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# Is Virtual Rehabilitation Technology Ready to Be Widely Integrated in the Rehabilitation Area? An IT Governance Perspective

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**Abstract:** In this work, the authors analyze virtual reality rehabilitation research on strokes in the past 8 years (2015–2022) from the perspective of Information Technology governance (how these initiatives sustain and extend organization strategy), using the "Four Ares" technique that is widely used in other sectors with a proven track record. Are we doing the right things? Are we doing them the right way? Are we getting them done well? Are we getting the benefits? Methods: The bibliography was exhaustively selected for evaluation considering these four questions, covering different aspects of existing evidence on this topic. Results: Some evidence of positive outcomes in patients with a stroke was found, and different approaches, types of measurement, platforms, and methods were analyzed to discern the present situation of research and recommendations. Conclusions: Positive outcomes on motor functions and on motivation and patient adherence to the treatment suggests this is an interesting field to research and examine in the future. Homogeneity on research design and larger samples are key to improving evidence and identifying the best strategies to use.

**Keywords:** stroke; virtual reality; virtual rehabilitation; IT governance; cerebrovascular disease; exergaming



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## 1. Introduction

The Global Burden of Diseases (GBD) in the adult ranking of the Institute for Health Metrics and Evaluation (IHME) [1] finds that cerebrovascular diseases (CVD) are the second most common diseases in the world, following Ischemic Heart Disease. Specifically, strokes are the most common manifestation of this disease and are the major cause of severe disability [2]. According to Maggio et al. [3], "a stroke can cause sensory, motor, and cognitive deficits as well as a further dependence on the activities of daily living and a decreased interaction in social and community events".

According to the same IHME dataset, strokes represent 5.65% of total disability-adjusted life years (DALYs) with a 0.46% increase from 2015 to 2019, the last year with processed data. From these numbers, the contribution to global DALYs of people 50 or older who suffered a stroke represents a total of 21.63%, while the age group below 50 accounts for 3.6% of global DALYs.

By looking at deaths, CVD (and specifically strokes) are in second place with 11.59% of total deaths based on the previous IHME dataset, so everything indicates that investing in rehabilitation and the prevention of strokes should be an important action to improve population health and make healthcare systems more sustainable [4]. Moreover, this type of disease is a great social, medical, and economic burden, so any intervention method, including the use of new technologies, can be very important. On the other hand, disease prevention, health promotion, and sustainability seem to be the main objectives that strategies of healthcare services in the world are pursuing according to Williams et al. [5].

Given the high prevalence and impact of CVD on the population, and especially strokes, we decided to analyze how the use of Virtual Rehabilitation (VR) can improve the health outcomes of these patients. In addition, rehabilitation processes for these patients are usually long, and rehabilitation at medical centers should be complemented with rehabilitation at home, so the use of technology can be especially helpful in these cases.

On the other hand, the information technology (IT) governance approach will help us to analyze outcomes from a results-based perspective, examining the impact and effectiveness of technology on an organization. It should be noted that that the focus here is not on the technology itself but rather on how it sustains and extends the organization's strategy.

In this paper, we assess whether there is enough scientific evidence to integrate, in a general way, the virtual reality rehabilitation for physical and cognitive intervention after suffering a CVD. We first present the challenge that CVD constitutes for society with the most recent data about DALYs and quality-adjusted life years (QALYs). We then review the strategies that different healthcare services are adopting to reduce the disease burden, and we carry out an information technology governance-based analysis to review how IT is supporting and extending these strategies, improving rehabilitation, prevention, and interventions to reduce the impact of this disease on patients' lives.

This study, initially focused on publications from 2015 to 2019, and it was extended to include the years 2020 and 2022 in order to incorporate the use of virtual reality in the pandemic situation generated by COVID-19 and after, where these approaches have been very useful [6] to maintain the intensity of treatment and permit patients to remain at home as much as possible [7].

We therefore assess the IT contribution to these objectives using the IT governance paradigm, using the "Four Ares" defined by John Thorp in his book *The Information Paradox* [8], one of the seminal works on IT governance, after reviewing the existing bibliography about virtual rehabilitation for patients who have suffered a stroke. Few studies, to date, have considered this type of approach in the study of the efficacy of virtual reality-based brain injury treatment.

## 2. Materials and Methods

Using an IT governance approach, we started by asking four questions that are called the Four Ares: (1) "Are we doing the right things?", also known as the Strategy Question. (2) "Are we doing them the right way?", also known as the Architecture Question. (3) "Are we getting them done well?", which is the Delivery Question. (4) "Are we getting the benefits?", which is the Value Question.

The way to find out if we are really doing the right things in the right way and completing them as well as realizing the benefits is to collect the information required to answer these four questions. Taking this question into account, we decided to perform a deep bibliographic review on the topic of virtual rehabilitation for patients who have suffered a stroke.

The studies were identified by searching on the Scopus, PubMed, Web of Science, Google Scholar, and Cochrane databases. All the studies that fulfilled our selected criteria and were published between 2015 and 2022 were evaluated for possible inclusion. The search combined the following terms: "virtual reality" AND/OR "stroke" AND/OR "cognitive rehabilitation"; "virtual reality" AND/OR "neurological patients"; "virtual reality" AND/OR "acquired brain injury" AND/OR "stroke". We have only selected texts in English and removed duplicates. All of the articles were evaluated according to the title, abstract, and text. We included studies that examined virtual reality (VR) in several neurological patients, excluding studies with less than 10 patients.

After these queries, we carried out the review as indicated in Figure 1.

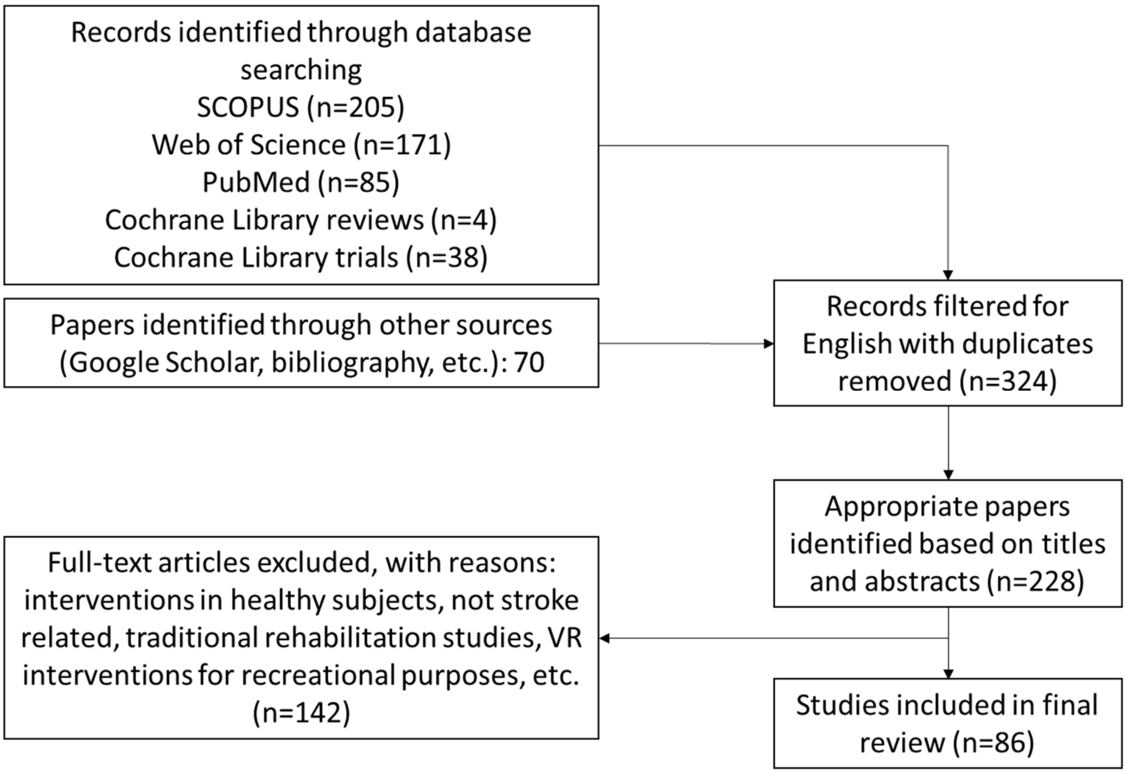


**Figure 1.** Review process diagram.

The inclusion criteria were: (1) studies published between 2015 and 2022, and (2) studies that used the keywords specified. The exclusion criteria were: (1) studies written in a language other than English or Spanish; (2) studies that focused on healthy subjects; (3) studies that did not include patients with strokes; (4) studies that did not use VR rehabilitation techniques or only used them for recreational purposes; (5) studies that had a sample size of less than 10 patients or provided a very low level of evidence; (6) editorials; and (7) studies that were only accessible as abstracts.

