COMMENTARY

Will virtual rehabilitation replace clinicians: a contemporary debate about technological versus human obsolescence

Tal Krasovsky1,2, Anat V. Lubetzky3, Philippe S. Archambault4,5 and W. Geoffrey Wright6*

Abstract

This article is inspired by a pseudo Oxford-style debate, which was held in Tel Aviv University, Israel at the International Conference on Virtual Rehabilitation (ICVR) 2019, which is the official conference of the International Society for Virtual Rehabilitation. The debate, between two 2-person teams with a moderator, was organized by the ICVR Program committee to address the question “Will virtual rehabilitation replace clinicians?” It brought together five academics with technical, research, and/or clinical backgrounds—Gerry Fluet, Tal Krasovsky, Anat Lubetzky, Philippe Archambault, W. Geoffrey Wright—to debate the pros and cons of using virtual reality (VR) and related technologies to help assess, diagnose, treat, and track recovery, and more specifically investigate the likelihood that advanced technology will ultimately replace human clinicians. Both teams were assigned a side to defend, whether it represented their own viewpoint or not, and to take whatever positions necessary to make a persuasive argument and win the debate. In this paper we present a recapitulation of the arguments presented by both sides, and further include an in-depth consideration of the question. We attempt to judiciously lay out a number of arguments that fall along a spectrum from moderate to extreme; the most extreme and/or indefensible positions are presented for rhetorical and demonstrative purposes. Although there may not be a clear answer today, this paper raises questions which are related to the basic nature of the rehabilitation profession, and to the current and potential role of technology within it.

Keywords: Automation, Artificial intelligence, Technology, Futurism, Clinical roles, Virtual reality, Telehealth

Background

Definition of the problem

To debate the question “Will virtual rehabilitation replace clinicians?” it is necessary to provide a definition for virtual rehabilitation. But first, we must define virtual reality (VR). Jaron Lanier, who is credited with first coining the term virtual reality, has defined it in many ways, some more poetic than others [1], but it can be succinctly expressed as “an artificial environment which is experienced through sensory stimuli (such as sights and sounds) provided by a computer and in which one’s actions partially determine what happens in the environment” [2]. We also provide an accepted definition of rehabilitation, to help better define the term virtual rehabilitation. Rehabilitation services help an individual maintain, restore, or improve skills and function for daily living that have been lost or impaired because a person was sick, hurt or living with temporary or permanent disability [3]. This leads to the definition for virtual rehabilitation, which is a neologism formed by combining the two terms just defined. Virtual rehabilitation refers to use of applications either based on, or improved by, VR [4] to support or enhance human health and function [5]. Although different views exist (e.g. [6]), for this discussion we chose to investigate the topic using a broad perspective, where VR may be a component of a complex system which incorporates additional physical interfaces.
for interaction with a patient—such as physical assistance (robotics) or augmented sensory feedback (haptics) [7]. The use of haptic feedback may be less developed and therefore less frequently included than the other types of VR sensory feedback (e.g. visual and auditory feedback), but haptics can help increase immersion and perceived realism in virtual environments when performing sensorimotor tasks [7]. We use this more inclusive definition for the term virtual rehabilitation in order to facilitate the discussion of the question, i.e., what type of virtual rehabilitation systems would be required to replace clinicians.

Almost 20 years ago, in a keynote address in the 1st International Workshop on VR Rehabilitation, it was noted by Dr. Grigore Burdea that “Certain unwise (and short-sighted) technologists have proclaimed that VR will replace the therapists altogether with computers” [4]. In the 20 years since then this has not happened, but the topic remains thought-provoking, and raises important questions related to the basic nature of the rehabilitation profession, and the current and potential role of technology within it. Furthermore, recent technological developments may (or may not) change this outlook in the future. We do not hope to resolve the debate in this paper, but instead to make a contemporary commentary on an insidious conflict that Karl Marx wrote about nearly two centuries ago: “The instrument of labour, when it takes the form of a machine, immediately becomes a competitor of the workman himself.” [8].

