-supported assessment of balance in standing and walking. *J. NeuroEng. Rehabil.* **2017**, *14*, 80. [CrossRef] [PubMed]
97. Sankai, Y. HAL: Hybrid Assistive Limb Based on Cybernics. In *Springer Tracts in Advanced Robotics*; Springer: Berlin/Heidelberg, Germany, 2010; Volume 66, pp. 25–34. [CrossRef]
98. Wang, P.; Low, K.H.; McGregor, A.H. A subject-based motion generation model with adjustable walking pattern for a gait robotic trainer: NaTUre-gaits. In Proceedings of the 2011 IEEE/RSJ International Conference on Intelligent Robots and Systems, San Francisco, CA, USA, 25–30 September 2011; pp. 1743–1748. [CrossRef]
99. Esquenazi, A.; Talaty, M. Robotics for Lower Limb Rehabilitation. *Phys. Med. Rehabil. Clin. N. Am.* **2019**, *30*, 385–397. [CrossRef]
100. Peshkin, M.; Brown, D.A.; Santos-Munne, J.J.; Makhlin, A.; Lewis, E.; Colgate, J.E.; Patton, J.; Schwandt, D. KineAssist: A Robotic Overground Gait and Balance Training Device. In Proceedings of the 9th International Conference on Rehabilitation Robotics, ICORR 2005, Chicago, IL, USA, 28 June–1 July 2005; Volume 2005, pp. 241–246. [CrossRef]
101. Seo, K.-H.; Lee, J.-J. The Development of Two Mobile Gait Rehabilitation Systems. *IEEE Trans. Neural Syst. Rehabil. Eng.* **2009**, *17*, 156–166. [CrossRef]
102. Olenšek, A.; Zadravec, M.; Matjačić, Z. A novel robot for imposing perturbations during overground walking: Mechanism, control and normative stepping responses. *J. NeuroEng. Rehabil.* **2016**, *13*, 55. [CrossRef]
103. Marchal-Crespo, L.; Riener, R. Robot-assisted gait training. In *Rehabilitation Robotics*; Elsevier: Amsterdam, The Netherlands, 2018; pp. 227–240. [CrossRef]
104. Shin, J.C.; Jeon, H.R.; Kim, D.; Cho, S.I.; Min, W.K.; Lee, J.S.; Oh, D.S.; Yoo, J. Effects on the Motor Function, Proprioception, Balance, and Gait Ability of the End-Effector Robot-Assisted Gait Training for Spinal Cord Injury Patients. *Brain Sci.* **2021**, *11*, 1281. [CrossRef]
105. Gandolfi, M.; Valè, N.; Dimitrova, E.; Zanolin, M.E.; Mattiuz, N.; Battistuzzi, E.; Beccari, M.; Geroin, C.; Picelli, A.; Waldner, A.; et al. Robot-Assisted Stair Climbing Training on Postural Control and Sensory Integration Processes in Chronic Post-stroke Patients: A Randomized Controlled Clinical Trial. *Front. Neurosci.* **2019**, *13*, 1143. [CrossRef] [PubMed]
106. Krishnan, C.; Ranganathan, R.; Kantak, S.S.; Dhaher, Y.Y.; Rymer, W.Z. Active robotic training improves locomotor function in a stroke survivor. *J. NeuroEng. Rehabil.* **2012**, *9*, 57. [CrossRef] [PubMed]
107. Pennycott, A.; Wyss, D.; Vallery, H.; Klamroth-Marganska, V.; Riener, R. Towards more effective robotic gait training for stroke rehabilitation: A review. *J. NeuroEng. Rehabil.* **2012**, *9*, 65. [CrossRef] [PubMed]
108. Martins, M.; Frizera, A.; Santos, C.P.; Ceres, R. Review and classification of human gait training and rehabilitation devices. *Assist. Technol. Res. Ser.* **2011**, *29*, 774–781. [CrossRef]

109. Mehrholz, J.; Pohl, M. Electromechanical-assisted gait training after stroke: A systematic review comparing end-effector and exoskeleton devices. *J. Rehabil. Med.* **2012**, *44*, 193–199. [CrossRef] [PubMed]