Finally, we used the selected 70 studies to obtain the answers to the four questions mentioned above, providing a complete review of the current situation in the virtual rehabilitation of patients with strokes, identifying the pros and cons together with some recommendations for the successful implementation of these initiatives.

## 3. Results and Questions Analysis

The aforementioned four questions helped us to define the value return of IT applied to the organization's challenges. According to IT governance good practices, if the answer to any of these questions is "no" or "partially not", we should redesign our IT approach for these challenges to align IT investment with organization strategy.

### *3.1. Strategic Question: Are We Doing the Right Things?*

It has been mentioned that strokes are an important public health issue and can cause severe brain damage and neurological consequences [9]. For instance, motor system deficits occur in more than 55% of individuals who suffer them, decreasing quality of life [10] and impacting daily living activities [11]. Moreover, cognitive deficits affect general functioning, including alterations in memory, attention, and cognitive functioning, among others [9]. On the other hand, evidence of the positive effect of virtual rehabilitation in different fields were found [12], even in the case of early detection of neurological diseases [13]. Evidence of the benefits of exergaming and multisensory stimulation (stimulating at least two of the visual, auditory, and somatosensory systems at the same time) shows promising results for rehabilitation after a stroke [14].

By looking at data from the last 8 years (2015–2022), we can affirm that, although many initiatives on virtual rehabilitation have been provided (a search for "virtual rehabilitation stroke" on Google Scholar between 2015 and 2022 returns 34,300 results), an increase of 32% of DALYs was observed from 1990 to 2019 according to the GBD 2019 Stroke Collaborators [15]. There is evidence of the benefits of these virtual reality rehabilitation solutions "as an adjunct for stroke rehabilitation with evident effectiveness for a variety of platforms, training parameters, and stages of recovery" [16], and we found other papers where the results were positive even when the game motivation rewards were moderate [17]. Nevertheless, in low and middle income countries, it could be a low-cost way to deliver this kind of rehabilitation at home [3].

In 2001, Schulteis and Rizzo [18] defined the advantages that virtual reality could have in rehabilitation (more realistic environments, stimulus control, and response measurement; provide hazardous situations in a safe environment; personalized training environments; consistency in training and assessment; and an increase in user motivation that should provide more adherence), and they defined potential areas of application: cognitive ability assessment, rehabilitation training, social retraining, education about managing the disease for patients and their families or caregivers.

Improvements in different aspects like balance, gait, etc. were determined in other studies such as Chen et al. [19], although we see later in this paper that evidence is not always enough.

The work enumerated a list of cost-benefit questions about the appropriateness of the VR approach as well as the transferability of the training to the real world and usability for patients and clinical users, plus ethics.

Motivation and participation are also key, according to Maggio et al. [20], who reviewed studies published between 2010 and 2017 about the use of virtual reality on stroke patients.

All previously cited sources confirm that strokes are clearly an important health problem that healthcare systems should deal with and that the use of virtual reality environments for rehabilitation have a positive impact on patients, reducing costs and improving accessibility to the health system without introducing relevant risks to the patients. [21]. Nevertheless, more evidence is needed, so we should evaluate the use of virtual reality environments strategically, since, at the end of the day, everything indicates that these systems can make healthcare systems more sustainable while maintaining quality.

### *3.2. Architecture Question: Are We Doing It the Right Way?*

By looking at initiatives on virtual rehabilitation meta-analysis studies, augmented feedback to patients, provided by exergaming solutions (playing video games intended as a workout that requires rigorous physical exercise), facilitates individualized training and exercising with higher intensity [22]. On the other hand, other studies [23] found that virtual reality provides a more realistic, motivating, and meaningful context to the patient and the immersive experience improves adherence [24].

Looking for scientific evidence, studies like TWIST [25] reached a large sample of 209 patients for 6 weeks using the Nintendo Wii™, concluding that the console was well accepted but more expensive than arm exercises and the results were not superior [26].

The EVREST study, with 141 patients also using the Nintendo Wii™, this time for two weeks, also concluded that no differences were found in motor rehabilitation between simple low-cost recreational activities and innovative non-immersive VR technologies [27]. On the other hand, more recent studies carried out by Unibaso-Markaida et al. [28] found that results were better for the Nintendo Wii™ intervention group than the control group, particularly for attention and processing speed.

The challenge of proving that VR improves rehabilitation outcomes has been constant since the beginning, although it still seems promising. In 2010, the pilot randomized clinical trial carried out by Saposnik et al. [10] explained that VR therapy combined with conventional therapy showed better outcomes, but that it could introduce a bias as the total time for rehabilitation increased with this combination. This is supported by more recent studies such as Rodriguez-Hernández et al. [29]. Later, the Cochrane systematic review by Laver et al. [30] showed that sample sizes were generally small, and interventions used different virtual reality devices and treatment goals. In the same Cochrane review, evidence was rated as low quality according to the GRADE system (Grading of Recommendations, Assessment, Development, and Evaluation). Despite this, the review found that a combination of virtual reality and conventional therapies presented a statistically significant difference for upper limb function compared to other approaches. What still needs to be determined is whether the reason for these results is a higher dose of therapy or the addition of VR therapy specifically.

Even in 2019, the work of Subramanian et al. [31] highlighted that the majority of the studies were measuring the extent but not the type of motor recovery; and meta-analysis from Lee et al. [11] showed that VR training was effective in improving motor function, but that to obtain the effects the treatment should last 8 weeks or more.

On the other hand, according to Kober et al. [32], sometimes using a 3D scenario instead of a standard 2D scenario could make a simple task more complex for patients, particularly for those not skilled in technology.

As indicated in Arienti et al. [33], the majority of systematic reviews (78%) showed poor methodological quality. Of those identified as virtual reality interventions (10 of 51, 19.6%), 1 was rated as of High quality, 2 as moderate and 7 as low or critically low.

Other works such as Cano Porras et al. [34] support the same conclusion, identifying the outcome of combining traditional and virtual rehabilitation on gait and balance, but a major part of the studies analyzed by them showed poor methodologic quality.

Another study by Kim et al. in 2018 [35] compared a VR specific system with a non VR specific system and showed similar efficacy in the short term, although total activity counts (a measure provided by accelerometers) was higher in VR users with no statistical significance, so it doesn't support using VR systems in this case. Again, the reduced size of the sample (12 patients using VR vs. 11 patients using non-VR) and the bias introduced by the design should be taken into consideration.

The work from Faria et al. [36] showed instead that comparing VR therapies to traditional paper and pencil therapies did not provide differences, although more intensive exercise was done in the VR group and this could have improved cognitive function. A more recent work [37] from the same researchers proved that VR therapy offered better outcomes in cognitive functioning, visuospatial ability, and executive functions compared to an adaptive paper-and-pencil environment.

Additionally, we can cite the work from Fusco et al. [38], where outcomes suggest that combining robotic rehabilitation with VR can accelerate the improvement of the patient according to their randomized, controlled, crossover, single-blinded, or pilot study.

Regarding the variability issues, we should be aware of the influence that the different tracking systems used for monitoring the patient's performance can have on the measurement of the outcome [39], and consider how the different approaches to exergaming can impact engagement and positive response, showing that collaborative gaming has better outcomes compared to cooperative and competitive gaming, although the latter can improve the sense of flow for players with higher motor skills [40]. On the other hand, other studies like Navarro et al. [41] and Lee et al. [42] show how competitiveness can be a motivating factor, specifically for attention rehabilitation, and can improve effectiveness.