The debate: will virtual rehabilitation replace clinicians?

The “yes” side

The concept of virtual rehabilitation replacing clinicians carries with it an unavoidable negative sentiment among practicing clinicians and researchers in this field, a concern that is not unique to rehabilitation professionals. The advances of artificial intelligence (AI) in the last few decades have led futurist Ray Kurzweil to suggest that we are at the “knee” of an exponential curve in terms of technological development [9], and that the effects of these developments in the next few decades will be radical in terms of merging physical and virtual reality. Technological advancements in the years to come will inevitably change the job market. Ford [10] identified the current advances of information technology as a tipping point which will change the face of the job market in different fields in unpredictable ways. Not only will the low-skilled workforce be replaced by technology, but also highly skilled professions which require both intellectual aptitude and years of training, are expected to undergo dramatic changes. These changes include, in some cases, a new division of labor (by “offshoring” parts of the manufacturing process to other countries using technology to maintain service quality) and in other cases replacement of human labor by robots or computers.

Virtual rehabilitation may be particularly well-suited to replace humans in the upcoming “era of the machines”. In recent years, a massive surge of VR applications has been used for motor rehabilitation of the upper limb [11], posture and gait [12, 13] as well as neuropsychological interventions [14, 15]. Enthusiasm regarding VR as a rehabilitation tool stems from several sources. First, VR is fun and enjoyable for most people, and a high degree of motivation assists with adherence to interventions [16]. Second, by using computerized assessment of performance in VR, clinicians can keep track of quantifiable indices of performance over time which enables optimal selection of difficulty levels for individual patients as well as optimized goal setting within the system [17]. Thus, therapists can more easily track performance and learning. Importantly, a VR rehabilitation session can be delivered remotely while the patient is at home; telerehabilitation programs are showing promise by obtaining comparable results to therapist-supervised programs e.g. for people after stroke [18, 19] and people with Parkinson’s disease [20, 21] at lower costs [22]. VR rehabilitation in the form of telerehabilitation can be provided on a large scale and for longer durations. This is particularly important because life expectancy continues to increase: average global life expectancy increased by 5.5 years between 2000 and 2016, the fastest increase since the 1960s [23]. Home rehabilitation services help aging adults improve or maintain their quality of life, physical function and independence; in doing so it extends their time in the community and away from hospitals [24, 25]. Despite this evidence, many clients who could benefit from home rehabilitation services do not receive them [26] and virtual rehabilitation can play a key role in this solution. The advantages of virtual rehabilitation discussed here, including cost-effectiveness and provision of care to remote areas not accessible to standard care, can increase health care quality and availability for all and support healthy aging in place.

The advantages of VR may imply that application of this technology should be widespread and that clinicians should, indeed, start “fearing for their jobs”. However, this is currently not the case. In fact, the health care system, in general, is traditionally considered less vulnerable to the type of change advocated by Ford [10]. Health care professionals, including those in rehabilitation, may be more indispensable than other workers. In the widely-cited paper of Frey & Osborne [27], the authors ranked 702 professions according to their risk of computerization. Physical therapists were ranked in the top 15% (90 out of 702) for resistance to automation...
and emotional parameter [34]. Some of these capabilities
sensors, which can potentially measure any physiological
tion [28, 33]), set-up time is an important barrier for VR implement-
etime and technical support for technology integration) and the therapists (who do not feel competent enough with the technology). Overcom-
ing these barriers may seem daunting, but other fields have
proven that technology is increasingly accomplishing
feats which were previously thought to be impossible. For example, in “The New Division of Labor: How Computers are Creating the Next Job Market”, authors Levy and Murnane [29] stated: “...executing a left turn against oncoming traffic involves so many factors that it is hard
imagine discovering the set of rules that can replicate
a driver’s behavior” (p. 20), suggesting that the acquisition
of tacit knowledge is impossible for machines. However,
only 15 years later, “deep learning” has revolutionized the
field of autonomous vehicles [30] to a point that autonomous vehicles are now performing test drives in the
United States [31]. In fact, deep leaning algorithms are increasingly performing tasks in various fields which
were previously considered impossible (from music to poetry). AI has already made its value known in the
medical fields related to cancer detection, heart disease, stroke recovery, and for programming human–machine interfaces to help recover movement control following spinal cord injury [32]. Extrapolating to the proliferation of virtual rehabilitation into clinical use, we suggest that
near future advancements of technology can change the
field of rehabilitation in fundamental ways.