110. Goffredo, M.; Iacovelli, C.; Russo, E.; Pournajaf, S.; Di Blasi, C.; Galafate, D.; Pellicciari, L.; Agosti, M.; Filoni, S.; Aprile, I.; et al. Stroke Gait Rehabilitation: A Comparison of End-Effector, Overground Exoskeleton, and Conventional Gait Training. *Appl. Sci.* **2019**, *9*, 2627. [CrossRef]
111. Gandolfi, M.; Geroin, C.; Picelli, A.; Munari, D.; Waldner, A.; Tamburin, S.; Marchioretto, F.; Smania, N. Robot-assisted vs. sensory integration training in treating gait and balance dysfunctions in patients with multiple sclerosis: A randomized controlled trial. *Front. Hum. Neurosci.* **2014**, *8*, 318. [CrossRef]
112. Mazzoleni, S.; Focacci, A.; Franceschini, M.; Waldner, A.; Spagnuolo, C.; Battini, E.; Bonaiuti, D. Robot-assisted end-effector-based gait training in chronic stroke patients: A multicentric uncontrolled observational retrospective clinical study. *NeuroRehabilitation* **2017**, *40*, 483–492. [CrossRef]
113. Maranesi, E.; Riccardi, G.R.; Di Donna, V.; Di Rosa, M.; Fabbietti, P.; Luzi, R.; Pranno, L.; Lattanzio, F.; Bevilacqua, R. Effectiveness of Intervention Based on End-effector Gait Trainer in Older Patients With Stroke: A Systematic Review. *J. Am. Med. Dir. Assoc.* **2020**, *21*, 1036–1044. [CrossRef] [PubMed]
114. Reha-Stim Medtec Gait Trainer GT, I. Available online: https://www.yumpu.com/en/document/read/43822488/gait-trainer-gt-i-reha-stim (accessed on 1 May 2024).
115. Reha-Stim Medtec Gait Trainer GT, II. Available online: https://reha-stim.com/gt-ii/ (accessed on 1 May 2024).
116. Tyromotion LEXO. Available online: https://tyromotion.com/en/products/lexo/ (accessed on 1 May 2024).
117. THERA-Trainers Lyra. Available online: https://thera-trainer.com/en/products/lyra/ (accessed on 1 May 2024).
118. CUREXO Inc. Morning Walk. Available online: https://www.curexo.com/english/medical/sub02.php (accessed on 1 May 2024).
119. REHA Technology G-EO System. Available online: https://www.rehatechnology.com/wp-content/uploads/products/GEOSystem/G-EO-System-GS-PB_1806_EN_web.pdf (accessed on 1 May 2024).
120. Movendo Technology Hunova. Available online: https://www.movendo.technology/our-products/hunova/?lang=en# (accessed on 1 May 2024).
121. Biodex Medical Systems Inc. Balance System SD. Available online: https://biodexrehab.com/products/balance-system-sd/ (accessed on 1 May 2024).
122. Motek Medical DynSTABLE. Available online: http://helmar-ms.pl/helmar-ms/plik/motek-medical_dynstable-stability-and-balance-learning-environment_nn4468.pdf (accessed on 1 May 2024).
123. LPG Systems Huber 360. Available online: https://www.lpgmedical.com/en/huber-360-evolution/ (accessed on 1 May 2024).
124. Vertigomed GeaHD. Available online: http://vertigomed.it/uk/index.php/vertigomed-prodotti/geahd/ (accessed on 1 May 2024).
125. Perry Dynamics Inc. PROPRIO 5000. Available online: https://www.perrydynamics.com/proprio-5000 (accessed on 1 May 2024).
126. Neurocom Inc. Smart EquiTest. Available online: https://pdf.medicalexpo.com/pdf/natus-medical/neurocom-smart-equitest/76900-168321.html (accessed on 1 May 2024).
127. TecnoBody ProKin. Available online: https://www.tecnobody.com/en/products/detail/prokin-252 (accessed on 1 May 2024).