Recently, Brassel et al. [43] collected different recommendations for the design and implementation of virtual reality for the rehabilitation of acquired brain injury (ABI): real-life, meaningful task settings, early and intensive practice of VR rehabilitation, goal-oriented, and with the ability to adapt to individual needs. The work also highlights the convenience of involving end users in the design and recommends taking into account health and safety aspects. Regarding the measurement of the results, this study includes the patient reported outcomes measurement (PROMs) in addition to measurement of clinical relevance and validity, long-term impact, etc.

Finally, the heterogeneity of game design is also discussed by Juras et al. [44] and Bermudez et al. [45], explaining the impact of Presence (embodiment in the virtual environment), Motor Learning (including the richness of the definition of the environment, the intrinsic and extrinsic feedback received, the specificity of the task, training dosing and adaptability, and customization of the software for the patient), and Motivation (which promotes learning and adherence through goal setting, rewards, challenge, and narrative structure). Visual, auditory, and haptic information seems highly relevant for post-stroke rehabilitation as well.

Specific VR toolkits for rehabilitation have been released recently, such as Lamontagne et al. [46], Williams et al. [47], and Lanzoni et al. [48], probably making it easier and faster to build specific virtual environments aligned with existing evidence that could be used by professionals and patients, so further studies can be carried out with a larger sample size and more homogeneity of solutions and assessment approaches. Metaverse, a specific approach to VR, could become another way of applying these VR techniques to patients [49,50].

In addition, some methodologies have been designed to guide the design of VR environments and challenges—-for example, Martinez-Moreno et al. [51] for activities of daily living (ADL).

In summary, there is a lot of heterogeneity in research designs, methods, techniques, measurements of the outcomes, etc., plus a lack of evidence in many cases as samples are frequently small. That is why we cannot affirm that we are doing it the right way, having different approaches with different outcomes, some with more positive results than others.

### *3.3. Delivery Question: Are We Getting Things Done Well?*

In the study by Lewis et al. [52] patients affirmed that they found VR rehabilitation activities "enjoyable and challenging". Although only 6 participants were involved and only 8 activities related to a submarine VR game were assessed, this study explains that getting the feedback of patients is important to identify motivation factors and stress factors: the feeling of "stretching myself", the existence of "purpose and expectations", and the expectation of "future improvements" are all motivation factors to consider when building or acquiring a VR rehabilitation game. Doing this as an additional task to the usual rehabilitation tasks was a negative factor for some patients. Nevertheless, besides measuring improvements in cognitive and physical skills, getting feedback from the patients will help researchers to improve the virtual rehabilitation approach as well.

Regarding this feedback, other authors such as Green et al. [53] have recently published findings on the co-creation of these virtual rehabilitation games with the patients, particularly with younger patients, and, additionally, what is called a "sense of community" was identified as a powerful driver for motivation, according to Vollebregt et al. [54].

Considering computer monitor VR environments versus head-mounted display VR environments, the latter show better results on engagement, transportation, flow, and sense of presence, while negative effects such as nausea are also more probable than in the former, according to studies such as Spreij et al. [55].

Taking clinicians into account, on the one hand, their training needs to be increased, according to Bartnicka et al. [56], and, on the other, based on their feedback, there are also several factors to consider, including good organization of the activities, overcoming the technological gap, and the fact that individual circumstances of participants can impact positively or negatively on user experience and on the success of this experience [48]. According to other studies reviewed [57], three factors have been identified as key to assessing the outcomes on the usability of virtual rehabilitation systems: effectiveness, efficiency, and satisfaction. Patient performance on rehabilitation exercises with VR can be measured objectively, the level of difficulty can be established and reviewed objectively according to this performance ([58,59]), and treatment can be personalized to the patient's condition.

Satisfaction has been measured using different systems not specifically oriented to virtual rehabilitation. However, specific questionnaires on virtual rehabilitation exist such as USEQ [60], which have proven their reliability to measure this factor.

As mentioned by Threapleton et al. [61], one of the main barriers to a more extended use of VR rehabilitation solutions is the physical space that these solutions require. Hospitals and clinics are places where space is scarce, and room for these solutions is generally in competition with room for the rest of the equipment that conventional physical and cognitive rehabilitation requires. When we try to set up these solutions in patients' homes, this is an issue that should be considered, especially if it is a long-term installation. Other aspects, such as power consumption in a context of energy prices escalating, and spare parts service, in case of malfunction, should be taken into account. Adherence to home-based treatment was studied by authors such as Fluet et al. [17] as well as Jonsdottir et al. [62], who observed that it mainly depends on motivational enhancements. Regarding motivation, recent studies such as Sramka et al. [63] showed higher motivation and an acceleration of rehabilitation using VR technology.

Comparing immersive and non-immersive VR environments for rehabilitation, some studies like Bevilacqua et al. [64] explain that non-immersive ones are preferred by older patients as they are more comfortable and with less secondary effects such as nausea, for instance.

So, going back to the delivery question, we can conclude that there is still discussion on which characteristics of virtual reality rehabilitation programs are the key for success, although creating an enjoyable experience for the users and preserving the usability can improve motivation, increasing the adherence and effectiveness of the treatment.

### *3.4. Value Question: Are We Getting the Benefits?*

The positive outcomes of VR rehabilitation therapies were rated by Aminov et al. [16] according to the use of specific virtual environments and standard computer games, showing better results in specific virtual environments. This study also showed that the best positive outcomes were on body structure and function, activity level, and, secondarily, on cognitive functions, although issues about sample size and on the variability of the measurement methods were identified. This also supports the idea that we should include the type of environment (specific or general purpose) as a relevant variable in future virtual rehabilitation studies to avoid potential bias.

According to Laver's 2012 and 2017 Cochrane reviews [30,65], using VR for stroke patients' rehabilitation was found to be significantly more effective for upper limb function and activities of daily living function recovery, but the authors mentioned that "further studies are required to confirm these findings".

A review by Zhang et al. [66] also supports the contribution of VR to stroke patients improving their upper- and lower-limb motor function, although no improvement was observed in cognitive functions. Nonetheless, there are other studies such as the one by Maier et al. [67] that found improvements in this area. Rutkowsky et al. [68] also highlight improvements in upper-limb and balance, but not in gait or hand dexterity.

Some other studies have started using the so called Adaptive Conjunctive Cognitive Training (ACCT) where a combination of different cognitive domain training is used with positive results. For instance, Maier et al. [67] and Park et al. [69] reported an improvement in attention and spatial awareness as well as in depressive symptoms [70]. However, other authors such as Zhang et al. [66], in a meta-analysis covering 23 randomized control trials with 894 patients, showed that improvements were significant only in executive function, memory, and visuo-spatial function, whilst in the case of global cognitive function, attention, verbal fluency, depression, and quality of life, they were not significant (compared to traditional methods).

Other studies showed that a combination of a conventional physiotherapy program with interactive semi-immersive tools present better results than without it—[71,72]. Levin et al. [73] showed that there could be more positive outcomes than traditional therapies for motor control and motor learning, thanks to feedback and other features, using the application of VR to make the accomplishment of motor control and learning principles easier.

Comparing and assessing outcomes from different studies is difficult given the different ways that authors measure them, while aforementioned authors such as Saposnik et al. prefer to focus on the Wolf Motor Function Test, Box and Block Test, and Stroke Impact Scale [10], others such as Da Silva et al. [74] use the SF-36 and Fugl–Meyer tests, whilst Turolla et al. [75] complement Fugl–Meyer with the Functional Independence Measure. This is particularly evident in research carried out by Subramanian et al. [31] where they mention that 42 different outcome measures were used across 100 studies. 17 different outcomes were aimed at measuring impairments, 16 were used to measure activity limitations, etc. Other studies such as Kalron and Zeilig [76] present the same conclusion, even in the case of traditional intervention (not only virtual reality interventions). So, we should add difficulties of measurement diversity to the difficulties of tools used, small samples, etc. This happens even in most recent studies like Xiao et al. [77], where they found that while Computer Assisted Cognitive Rehabilitation showed significant difference in Stroke patients, the use of VR did not show equivalent benefits. Furthermore, recent studies like Li et al. [78] showed that other alternative techniques like acupuncture or transcranial magnetic stimulation showed more consistent results than VR use.