It is thus suggested here, that the question “will virtual rehabilitation replace clinicians?” may be phrased better as “when will virtual rehabilitation replace clinicians?” Although the answer to this question is speculative, one can highlight the ways to overcome existing barriers which inhibit an early disruption of the rehabilitation field by technological advancement. These can be divided into three main domains: (1) the technology, (2) the clinicians, and (3) the patients. Examining the first domain of technological progress, it is proposed that substan-
tial improvements are needed in terms of ease of use (e.g. set-up time is an important barrier for VR implement-
tion [28, 33]), reliability of the technology (e.g. works every time such that the clinician and patient develop trust in the system) and capabilities. New capabilities of VR systems can be, for example, the addition of sen-
sors, which can potentially measure any physiological and emotional parameter [34]. Some of these capabilities
are already being implemented. For example, cognitive
load can be evaluated via direct assessment of brain activ-
ation, using functional near-infrared spectroscopy [35] or electroencephalography [36]. When integrated into
virtual reality exposure therapy sessions [37], a combina-
tion of VR-based exposure and close monitoring of patient cognitive state improved both physiological and
cognitive symptoms of anxiety. This type of technology, which until recently was considered too costly to be clinically applicable, is becoming a consumer product, and
simple low-cost devices already exist on the market, for example to assess the level of relaxation/arousal through
electroencephalography [38]. When combined with VR
systems, close monitoring of physiological and sensory
states can improve algorithms for goal-setting during practice, by generating adequate challenge and avoiding
patient frustration. The accurate quantification of patient
performance and the complexity of machine learning
allow automated or semi-automated goal setting, which
has the potential to further reduce treatment costs, main-
tain patient engagement and effectively lead patients to
achieve treatment goals [17]. In some fields, such as post-
stroke rehabilitation, automated and semi-automated
goal setting in VR is showing promise in improving
patient outcomes [39, 40]. The second domain, that of the
clinicians, may be addressed via educational strategies
that help train future clinicians for a more technological
working environment and effectively prepare them for
new and different professional roles. A recent study dem-
strated that a virtual rehabilitation therapy program is
equally effective when supervised by a physical therapist or by a rehabilitation assistant [41]. These results should
raise a red flag for educators of rehabilitation profes-
sionals, suggesting that in a future working environment, a
clinician needs to assume new roles and responsibilities and let go of some of their traditional roles in order to
survive. Embracing the challenges of a new work envi-
ronment can lead clinicians to focus on aspects which
were not previously considered to be a main part of their
role—or to assume new roles altogether. In this environ-
ment, where the technology is more advanced and the
clinicians are ready to assume different professional roles,
the third and perhaps most important domain, that of the
patients themselves, can also evolve. Patients today
may be “technophobic” and apprehensive towards virtual
rehabilitation applications, but effective technology and
a positive approach by a clinician can ameliorate their
view of virtual rehabilitation. Additionally, technological advancements in AI have begun to allow for rapid adap-
tation of the therapy to the current needs of the patient.
Such personalization of the therapy in real-time during
their therapeutic exercises will not only improve out-
comes as mentioned above [29, 30], but it can help the
patient achieve an optimal state of experience, i.e. “flow” [42]. Achieving such a state of increased attentional engagement, cognitive absorption, and mental arousal can tap into a patient’s intrinsic motivators [43], which can make therapy more appetitive than aversive.