128. FRAMIRAL MultiTest Equilibre. Available online: https://framiral.fr/web/wp-content/uploads/2022/02/PL_MTT-Plaquette_MULTITEST-rev018.1.pdf (accessed on 1 May 2024).
129. Motek Medical CAREN. Available online: https://www.motekmedical.com/solution/caren/ (accessed on 1 May 2024).
130. Liu, X.-J.; Wang, J. *Parallel Kinematics*; Springer: Berlin/Heidelberg, Germany, 2014. [CrossRef]
131. Risk-Mora, D.Y.; Durango-Idárraga, S.; Jiménez-Cortés, H.N.; Rodríguez-Sotelo, J.L. Mechanical Design of a 2-PRR Parallel Manipulator for Gait Retraining System. *Machines* **2023**, *11*, 788. [CrossRef]
132. Kose, K.C.; Ozgoren, M.K.; Tekce, F.; Doner, N. Design and kinematic analysis of a novel rehabilitative robotic walking simulation device. *Proc. Inst. Mech. Eng. Part H: J. Eng. Med.* **2021**, *235*, 770–779. [CrossRef] [PubMed]
133. Xie, S.; Ren, G.; Xiong, J.; Lu, Y. A Trajectory Tracking Control of a Robot Actuated With Pneumatic Artificial Muscles Based on Hysteresis Compensation. *IEEE Access* **2020**, *8*, 80964–80977. [CrossRef]
134. Wang, H.; Li, W.; Liu, H.; Zhang, J.; Liu, S. Conceptual design and dimensional synthesis of a novel parallel mechanism for lower-limb rehabilitation. *Robotica* **2019**, *37*, 469–480. [CrossRef]
135. Zhang, C.; Lan, B.; Matsuura, D.; Mougenot, C.; Sugahara, Y.; Takeda, Y. Kinematic design of a footplate drive mechanism using a 3-DOF parallel mechanism for walking rehabilitation device. *J. Adv. Mech. Des. Syst. Manuf.* **2018**, *12*, JAMDSM0017. [CrossRef]
136. Azcaray, H.; Blanco, A.; García, C.; Adam, M.; Reyes, J.; Guerrero, G.; Guzmán, C. Robust GPI Control of a New Parallel Rehabilitation Robot of Lower Extremities. *Int. J. Control Autom. Syst.* **2018**, *16*, 2384–2392. [CrossRef]
137. Maddalena, M.; Saadat, M.; Rastegarpanah, A.; Loureiro, R.C.V. An optimized design of a parallel robot for gait training. In Proceedings of the 2017 International Conference on Rehabilitation Robotics (ICORR), London, UK, 17–20 July 2017; pp. 418–423. [CrossRef]
138. Rastegarpanah, A.; Saadat, M.; Borboni, A.; Stolkin, R. Application of a parallel robot in lower limb rehabilitation: A brief capability study. In Proceedings of the 2016 International Conference on Robotics and Automation for Humanitarian Applications (RAHA), Amritapuri, India, 18–20 December 2016; pp. 1–6. [CrossRef]

139. Azar, W.A.; Akbarimajd, A.; Parvari, E. Intelligent Control Method of a 6-DOF parallel robot Used for Rehabilitation Treatment in lower limbs. *Automatika* **2016**, *57*, 466–476. [CrossRef]
140. Elías, D.; Callupe, R.; Ceccarelli, M. Characteristics of a Walking Simulator with Parallel Manipulators. *Mech. Mach. Sci.* **2015**, *26*, 137–145. [CrossRef]
141. Mao, Y.C.; Juan, D.J.; Wen, S.A.; Tsai, W.C.; He, J.T. Design and Analysis of a Multiple-DOF Bipedal Gait Test System. *Appl. Mech. Mater.* **2013**, *433–435*, 812–815. [CrossRef]
142. Yoon, J.; Novandy, B.; Yoon, C.-H.; Park, K.-J. A 6-DOF Gait Rehabilitation Robot With Upper and Lower Limb Connections That Allows Walking Velocity Updates on Various Terrains. *IEEE/ASME Trans. Mechatron.* **2010**, *15*, 201–215. [CrossRef]
143. Yoon, J.; Ryu, J. A Novel Locomotion Interface with Two 6-DOF Parallel Manipulators That Allows Human Walking on Various Virtual Terrains. *Int. J. Robot. Res.* **2006**, *25*, 689–708. [CrossRef]
144. Boian, R.F.; Bouzit, M.; Burdea, G.C.; Deutsch, J.E. Dual Stewart platform mobility simulator. In Proceedings of the 26th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, San Francisco, CA, USA, 1-5 September 2004; Volume 4, pp. 4848–4851. [CrossRef]