On the positive side, there are some encouraging results, such as in the work of Cano Porras et al. [79], with a retrospective study of 167 patients in a large rehabilitation center for 3 years that showed significant improvements in functional measures of balance and gait.

Another study showing positive outcomes is Moreno et al. [80], especially in cognitive functions, although it found that whilst the overall quality of the studies was good, there were no studies with a Downs and Black rating of excellent, and so they note that future research should focus on randomized controlled studies. The most interesting is the set of recommendations included at the end of the review for future studies: to describe the clinical information of the samples, to conduct longitudinal studies, to compare different levels of immersion, to systematically assess user acceptance and adverse events, to use well-known measures independent of the culture, countries, etc., to report the effect sizes (the "strength") of the outcomes, and to provide examples of generalization to real situations.

Finally, in 2022, we found more studies supporting the positive outcomes of VR interventions, such as Chatterjee et al. [81], which showed, in a double-blind randomized control trial, particular benefits on stroke survivors with severe cognitive impairment as well as a reduction of the time spent in hospital for all patients that received the VR treatment.

Regarding the perceived quality of patients, there is a clear motivation for improvement, according again to Lee et al. [11] and Gil-Gomez et al. [60], although in terms of mastery confidence and incompetence fear, 3D virtual reality environments have worse results than more extensive 2D environments [32].

We can thereby conclude that we are clearly deriving some benefits from these initiatives, more in motor functions than in cognitive functions, and in patients' motivation and adherence as well, although the measurement of these benefits is too heterogeneous to be compared or aggregated. Nevertheless, larger studies like Cano Porras et al. [79] and Zhang et al. [66] have provided more solid evidence of the benefits in recent years.

Table 1 shows a summary of the studies selected, regarding the four "Are" questions:

**Table 1.** Summary table of the different aspects evaluated in the different "are" questions together with bibliographic references that support them.

| | *Strategic Question: Are We Doing the Right Things?* | *Architecture Question: Are We Doing Them the Right Way?* | *Delivery Question: Are We Getting Things Done Well?* | *Value Question: Are We Getting the Benefits?* |
|---|---|---|---|---|
| Problem definition | Saposnik et al., 2010 [10]<br>Lee et al., 2019 [11]<br>GBD Stroke Collaborators 2019 [15] | | | |
| Why virtual rehabilitation | Carregosa et al., 2018 [12]<br>Wagner et al., 2019 [13]<br>Aminov et al., 2018 [16]<br>Fluet et al., 2019 [17]<br>Maggio et al., 2019 [3]<br>Schulteis and Rizzo, 2001 [18] | Brachman et al., 2021 [22]<br>Katz et al., 2005 [23]<br>Cano Porras et al., 2018 [34] | | |
| Best practices | Maggio et al., 2019 [20] | Adie et al., 2014 [25]<br>Adie et al., 2017 [26]<br>Saposnik et al., 2016 [27]<br>Unibaso-Markaida et al., 2019 [28]<br>Subramanian et al., 2019 [31]<br>Lee et al., 2019 [11]<br>Kober et al., 2016 [32]<br>Lloréns et al., 2015 [39]<br>Pereira et al., 2019 [40]<br>Navarro et al., 2020 [41]<br>Lee et al., 2020 [42]<br>Brassel et al., 2021 [43]<br>Juras et al., 2019 [44]<br>Bermúdez i Badia et al., 2016 [45]<br>Lamontagne et al., 2019 [46]<br>Williams et al. [47]<br>Lanzoni et al., 2022 [48]<br>Parisi et al., 2022 [49]<br>Calabrò et al., 2022 [50]<br>Martinez-Moreno et al., 2016 [51] | Bartnicka et al., 2019 [56]<br>Demers et al., 2019 [82]<br>Frøkjær et al., 2000 [57]<br>ISO [83]<br>Rizzo and Kim, 2005 [58]<br>Scano et al., 2018 [59] | Chen et al. [72] |

**Table 1.** *Cont.*

| | *Strategic Question: Are We Doing the Right Things?* | *Architecture Question: Are We Doing Them the Right Way?* | *Delivery Question: Are We Getting Things Done Well?* | *Value Question: Are We Getting the Benefits?* |
|---|---|---|---|---|
| Benefits | Chen et al., 2016 [19]<br>Aliprandi et al., 2022 [21] | Riva et al., 2003 [24]<br>Saposnik et al., 2010 [10]<br>Rodríguez Hernández et al., 2020 [29]<br>Laver et al., 2017 [30]<br>Kim et al., 2018 [35]<br>Faria et al., 2019 [36]<br>Faria et al., 2020 [37] | | Aminov et al., 2018 [16]<br>Laver et al., 2017 [30]<br>Laver et al., 2012 [65]<br>Zhang et al., 2021 [66]<br>Maier et al., 2020 [67]<br>Rutkowsky et al., 2020 [68]<br>Park et al., 2020 [69]<br>De Luca et al., 2018 [71]<br>Levin et al., 2015 [73]<br>Saposnik et al., 2010 [10]<br>Da Silva et al., 2015 [74]<br>Turolla et al., 2013 [75]<br>Xiao et al., 2022 [77]<br>Li et al., 2022 [78]<br>Cano Porras et al., 2019 [79]<br>Moreno et al., 2019 [80]<br>Chatterjee et al., 2022 [81] |
| Patients' experience | | | Lewis et al., 2011 [52]<br>Green et al., 2019 [53]<br>Vollebregt et al., 2019 [54]<br>Spreij et al., 2022 [55]<br>Gil-Gómez et al., 2017 [60]<br>Threapleton et al., 2016 [61]<br>Fluet et al., 2019 [17]<br>Jonsdottir et al., 2021 [62]<br>Sramka et al., 2020 [63]<br>Bevilacqua et al., 2019 [64] | |
| Quality of research | | Arienti et al., 2019 [33] | | Subramanian et al., 2019 [31]<br>Kalron and Zeilig, 2015 [76] |

## 4. Discussion

As we have seen through this bibliographic review from an IT governance perspective, there are many challenges related to homogenizing the practice of using virtual reality for rehabilitation and the measurement of results, making it difficult to attain a critical mass that can demonstrate the results this technology promises.

### *4.1. Comparability*

In summary, we have found a great variety of implementation parameters and design factors, such as the virtual reality technology used (immersive vs. non immersive, general purpose vs. specific equipment, competitive vs. collaborative vs. cooperative, etc.); the game design factor (adaptability, rewards, narrative, etc.); the combination of virtual reality with conventional methods or not; sample size; duration and intensity of treatment; outcome measurement methods (SF-36, Fugl-Meyer, Wolf Motor Function, etc.); and the type of functions to measure (upper limb, lower limb, cognitive, activity of daily life, gait speed, etc.).

This variety makes it difficult to compare the different studies and reduces the effectiveness of meta-analysis. Despite this heterogeneity, there are some valid conclusions, although there is still discussion about which characteristics of virtual reality rehabilitation programs are the key to success: specific environments for post-stroke rehabilitation show better outcomes than general purpose ones; a treatment period of 8 weeks or more is preceptive to obtaining relevant outcomes; VR can help at least in scalability needs in a context of scarce human resources and facilities to develop conventional therapies, increasing the therapy time quickly and with little investment; combining VR with conventional therapy presents better outcomes; and motivation can be improved, creating an enjoyable experience for the users, thereby preserving the usability and increasing both the adherence and effectiveness of the treatment.

### *4.2. Efficiency and Accessibility*

We can also affirm that VR intervention programs lower costs [11] by reducing clinician time without reducing the time the patient spends on rehabilitation, and this cost reduction is greater than the cost increment of acquiring the hardware and software needed. Furthermore, this type of intervention can reach more patients, covering people that are far from clinical centers, and counteract difficulties in hiring specialists in some geographical areas.