To summarize the “yes” side, given the incredible advancement of technologies in recent years, we can safely state that acceptance of VR-based tools in the clinic is already happening and with that a pathway towards automation exists, which has been witnessed in human history many times before. Calls for change in content of the professional practice in light of advancing technology are being raised in other professions such as nursing [44], and while the timeframe for this change is not provided, it is suggested here that it may be sooner than we think.

The “no” side
Rapidly evolving technologies are constantly adding tools to rehabilitation that were not available in the recent past. Clinicians can now immerse their patients in different virtual worlds to reduce pain or anxiety, they can encourage them to move by playing games, they can quantify performance measures that are not easily detectable by the naked eye. However, although automatization has happened in many fields, the field of rehabilitation does not seem to follow the same rate of technological change [10]. The following are several arguments as to why we cannot take clinicians out of this equation and even if it were possible, whether it would be advisable.

If virtual rehabilitation were ever to replace physical rehabilitation a required first step would be to know exactly what it is that we are replacing. Physical rehabilitation can broadly be defined as the process of restoring and regaining physical strength and function [45]. The process often involves contact with various health disciplines, such as physiatrists, physical, occupational, speech and recreation therapists, psychologists, and nurses. Input from some or all of these professionals is typically required to help an individual achieve the highest level of functional independence and quality of life. Replacing physical or cognitive rehabilitation would require clear definition of action plans according to ‘standard of care’ and training software according to a finite number of clinical decision options. And yet defining ‘standard of care’ has often proven to be challenging. We suggest that a main reason for this is the high degree of personalization of the treatment regimen which is required for planning and carrying out rehabilitation interventions. The International Classification of Functioning, Disability and Health [46] calls for accounting for personal and environmental factors as much as one should consider the pathology and impairments associated with a condition.

The physician Sir William Osler stated: ‘it is much more important to know what sort of patient has a disease than what sort of disease a patient has’ [47]. With that, the hallmark of rehabilitation is the ability to individualize a program. As stated in Locsin and Ito, who asked whether robots can replace nurses: “knowing persons more fully as participants in their care is acclaimed best, rather than considering them as objects and recipients of care” (p. 5) [44]. Indeed, the act of providing a clinical rehabilitation service consists of much more than providing motor or cognitive exercises. The clinician, broadly, establishes a therapeutic alliance with each client. The confidence that clients have towards their therapists helps establish a collaborative approach. Therapeutic alliance increases clients’ commitment to their therapy, their satisfaction with interventions, and is directly linked to positive rehabilitation outcomes [48–50]. Rehabilitation professionals, as with any other healthcare professional, also have the duty of offering other services to their clients, above and beyond therapy for specific health issues. These roles include, among others, education to inform the clients, their family, and/or their caregivers about health conditions (etiology, symptoms, prevention measures, etc.). This needs to be proactively initiated by the therapist according to patient- and family-specific context (e.g. education, religion, mentality, relationships) and be done with maximal sensitivity. When needed, clinicians also refer clients to other members of the interprofessional team. If VR is to replace clinicians, it would have to do so not only to provide therapy to clients based on their specific needs, but also replace clinicians in their other roles—a feat which is still far from possible in our current technological state of affairs.

Proponents of technology claim that virtual rehabilitation can increase accessibility to care due to reduced costs and removal of barriers due to geographical distance, and thus promote equality. However, access to technology, even at the basic levels of running a computerized application, would require reading and following instructions, solving basic technological malfunctions (e.g. faulty internet connection) and thus would require a minimal level of physical and cognitive function, or the close assistance of a caregiver [51]. Furthermore, there exists a huge mismatch between the pace at which technology evolves and the pace of generating new evidence and implementing this evidence into clinical practice. The rapid pace of technology advancement inevitably generates an inability of clinicians to keep up with software and hardware versions [28]. If virtual rehabilitation were to replace all clinicians, who would develop the training modules? Who will assure knowledge transfer and skill development? Here, proponents of technology would argue that AI will assume this role. However, it appears that we are still far from that scenario. While there have been tremendous
advances in AI applications over the past years, current algorithms may oversimplify their classification process, to a point that safety may be of concern. For example, researchers have shown that by adding coherent noise to an image, they can trick image-recognition algorithms such that these fail at an alarming rate [52]. Likewise, the Tencent Keen Security Lab was recently able to trick a Tesla car to falsely recognize a stop sign as a speed limit sign, using specifically designed stickers placed on the sign [53]. Much development is still required in terms of AI algorithms before these can be considered as safe and reliable enough to remove the human in the loop by taking the clinician out of the process.