145. Yoon, J.; Ryu, J.; Burdea, G. Design and analysis of a novel virtual walking machine. In Proceedings of the 11th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, HAPTICS 2003. Proceedings, Los Angeles, CA, USA, 22–23 March 2003; pp. 374–381. [CrossRef]
146. Yano, H.; Kasai, K.; Saitou, H.; Iwata, H. Development of a gait rehabilitation system using a locomotion interface. *J. Vis. Comput. Animat.* **2003**, *14*, 243–252. [CrossRef]
147. Yano, H.; Noma, H.; Iwata, H.; Miyasato, T. Shared walk environment using locomotion interfaces. In Proceedings of the 2000 ACM Conference on Computer Supported Cooperative Work, Philadelphia, PA, USA, 2–6 December 2000; pp. 163–170. [CrossRef]
148. Summa, S.; Gori, R.; Castelli, E.; Petrarca, M. Development of a dynamic oriented rehabilitative integrated system. In Proceedings of the 2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Berlin, Germany, 23–27 July 2019; pp. 5245–5250. [CrossRef]
149. Zermane, A.; Guiatni, M.; Alouane, M.A.; Alloun, F.; Tair, M. Optimal Mechatronics Design and Control of a 3-PRS Robotic Platform for Vertigo Diagnosis. In Proceedings of the 2023 International Conference on Control, Automation and Diagnosis (ICCAD), Rome, Italy, 10–12 May 2023; pp. 1–7. [CrossRef]
150. Ersoy, T.; Hocaoglu, E. A 3-DoF robotic platform for the rehabilitation and assessment of reaction time and balance skills of MS patients. *PLoS ONE* **2023**, *18*, e0280505. [CrossRef]
151. Ishizaki, M.T.; da Silva, A.R.F.; de Almeida Moura, L.; dos Reis, P.C.; Lazzareschi, L.; da Silva Boschi, S.R.M.; Martini, S.C.; Scardovelli, T.A.; da Silva, A.P. Development of a dynamic balance analysis and training system through posturography in a bipodal force platform with biaxial rotation. *Res. Biomed. Eng.* **2022**, *38*, 839–855. [CrossRef]
152. Rivera, O.; Abril, J.D.; Niño-Suarez, P.A.; Avilés, O.F.; Castillo-Castañeda, E. Two DoF Robotic Platform for Balance Rehabilitation Tasks. *Mech. Mach. Sci.* **2021**, *94*, 332–340. [CrossRef] [PubMed]
153. Baselizadeh, A.; Behjat, A.; Torabi, A.; Behzadipour, S. Using robotic mechanical perturbations for enhanced balance assessment. *Med. Eng. Phys.* **2020**, *83*, 7–14. [CrossRef]
154. Patane, F.; Cappa, P. A 3-DOF Parallel Robot With Spherical Motion for the Rehabilitation and Evaluation of Balance Performance. *IEEE Trans. Neural Syst. Rehabil. Eng.* **2011**, *19*, 157–166. [CrossRef]
155. Yano, H.; Tamefusa, S.; Tanaka, N.; Saitou, H.; Iwata, H. Gait rehabilitation system for stair climbing and descending. In Proceedings of the 2010 IEEE Haptics Symposium, Waltham, MA, USA, 25–26 March 2010; pp. 393–400. [CrossRef]
156. Yano, H.; Tanaka, N.; Kamibayashi, K.; Saitou, H.; Iwata, H. Development of a Portable Gait Rehabilitation System for Home-Visit Rehabilitation. *Sci. World J.* **2015**, *2015*, 849831. [CrossRef]
157. Boehm, W.L.; Gruben, K.G. Development of KIINCE: A kinetic feedback-based robotic environment for study of neuromuscular coordination and rehabilitation of human standing and walking. *J. Rehabil. Assist. Technol. Eng.* **2018**, *5*, 205566831879358. [CrossRef]
158. Ji, J.; Wang, Y.; Zhang, G.; Lin, Y.; Wang, G. Design and Simulation Analysis of a Robot-Assisted Gait Trainer with the PBWS System. *J. Healthc. Eng.* **2021**, *2021*, 2750936. [CrossRef] [PubMed]
159. Chen, S.; Wang, Y.; Li, S.; Wang, G.; Huang, Y.; Mao, X. Lower limb rehabilitation robot. In Proceedings of the 2009 ASME/IFToMM International Conference on Reconfigurable Mechanisms and Robots, ReMAR, London, UK, 22–24 June 2009; pp. 439–443.