Even in the case of clinical trials involving neurological patients, virtual rehabilitation could mark a difference, permitting the participation of patients with difficulties in accessing healthcare facilities and keeping homogeneity in assessment across several countries [84].

### *4.3. Normalization and Sample Sizes Could Improve Evidence*

Recent studies like Cano Porras et al. [79] manage larger samples and still show better outcomes, and works like Moreno et al. [80] establish interesting recommendations for improving the design of future studies, so we can assume that it is just a matter of time before better evidence is available.

On the other hand, studies like Gil-Gómez et al. [60] have defined guidelines to measure the usability of these systems and the existence of VR kits specifically designed for virtual rehabilitation [46], indicating a promising future for this kind of technology.

## 5. Conclusions

Additionally, we believe that our work can also help to highlight the challenges and the best practices available according to the literature and introduce the IT governance perspective that has been particularly useful to extract value from technology in other disciplines.

To summarize the clinical benefits, we consider that there is enough evidence of positive clinical outcomes for stroke patients, specifically in motor function, to support further research in this field, especially when the use of virtual rehabilitation techniques makes rehabilitation more accessible to more people and often improves motivation and, therefore, adherence to the treatment. A combination of VR rehabilitation and traditional rehabilitation is another scenario where we get better results than in traditional rehabilitation alone, preventing patients feeling overloaded. Furthermore, an interesting possibility would be to develop capabilities in the VR tools to work on both cognitive and motor functions, allowing the patients to perform dual tasks. These types of tasks have been used in recent decades as an efficient strategy to recover cognitive and motor impairments related to CVD ([85]).

Returning to the question posed in the title, based on IT governance parameters, the conclusion is that more robust evidence is still needed to demonstrate which virtual rehabilitation approach provides the best results for acquired brain injury rehabilitation practice, specifically in stroke patients. Such evidence is essential to ensure the wide adoption and integration of this technology in the field of rehabilitation.

As a proposal of further research, we need to promote studies with larger samples that provide more evidence for the outcomes, with special attention to the homogeneity of measurement tools and methods. Another potential line of work is to identify which kind of VR environment provides the best results in the intervention of cognitive function (if any) and which one provides better results in motor function. Finally, the influence of collaborative and competitive environments on both motivation and adherence to the treatment is another interesting line of research to work on.

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## References

1. Institute for Health Metrics and Evaluation GBD Compare Viz Hub. Available online: https://vizhub.healthdata.org/gbd-compare/ (accessed on 15 March 2022).
2. Feske, S.K. Ischemic Stroke. *Am. J. Med.* **2021**, *134*, 1457–1464. [CrossRef] [PubMed]
3. Maggio, M.G.; Maresca, G.; De Luca, R.; Stagnitti, M.C.; Porcari, B.; Ferrera, M.C.; Galletti, F.; Casella, C.; Manuli, A.; Calabrò, R.S. The Growing Use of Virtual Reality in Cognitive Rehabilitation: Fact, Fake or Vision? A Scoping Review. *J. Natl. Med. Assoc.* **2019**, *111*, 457–463. [CrossRef] [PubMed]
4. Saini, V.; Guada, L.; Yavagal, D.R. Global Epidemiology of Stroke and Access to Acute Ischemic Stroke Interventions. *Neurology* **2021**, *97*, S6–S16. [CrossRef] [PubMed]
5. World Health Organization. Assuring the Quality of Public Health Services. In *Organization and Financing of Public Health Services in Europe*; Williams, G., Nolte, E., Eds.; Health Policy Series; WHO Regional Office for Europe: Copenhagen, Denmark, 2018; ISBN 978-92-890-5172-9.
6. Matamala-Gomez, M.; Bottiroli, S.; Realdon, O.; Riva, G.; Galvagni, L.; Platz, T.; Sandrini, G.; De Icco, R.; Tassorelli, C. Telemedicine and Virtual Reality at Time of COVID-19 Pandemic: An Overview for Future Perspectives in Neurorehabilitation. *Front. Neurol.* **2021**, *12*, 646902. [CrossRef] [PubMed]
7. Mantovani, E.; Zucchella, C.; Bottiroli, S.; Federico, A.; Giugno, R.; Sandrini, G.; Chiamulera, C.; Tamburin, S. Telemedicine and Virtual Reality for Cognitive Rehabilitation: A Roadmap for the COVID-19 Pandemic. *Front. Neurol.* **2020**, *11*, 926. [CrossRef]
8. Thorp, J. *The Information Paradox: Realizing the Business Benefits of Information Technology*; McGraw-Hill: Toronto, ON, Canada, 1998; ISBN 978-0-07-134265-0.
9. Zhao, Y.; Zhang, X.; Chen, X.; Wei, Y. Neuronal Injuries in Cerebral Infarction and Ischemic Stroke: From Mechanisms to Treatment (Review). *Int. J. Mol. Med.* **2021**, *49*, 15. [CrossRef]