An additional concern for virtual rehabilitation is its lack of flexibility. To this end, the quality of the VR experience, as well as the accuracy of tracking and interpretation of movements, depend on the interaction between human movement, a computer program and an interface, e.g., a controller, a camera, a head-mounted display (HMDs) or a robotic device. Although considerable advances have been made in this respect (e.g. [54, 55]), VR rehabilitation applications are rarely independent of a specific device (e.g. HMD, glove, camera) and the efforts to migrate a VR application from one platform to another are costly [51]. The lack of flexibility of VR applications is demonstrated also when a modification to a VR session is required in order to fit a specific patient’s needs. Although the ability to flexibly modify training parameters is an asset of VR [56], the conflict between overwhelming the therapist with “too many controls” and providing a “one size fits all” solution is still an issue today [28]. We suggest that the fact that the industry has been unable to solve this problem in more than 15 years of research [51] stems from a fundamental issue with the compatibility of virtual rehabilitation with the requirements of the clinical world. Balancing flexibility with ease-of-operation to support effective training may be an insoluble problem, which would make it a limiting factor keeping VR from replacing clinicians.

A final but alarming point is safety: what happens when things go wrong? HMDs, for example, have the advantage of providing 3D, stereoscopic vision, increasing realism and sense of presence. However, a still unsolved issue is the possibility of appearance of symptoms of cybersickness, such as nausea, vertigo and disorientation [57]. Although these side-effects vary by device, recent research demonstrates that across platforms, these symptoms may increase with exposure time [58]. Effects of using a VR device may vary by task, as well. Indeed, walking on a treadmill while viewing a congruent scene through an HMD is associated with greater postural instability, as well as some changes in gait patterns, as compared to walking without an HMD [59]. This suggests that some tasks may not be fully transferrable to a VR environment, and highlights the importance of a clinician in choosing the proper VR rehabilitation application and supervising their performance. Finally, if an emergency occurs which is associated with technology—and this may occur even in healthy users of technology (e.g. [60]), the question of responsibility of the health care provider, VR company or supervising therapist inevitably arises, and this question is far from settled.

To summarize the “no” side, despite the incredible advancement of technologies in recent years, we can safely state that “technologies are only as good as their makers” [61]. The issues with which the virtual rehabilitation community was dealing with more than a decade ago are still relevant today. The question of taking clinicians out of the equation involves a great leap in abilities of technology, which has not occurred over decades of research and application of VR technology in rehabilitation. Even if this change were to happen, it may lead to deterioration in the level of care, to social inequality, and to reduced patient safety. These are unacceptable risks for the rehabilitation field.