160. Vu, D.-S.; Foucault, S.; Gosselin, C.; Kovecses, J. Design of a locomotion interface for gait simulation based on belt-driven parallel mechanisms. In Proceedings of the 2015 IEEE International Conference on Robotics and Automation (ICRA), Seattle, WA, USA, 26–30 May 2015; pp. 1581–1586. [CrossRef]
161. Haslinger, W.; Müller, L.; Mildner, E.; Löfler, S.; Kern, H.; Raschner, C. Assessment of a Newly Developed, Active Pneumatic-Driven, Sensorimotor Test and Training Device. *Sensors* **2014**, *14*, 24174–24187. [CrossRef] [PubMed]
162. Kharboutly, H.; Ma, J.; Benali, A.; Thoumie, P.; Pasqui, V.; Bouzit, M. Design of Multiple Axis Robotic Platform for Postural Stability Analysis. *IEEE Trans. Neural Syst. Rehabil. Eng.* **2015**, *23*, 93–103. [CrossRef] [PubMed]
163. Ding, Y.; Sivak, M.; Weinberg, B.; Mavroidis, C.; Holden, M.K. NUVABAT: Northeastern university virtual ankle and balance trainer. In Proceedings of the 2010 IEEE Haptics Symposium, Waltham, MA, USA, 25–26 March 2010; pp. 509–514. [CrossRef]

164. Amritha, N.; Mahima, M.M.; Namitha, K.; Unnikrishnan, R.; Harish, M.T.; Sankaran Ravi, M.D.; Bhavani, R.R. Design and development of balance training platform and games for people with balance impairments. In Proceedings of the 2016 International Conference on Advances in Computing, Communications and Informatics (ICACCI), Jaipur, India, 21–24 September 2016; pp. 960–966. [CrossRef]
165. Retirado, M.G.F.; Reyes, S.J.R. Development of an Active Balance Training Platform for a Gamified Physical Rehabilitation. In Proceedings of the 2018 2nd European Conference on Electrical Engineering and Computer Science (EECS), Bern, Switzerland, 20–22 December 2018; pp. 279–289. [CrossRef]
166. Mansfield, A.; Peters, A.L.; Liu, B.A.; Maki, B.E. A perturbation-based balance training program for older adults: Study protocol for a randomised controlled trial. *BMC Geriatr.* **2007**, *7*, 12. [CrossRef]
167. Huamanchahua, D.; Tadeo-Gabriel, A.; Chavez-Raraz, R.; Serrano-Guzman, K. Parallel Robots in Rehabilitation and Assistance: A Systematic Review. In Proceedings of the 2021 IEEE 12th Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON), New York, NY, USA, 1–4 December 2021; pp. 0692–0698. [CrossRef]
168. Diego, P.; Macho, E.; Herrero, S.; Corral, J.; Diez, M.; Campa, F.J.; Pinto, C. A Novel Family of 2T2R Parallel Manipulators with Potential for Balance Rehabilitation. In *Advances in Mechanism and Machine Science, Proceedings of the IFToMM WC 2023. Mechanisms and Machine Science, Tokyo, Japan, 5–10 November 2023*; Okada, M., Ed.; Springer: Cham, Switzerland, 2023; Volume 147, pp. 503–512. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.