10. Saposnik, G.; Teasell, R.; Mamdani, M.; Hall, J.; McIlroy, W.; Cheung, D.; Thorpe, K.E.; Cohen, L.G.; Bayley, M. Effectiveness of Virtual Reality Using Wii Gaming Technology in Stroke Rehabilitation: A Pilot Randomized Clinical Trial and Proof of Principle. *Stroke* **2010**, *41*, 1477–1484. [CrossRef]
11. Lee, H.S.; Park, Y.J.; Park, S.W. The Effects of Virtual Reality Training on Function in Chronic Stroke Patients: A Systematic Review and Meta-Analysis. *BioMed Res. Int.* **2019**, *2019*, 7595639. [CrossRef]
12. Carregosa, A.A.; Aguiar dos Santos, L.R.; Masruha, M.R.; Coêlho, M.L.d.S.; Machado, T.C.; Souza, D.C.B.; Passos, G.L.L.; Fonseca, E.P.; Ribeiro, N.M.d.S.; de Souza Melo, A. Virtual Rehabilitation through Nintendo Wii in Poststroke Patients: Follow-Up. *J. Stroke Cerebrovasc. Dis.* **2018**, *27*, 494–498. [CrossRef]
13. Wagner, S.; Preim, B.; Saalfeld, P.; Belger, J. Crossing IVRoad: A VR Application for Detecting Unilateral Visuospatial Neglect in Poststroke Patients. In Proceedings of the 2019 International Conference on Virtual Rehabilitation (ICVR), Tel Aviv, Israel, 21–24 July 2019; pp. 1–2.
14. Tinga, A.M.; Visser-Meily, J.M.A.; van der Smagt, M.J.; Van der Stigchel, S.; van Ee, R.; Nijboer, T.C.W. Multisensory Stimulation to Improve Low- and Higher-Level Sensory Deficits after Stroke: A Systematic Review. *Neuropsychol. Rev.* **2016**, *26*, 73–91. [CrossRef]
15. GBD 2019 Stroke Collaborators 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]
16. Aminov, A.; Rogers, J.M.; Middleton, S.; Caeyenberghs, K.; Wilson, P.H. What Do Randomized Controlled Trials Say about Virtual Rehabilitation in Stroke? A Systematic Literature Review and Meta-Analysis of Upper-Limb and Cognitive Outcomes. *J. Neuroeng. Rehabil.* **2018**, *15*, 29. [CrossRef]
17. Fluet, G.G.; Qiu, Q.; Patel, J.; Cronce, A.; Merians, A.S.; Adamovich, S.V. Autonomous Use of the Home Virtual Rehabilitation System: A Feasibility and Pilot Study. *Games Health J.* **2019**, *8*, 432–438. [CrossRef] [PubMed]
18. Schultheis, M.T.; Rizzo, A.A. The Application of Virtual Reality Technology in Rehabilitation. *Rehabil. Psychol.* **2001**, *46*, 296–311. [CrossRef]
19. Chen, L.; Lo, W.L.A.; Mao, Y.R.; Ding, M.H.; Lin, Q.; Li, H.; Zhao, J.L.; Xu, Z.Q.; Bian, R.H.; Huang, D.F. Effect of Virtual Reality on Postural and Balance Control in Patients with Stroke: A Systematic Literature Review. *BioMed Res. Int.* **2016**, *2016*, 7309272. [CrossRef] [PubMed]
20. Maggio, M.G.; Latella, D.; Maresca, G.; Sciarrone, F.; Manuli, A.; Naro, A.; De Luca, R.; Calabrò, R.S. Virtual Reality and Cognitive Rehabilitation in People with Stroke: An Overview. *J. Neurosci. Nurs.* **2019**, *51*, 101–105. [CrossRef]
21. Aliprandi, M.; Pan, Y.; Mosley, C.; Gough, S. What Is the Cost of Including Virtual Reality in Neurological Rehabilitation? A Scoping Review. *Phys. Ther. Rev.* **2022**, *27*, 329–345. [CrossRef]
22. Brachman, A.; Marszałek, W.; Kamieniarz, A.; Michalska, J.; Pawłowski, M.; Akbaş, A.; Juras, G. The Effects of Exergaming Training on Balance in Healthy Elderly Women—A Pilot Study. *Int. J. Enivorn. Res. Publish Health* **2021**, *18*, 1412. [CrossRef]
23. Katz, N.; Ring, H.; Naveh, Y.; Kizony, R.; Feintuch, U.; Weiss, P.L. Interactive Virtual Environment Training for Safe Street Crossing of Right Hemisphere Stroke Patients with Unilateral Spatial Neglect. *Disabil. Rehabil.* **2005**, *27*, 1235–1244. [CrossRef]
24. Riva, G.; Davide, F.; IJsselsteijn, W.A. (Eds.) *Being There: Concepts, Effects and Measurements of User Presence in Synthetic Environments*; Emerging Communication: Studies in New Technologies and Practices in Communication; IOS Press: Amsterdam, The Netherlands; Washington, DC, USA; Ohmsha: Tokyo, Japan, 2003; ISBN 978-1-58603-301-9.
25. Adie, K.; Schofield, C.; Berrow, M.; Wingham, J.; Freeman, J.; Humfryes, J.; Pritchard, C. Does the Use of Nintendo Wii Sports™ Improve Arm Function and Is It Acceptable to Patients after Stroke? Publication of the Protocol of the Trial of Wii™ in Stroke—TWIST. *IJGM* **2014**, *2014*, 475–481. [CrossRef]
26. Adie, K.; Schofield, C.; Berrow, M.; Wingham, J.; Humfryes, J.; Pritchard, C.; James, M.; Allison, R. Does the Use of Nintendo Wii Sports™ Improve Arm Function? Trial of Wii™ in Stroke: A Randomized Controlled Trial and Economics Analysis. *Clin. Rehabil.* **2017**, *31*, 173–185. [CrossRef] [PubMed]
27. Saposnik, G.; Cohen, L.G.; Mamdani, M.; Pooyania, S.; Ploughman, M.; Cheung, D.; Shaw, J.; Hall, J.; Nord, P.; Dukelow, S.; et al. Efficacy and Safety of Non-Immersive Virtual Reality Exercising in Stroke Rehabilitation (EVREST): A Randomised, Multicentre, Single-Blind, Controlled Trial. *Lancet Neurol.* **2016**, *15*, 1019–1027. [CrossRef] [PubMed]
28. Unibaso-Markaida, I.; Iraurgi, I.; Ortiz-Marques, N.; Amayra, I.; Martinez-Rodriguez, S. Effect of the Wii Sports Resort on the Improvement in Attention, Processing Speed and Working Memory in Moderate Stroke. *J. Neuroeng. Rehabil.* **2019**, *16*, 32. [CrossRef] [PubMed]
29. Rodriguez Hernandez, J.; Cano-De-La-Cuerda, R.; Munoz Villena, A.; Cano-Manas, M.; Collado-Vazquez, S. Virtual Reality Based Therapy Effects on Balance and Postural Control of Subacute Stroke Patients: A Randomized Controlled Trial. *Int. J. Stroke* **2020**, *15*, 190. [CrossRef]
30. Laver, K.E.; Lange, B.; George, S.; Deutsch, J.E.; Saposnik, G.; Crotty, M. Virtual Reality for Stroke Rehabilitation. *Cochrane Database Syst. Rev.* **2017**, *2018*, CD008349. [CrossRef]
31. Subramanian, S.K.; Cross, M.K.; Hirschhauser, C.S.; Johnson, V.B.; Reistetter, T.A. Post-Stroke Upper Limb Rehabilitation Using Virtual Reality Interventions: Do Outcome Measures Assess Extent or Type of Motor Improvement? In Proceedings of the 2019 International Conference on Virtual Rehabilitation (ICVR), Tel Aviv, Israel, 21–24 July 2019; pp. 1–6.
32. Kober, S.E.; Reichert, J.L.; Schweiger, D.; Neuper, C.; Wood, G. *Effects of a 3D Virtual Reality Neurofeedback Scenario on User Experience and Performance in Stroke Patients*; Springer: Berlin/Heidelberg, Germany, 2016; Volume 10056 LNCS, p. 94. ISBN 9783319501819. ISSN 03029743.