**Conclusion**

Technology has been advancing at an exponential rate for many decades (Moore’s Law), hence where we will be in 10–20 years in not yet known. For the rehabilitation field, it is unknown whether we will have a contemporary Luddite rebellion in our future or instead an age of technophilia, which will allow for a rapid adoption of virtual rehabilitation. The points raised in this debate highlight the complexity of the issues surrounding this question. Prior to the debate, 100% of the clinicians, scientists, and technologists in the audience all voted ‘no’. However, a post-debate vote revealed the audience was split in their support for either side. We believe that this is due to the fact that while the current state of affairs clearly supports a “no” (as evidenced by the fact that VR has not replaced clinicians), considering the possibilities, the future state of affairs may suggest a “maybe” (Fig. 1). An example of this can be drawn from recent events surrounding a pandemic that urgently increased the need for telemedicine in order to facilitate treatment delivery in remote areas and reduce disease transmission in densely populated areas. The level of need rose so abruptly that some governments passed policies restructuring how telemedicine could be billed. In the United States, insurance companies made it possible to provide acute care to patients using a combination of telehealth and on-site clinicians [62]. While circumstances surrounding this are extreme, they highlight a compromise that should be considered. Clinicians and technologists should work together with a strong consideration for how environmental,
In the process of technological change, humans are the driving force [61]. Clinical expertise, based on years of research and experience, needs to be an important input in the generation of novel VR solutions such that these will produce meaningful and effective experiences for patients. Furthermore, novel VR rehabilitation applications may not necessarily replace every aspect of the clinician’s role. Instead, clinicians should be encouraged to acknowledge the advantages offered by technology, which may free them of some aspects of the profession and allow development in others. The reality is that while VR may not replace clinicians, under certain circumstances—which involve better technology and increased acceptance from all stakeholders (namely patients, caregivers, clinicians, healthcare and insurance providers)—it may replace some aspects of a clinician’s current job description in upcoming years. Clinicians, like people from other professions, will need to perform in an eco-system where technology is a key player. This will necessarily involve some adaptation in the thought process and decision making, which we are all currently going through. Rehabilitation specialists may benefit from exposure to technology early in their training, which will make them more ready to adopt new tools and expand their toolbox. For technologists, it is clear that any progress should be made in close collaboration with clinicians, patients, caregivers, and healthcare and insurance providers so as to increase availability and usability of the technology. It is essential that technological solutions for rehabilitation are trustworthy in order for them to be useful. What history may tell us, is that careful consideration of these issues and measured progress will allow all stakeholders to be involved in the advancement of the clinical approach to care, which will best serve all involved parties, but first and foremost the patients.

Abbreviations
AI: Artificial intelligence; fNIRS: Functional near-infrared spectroscopy; HMD: Head-mounted display; ICVR: International Conference on Virtual Rehabilitation; VR: Virtual reality.

Acknowledgements
We would like to thank Prof. Gerry Fluet for helping to organize and then moderating the debate and Prof. Patrice L. (Tamar) Weiss for her thoughtful
comments and critical review of early versions of this manuscript. Special thanks to Eric Newby for help with the figure.

**Authors’ contribution**
All authors participated at the debate held at ICVR 2019 and WGW helped organize it. TK and AVL drafted a first version of the manuscript. WGW and PA edited and revised the manuscript. All authors read and approved the final manuscript.

**Funding**
No funding source is to be declared.

**Availability of data and materials**
Not applicable.

**Ethics approval and consent to participate**
Not applicable.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare that they have no competing interests.

**Author details**
1. Department of Physical Therapy, University of Haifa, Haifa, Israel.
2. Pediatric Rehabilitation Department, Sheba Medical Center, Ramat Gan, Israel.
3. Department of Physical Therapy, Steinhardt School of Culture Education and Human Development, New York University, New York, NY, USA.
4. School of Physical & Occupational Therapy, McGill University, Montreal, Canada.
5. CRIR - Centre de Recherche Interdisciplinaire en réadaptation, Montreal, Canada.
6. Neuromotor Sciences Program, Department of Health and Rehabilitation Sciences, Temple University, Philadelphia, PA, USA.

Received: 10 April 2020   Accepted: 7 October 2020
Published online: 09 December 2020