33. Arienti, C.; Lazzarini, S.G.; Pollock, A.; Negrini, S. Rehabilitation Interventions for Improving Balance Following Stroke: An Overview of Systematic Reviews. *PLoS ONE* **2019**, *14*, e0219781. [CrossRef]
34. Cano Porras, D.; Siemonsma, P.; Inzelberg, R.; Zeilig, G.; Plotnik, M. Advantages of Virtual Reality in the Rehabilitation of Balance and Gait: Systematic Review. *Neurology* **2018**, *90*, 1017–1025. [CrossRef]
35. Kim, W.-S.; Cho, S.; Park, S.H.; Lee, J.-Y.; Kwon, S.; Paik, N.-J. A Low Cost Kinect-Based Virtual Rehabilitation System for Inpatient Rehabilitation of the Upper Limb in Patients with Subacute Stroke: A Randomized, Double-Blind, Sham-Controlled Pilot Trial. *Medicine* **2018**, *97*, e11173. [CrossRef]
36. Faria, A.L.; Paulino, T.; i Badia, S.B. Comparing Adaptive Cognitive Training in Virtual Reality and Paper-Pencil in a Sample of Stroke Patients. In Proceedings of the 2019 International Conference on Virtual Rehabilitation (ICVR), Tel Aviv, Israel, 21–24 July 2019; pp. 1–7.
37. Faria, A.L.; Faria, A.L.; Faria, A.L.; Pinho, M.S.; Pinho, M.S.; Bermúdez I Badia, S.; Bermúdez I Badia, S.; Bermúdez I Badia, S. A Comparison of Two Personalization and Adaptive Cognitive Rehabilitation Approaches: A Randomized Controlled Trial with Chronic Stroke Patients. *J. Neuroeng. Rehabil.* **2020**, *17*, 78. [CrossRef]
38. Fusco, A.; Giovannini, S.; Castelli, L.; Coraci, D.; Gatto, D.; Reale, G.; Pastorino, R.; Padua, L. Virtual Reality and Lower Limb Rehabilitation: Effects on Motor and Cognitive Outcome—A Crossover Pilot Study. *J. Clin. Med.* **2022**, *11*, 2300. [CrossRef]
39. Lloréns, R.; Noé, E.; Naranjo, V.; Borrego, A.; Latorre, J.; Alcañiz, M. Tracking Systems for Virtual Rehabilitation: Objective Performance vs. Subjective Experience. A Practical Scenario. *Sensors* **2015**, *15*, 6586–6606. [CrossRef] [PubMed]
40. Pereira, F.; Bermudez i Badia, S.; Jorge, C.; da Silva Cameirao, M. Impact of Game Mode on Engagement and Social Involvement in Multi-User Serious Games with Stroke Patients. In Proceedings of the 2019 International Conference on Virtual Rehabilitation (ICVR), Tel Aviv, Israel, 21–24 July 2019; pp. 1–6.
41. Navarro, M.D.; Llorens, R.; Borrego, A.; Alcañiz, M.; Noé, E.; Ferri, J. Competition Enhances the Effectiveness and Motivation of Attention Rehabilitation After Stroke. A Randomized Controlled Trial. *Front. Hum. Neurosci.* **2020**, *14*, 575403. [CrossRef] [PubMed]
42. Lee, C.-H.; Kim, Y.-S.; Jung, J.-H. Effectiveness of Virtual Reality Based Cognitive Rehabilitation on Cognitive Function, Motivation and Depression in Stroke Patients. *Med. Leg. Update* **2020**, *20*, 1880–1886. [CrossRef]
43. Brassel, S.; Power, E.; Campbell, A.; Brunner, M.; Togher, L. Recommendations for the Design and Implementation of Virtual Reality for Acquired Brain Injury Rehabilitation: Systematic Review. *J. Med. Internet Res.* **2021**, *23*, e26344. [CrossRef]
44. Juras, G.; Brachman, A.; Michalska, J.; Kamieniarz, A.; Pawłowski, M.; Hadamus, A.; Białoszewski, D.; Błaszczyk, J.; Słomka, K.J. Standards of Virtual Reality Application in Balance Training Programs in Clinical Practice: A Systematic Review. *Games Health J.* **2019**, *8*, 101–111. [CrossRef]
45. Bermúdez i Badia, S.; Fluet, G.G.; Llorens, R.; Deutsch, J.E. Virtual Reality for Sensorimotor Rehabilitation Post Stroke: Design Principles and Evidence. In *Neurorehabilitation Technology*; Reinkensmeyer, D.J., Dietz, V., Eds.; Springer International Publishing: Cham, Switzerland, 2016; pp. 573–603. ISBN 978-3-319-28601-3.
46. Lamontagne, A.; Anita, M.; Blanchette, A.K.; Fung, J.; McFadyen, B.J.; Sangani, S.; Robitaille, N.; Deblock-Bellamy, A.; Buhler, M.A.; Perez, C. Development of a Virtual Reality Toolkit to Enhance Community Walking after Stroke. In Proceedings of the 2019 International Conference on Virtual Rehabilitation (ICVR), Tel Aviv, Israel, 21–24 July 2019; pp. 1–3.
47. Williams, R.M.; Alikhademi, K.; Gilbert, J.E. Design of a Toolkit for Real-Time Executive Function Assessment in Custom-Made Virtual Experiences and Interventions. *Int. J. Hum. Comput. Stud.* **2022**, *158*, 102734. [CrossRef]
48. Lanzoni, D.; Vitali, A.; Regazzoni, D.; Rizzi, C. Design of Customized Virtual Reality Serious Games for the Cognitive Rehabilitation of Retrograde Amnesia After Brain Stroke. *J. Comput. Inf. Sci. Eng.* **2022**, *22*, 031009. [CrossRef]
49. Parisi, A.; Bellinzona, F.; Di Lernia, D.; Repetto, C.; De Gaspari, S.; Brizzi, G.; Riva, G.; Tuena, C. Efficacy of Multisensory Technology in Post-Stroke Cognitive Rehabilitation: A Systematic Review. *J. Clin. Med.* **2022**, *11*, 6324. [CrossRef]
50. Calabrò, R.S.; Cerasa, A.; Ciancarelli, I.; Pignolo, L.; Tonin, P.; Iosa, M.; Morone, G. The Arrival of the Metaverse in Neurorehabilitation: Fact, Fake or Vision? *Biomedicines* **2022**, *10*, 2602. [CrossRef]
51. Martinez-Moreno, J.M.; Sanchez-Gonzalez, P.; Luna, M.; Roig, T.; Tormos, J.M.; Gomez, E.J. Modelling Ecological Cognitive Rehabilitation Therapies for Building Virtual Environments in Brain Injury. *Methods Inf. Med.* **2016**, *55*, 50–59. [CrossRef]
52. Lewis, G.N.; Woods, C.; Rosie, J.A.; Mcpherson, K.M. Virtual Reality Games for Rehabilitation of People with Stroke: Perspectives from the Users. *Disabil. Rehabil. Assist. Technol.* **2011**, *6*, 453–463. [CrossRef] [PubMed]
53. Green, D.; Boltin, S.; Ward, A.; Gowing, F.; Hutchon, B. Coproducing Virtual Reality Technologies for Rehabilitation. In Proceedings of the 2019 International Conference on Virtual Rehabilitation (ICVR), Tel Aviv, Israel, 21–24 July 2019; pp. 1–2.
54. Vollebregt, B.; Reinikka, K.; Vasiliu, D.; Pepe, A.; Prasanna, S.S.; Jain, A.; Lawrence-Dewar, J.; Johnson, V.B.K. The Impact of a Hand Training Programme in Chronic Stroke Survivors: A Qualitative Analysis of Participant Perceived Benefits. In Proceedings of the 2019 International Conference on Virtual Rehabilitation (ICVR), Tel Aviv, Israel, 21–24 July 2019; pp. 1–2.
55. Spreij, L.A.; Visser-Meily, J.M.A.; Sibbel, J.; Gosselt, I.K.; Nijboer, T.C.W. Feasibility and User-Experience of Virtual Reality in Neuropsychological Assessment Following Stroke. *Neuropsychol. Rehabil.* **2022**, *32*, 499–519. [CrossRef] [PubMed]
56. Bartnicka, J.; Herrera, C.; Portilla, R.; Zietkiewicz, A.; Mleczko, K.; Pavan, E.; Donoso, E.V.; Garrido, D. *Educational Needs in Neurological Rehabilitation—"Brain4train" Survey Outcomes from European Countries*; Springer: Berlin/Heidelberg, Germany, 2019; Volume 785, p. 396. ISBN 9783319938813. ISSN 21945357.

57. Frøkjær, E.; Hertzum, M.; Hornbæk, K. Measuring Usability: Are Effectiveness, Efficiency, and Satisfaction Really Correlated? In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems—CHI'00, The Hague, The Netherlands, 1–6 April 2000; ACM Press: The Hague, The Netherlands, 2000; pp. 345–352.
58. Rizzo, A. "Skip"; Kim, G.J. A SWOT Analysis of the Field of Virtual Reality Rehabilitation and Therapy. *Presence Teleoper. Virtual Environ.* **2005**, *14*, 119–146. [CrossRef]
59. Scano, A.; Chiavenna, A.; Malosio, M.; Molinari Tosatti, L.; Molteni, F. Kinect V2 Implementation and Testing of the Reaching Performance Scale for Motor Evaluation of Patients with Neurological Impairment. *Med. Eng. Phys.* **2018**, *56*, 54–58. [CrossRef]
60. Gil-Gómez, J.-A.; Manzano-Hernández, P.; Albiol-Pérez, S.; Aula-Valero, C.; Gil-Gómez, H.; Lozano-Quilis, J.-A. USEQ: A Short Questionnaire for Satisfaction Evaluation of Virtual Rehabilitation Systems. *Sensors* **2017**, *17*, 1589. [CrossRef]
61. Threapleton, K.; Drummond, A.; Standen, P. Virtual Rehabilitation: What Are the Practical Barriers for Home-Based Research? *Digit. Health* **2016**, *2*, 205520761664130. [CrossRef]
62. Jonsdottir, J.; Baglio, F.; Gindri, P.; Isernia, S.; Castiglioni, C.; Gramigna, C.; Palumbo, G.; Pagliari, C.; Di Tella, S.; Perini, G.; et al. Virtual Reality for Motor and Cognitive Rehabilitation From Clinic to Home: A Pilot Feasibility and Efficacy Study for Persons With Chronic Stroke. *Front. Neurol.* **2021**, *12*, 601131. [CrossRef]
63. Sramka, M.; Lacko, J.; Ruzicky, E.; Masan, J. Combined Methods of Rehabilitation of Patients after Stroke: Virtual Reality and Traditional Approach. *Neuroendocrinol. Lett.* **2020**, *41*, 123–133.
64. Bevilacqua, R.; Maranesi, E.; Riccardi, G.R.; Di Donna, V.; Pelliccioni, P.; Luzi, R.; Lattanzio, F.; Pelliccioni, G. Non-Immersive Virtual Reality for Rehabilitation of the Older People: A Systematic Review into Efficacy and Effectiveness. *J. Clin. Med.* **2019**, *8*, 1882. [CrossRef]
65. Laver, K.; George, S.; Thomas, S.; Deutsch, J.E.; Crotty, M. Cochrane Review: Virtual Reality for Stroke Rehabilitation. *Eur. J. Phys. Rehabil. Med.* **2012**, *48*, 523–530.
66. Zhang, Q.; Fu, Y.; Lu, Y.; Zhang, Y.; Huang, Q.; Yang, Y.; Zhang, K.; Li, M. Impact of Virtual Reality-Based Therapies on Cognition and Mental Health of Stroke Patients: Systematic Review and Meta-Analysis. *J. Med. Internet Res.* **2021**, *23*, e31007. [CrossRef] [PubMed]
67. Maier, M.; Ballester, B.R.; Leiva Bañuelos, N.; Duarte Oller, E.; Verschure, P.F.M.J. Adaptive Conjunctive Cognitive Training (ACCT) in Virtual Reality for Chronic Stroke Patients: A Randomized Controlled Pilot Trial. *J. Neuroeng. Rehabil.* **2020**, *17*, 42. [CrossRef]
68. Rutkowski, S.; Kiper, P.; Cacciante, L.; Cieślik, B.; Mazurek, J.; Turolla, A.; Szczepańska-Gieracha, J. Use of Virtual Reality-Based Training in Different Fields of Rehabilitation: A Systematic Review and Meta-Analysis. *J. Rehabil. Med.* **2020**, *52*, jrm00121. [CrossRef] [PubMed]
69. Park, J.-S.; Jung, Y.-J.; Lee, G. Virtual Reality-Based Cognitive-Motor Rehabilitation in Older Adults with Mild Cognitive Impairment: A Randomized Controlled Study on Motivation and Cognitive Function. *Healthcare* **2020**, *8*, 335. [CrossRef]
70. Blázquez-González, P.; Mirón-González, R.; Lendínez-Mesa, A.; Moro-Tejedor, M.N.; Cobo-Sánchez, J.L.; Mancebo-Salas, N.; Camacho-Arroyo, M.T.; Rodríguez-Leal, L.; Luengo-González, R. Efficacy of the Therapeutic Use of Video Games on the Depressive State of Stroke Patients: Protocol for Systematic Review and Meta-Analysis. *PLoS ONE* **2022**, *17*, e0275740. [CrossRef] [PubMed]
71. De Luca, R.; Russo, M.; Naro, A.; Tomasello, P.; Leonardi, S.; Santamaria, F.; Desireè, L.; Bramanti, A.; Silvestri, G.; Bramanti, P.; et al. Effects of Virtual Reality-Based Training with BTs-Nirvana on Functional Recovery in Stroke Patients: Preliminary Considerations. *Int. J. Neurosci.* **2018**, *128*, 791–796. [CrossRef]
72. Chen, X.; Liu, F.; Lin, S.; Yu, L.; Lin, R. Effects of Virtual Reality Rehabilitation Training on Cognitive Function and Activities of Daily Living of Patients With Poststroke Cognitive Impairment: A Systematic Review and Meta-Analysis. *Arch. Phys. Med. Rehabil.* **2022**, *103*, 1422–1435. [CrossRef]
73. Levin, M.F.; Weiss, P.L.; Keshner, E.A. Emergence of Virtual Reality as a Tool for Upper Limb Rehabilitation: Incorporation of Motor Control and Motor Learning Principles. *Phys. Ther.* **2015**, *95*, 415–425. [CrossRef]
74. da Silva Ribeiro, N.M.; Ferraz, D.D.; Pedreira, É.; Pinheiro, Í.; da Silva Pinto, A.C.; Neto, M.G.; dos Santos, L.R.A.; Pozzato, M.G.G.; Pinho, R.S.; Masruha, M.R. Virtual Rehabilitation via Nintendo Wii® and Conventional Physical Therapy Effectively Treat Post-Stroke Hemiparetic Patients. *Top. Stroke Rehabil.* **2015**, *22*, 299–305. [CrossRef] [PubMed]
75. Turolla, A.; Dam, M.; Ventura, L.; Tonin, P.; Agostini, M.; Zucconi, C.; Kiper, P.; Cagnin, A.; Piron, L. Virtual Reality for the Rehabilitation of the Upper Limb Motor Function after Stroke: A Prospective Controlled Trial. *J. Neuroeng. Rehabil.* **2013**, *10*, 85. [CrossRef] [PubMed]
76. Kalron, A.; Zeilig, G. Efficacy of Exercise Intervention Programs on Cognition in People Suffering from Multiple Sclerosis, Stroke and Parkinson's Disease: A Systematic Review and Meta-Analysis of Current Evidence. *NeuroRehabilitation* **2015**, *37*, 273–289. [CrossRef] [PubMed]
77. Xiao, Z.; Wang, Z.; Ge, S.; Zhong, Y.; Zhang, W. Rehabilitation Efficacy Comparison of Virtual Reality Technology and Computer-Assisted Cognitive Rehabilitation in Patients with Post-Stroke Cognitive Impairment: A Network Meta-Analysis. *J. Clin. Neurosci.* **2022**, *103*, 85–91. [CrossRef] [PubMed]
78. Li, Z.; Yang, L.; Qiu, H.; Wang, X.; Zhang, C.; Zhang, Y. Comparative Efficacy of 5 Non-Pharmacological Therapies for Adults with Post-Stroke Cognitive Impairment: A Bayesian Network Analysis Based on 55 Randomized Controlled Trials. *Front. Neurol.* **2022**, *13*, 977518. [CrossRef] [PubMed]

79. Cano Porras, D.; Sharon, H.; Inzelberg, R.; Ziv-Ner, Y.; Zeilig, G.; Plotnik, M. Advanced Virtual Reality-Based Rehabilitation of Balance and Gait in Clinical Practice. *Ther. Adv. Chronic Dis.* **2019**, *10*, 2040622319868379. [CrossRef]
80. Moreno, A.; Wall, K.J.; Thangavelu, K.; Craven, L.; Ward, E.; Dissanayaka, N.N. A Systematic Review of the Use of Virtual Reality and Its Effects on Cognition in Individuals with Neurocognitive Disorders. *Alzheimers Dement. Transl. Res. Clin. Interv.* **2019**, *5*, 834–850. [CrossRef]
81. Chatterjee, K.; Buchanan, A.; Cottrell, K.; Hughes, S.; Day, T.W.; John, N.W. Immersive Virtual Reality for the Cognitive Rehabilitation of Stroke Survivors. *IEEE Trans. Neural Syst. Rehabil. Eng.* **2022**, *30*, 719–728. [CrossRef]
82. Demers, M.; Nguyen, A.-V.; Ong, Y.-L.A.; Luo, C.X.; Thuraisingam, T.; Rubino, M.; Levin, M.F.; Kaizer, F.; Archambault, P.S. Exergaming for Stroke Rehabilitation: Lessons Learned for Future Implementation Strategies. In Proceedings of the 2019 International Conference on Virtual Rehabilitation (ICVR), Tel Aviv, Israel, 21–24 July 2019; pp. 1–3.
83. International Standards Organization. *ISO 9241-11:2018*; Ergonomics of Human-System Interaction—Part 11: Usability: Definitions and Concepts. ISO: Geneva, Switzerland, 2018.
84. Chiamulera, C.; Mantovani, E.; Tamburin, S. Remote Clinical Trials: A Timely Opportunity for a Virtual Reality Approach and Its Potential Application in Neurology. *Br. J. Clin. Pharmacol.* **2021**, *87*, 3639–3642. [CrossRef]
85. Zhou, Q.; Yang, H.; Zhou, Q.; Pan, H. Effects of Cognitive Motor Dual-Task Training on Stroke Patients: A RCT-Based Meta-Analysis. *J. Clin. Neurosci.* **2021**, *92*, 175–182. [CrossRef]