**References**
1. Lanier J. Dawn of the new everything: encounters with reality and virtual reality. New York: Henry Holt and Company; 2017.
2. Virtual Reality. Merriam-Webster.com Dict. Merriam-Webster.
3. O’Sullivan SB, Schmitz TJ, Fulk G. Physical rehabilitation. Philadelphia: F.A. Davis; 2019.
4. Burdea G. Keynote address: Virtual rehabilitation-benefits and challenges. in: Virtual reality: feasibility of implementation in rehabilitation: moving the field forward. Phys Ther. 2015;95:441–8.
5. Weiss PL (Tamar), Keshner EA, Levin MF. Virtual reality for physical and motor rehabilitation. New York: Springer; 2014.
6. Proffitt R, Lange B. Considerations in the efficacy and effectiveness of virtual reality interventions for stroke rehabilitation: moving the field forward. Phys Ther. 2015;95:415–25.
7. Buttolo P, Oboe R, Hannaford B. Architectures for shared haptic virtual environments. Comput Graph. 1997;21:421–9.
8. Marx K. Capital: volume one. New York: Courier Dover Publications; 2019.
9. Kurzweil R. The singularity is near: when humans transcend biology. New York: Penguin; 2005.
10. Ford M. Rise of the robots: technology and the threat of a jobless future. New York: Basic Books; 2015.
11. Levin MF, Weiss PL, Keshner EA. Emergence of virtual reality as a tool for upper limb rehabilitation: incorporation of motor control and motor learning principles. Phys Ther. 2015;95:415–25.
12. Keshner EA, Fung J. The quest to apply VR technology to rehabilitation: tribulations and treasures. J Vestib Res. 2017;27:1–5.
13. Porras DC, Siemonsma P, Inzelberg R, Zeilig G, Plotnik M. Advantages of virtual reality in the rehabilitation of balance and gait: systematic review. Neurology. 2018;90:1017–25.
14. Rizzo AA, Schultheis M, Kerns KA, Mateer C. Analysis of assets for virtual reality applications in neuropsychology. Neuropsychol Rehabil. 2004;14:207–39.
15. Rizzo AS, Shilling R. Clinical virtual reality tools to advance the prevention, assessment, and treatment of PTSD. Eur J Psychotraumatol. 2017;8:1414560.
16. Howard MC. A meta-analysis and systematic literature review of virtual reality rehabilitation programs: Comput Hum Behav. 2017;70:317–27.
17. Vaughn N, Gabrys B, Dubey VN. An overview of self-adaptive technologies within virtual reality training. Comput Sci Rev. 2016;22:65–87.
18. Schroder J, van Creikinge T, Embrecht S, Celis X, Schuppen JV, Truken S, et al. Combining the benefits of tele-rehabilitation and virtual reality-based balance training: a systematic review on feasibility and effectiveness. Disabil Rehabil Assist Technol. 2019;14:2–11.
19. Cramer SC, Dodakian L, Lee Y, See J, Augsburger R, McKenzie A, et al. Efficacy of home-based telerehabilitation vs in-clinic therapy for adults after stroke: a randomized clinical trial. JAMA Neurol. 2019;76:1079–87.
20. Gandolfi M, Geroin C, Dimitrova E, Boldrini P, Waldner A, Bonadiman S, et al. Virtual reality telerehabilitation for postural instability in Parkinson’s disease: a multicenter, single-blind, randomized, controlled trial [Internet]. BioMed Res. Int. 2017 [cited 2019 Oct 17]. Available from: https://www.hindawi.com/journals/bmri/2017/7796286/abs/.
21. Mirelman A, Rochester L, Maidan I, Del Din S, Alcock L, Nieuwhof F, et al. Addition of a non-immersive virtual reality component to treadmill training to reduce fall risk in older adults (V-TIME): a randomised controlled trial. The Lancet. 2016;388:1170–82.
22. Llorrens R, Noé E, Colomer C, Alcaraz M. Effectiveness, usability, and cost-benefit of a virtual reality-based telerehabilitation program for balance recovery after stroke: a randomized controlled trial. Arch Phys Med Rehabil. 2015;96:418-425.e2.
23. WHO [ Life expectancy [Internet]. WHO. World Health Organization; [cited 2020 Feb 28]. Available from: https://www.who.int/gho/mortality_burden_disease/life_tables/situation_trends_text/en/.
24. Crotty M, Whitehead C, Miller M, Gray S. Patient and caregiver outcomes 12 months after home-based therapy for hip fracture: a randomized controlled trial. Arch Phys Med Rehabil. 2003;84:1237–9.
25. Cook RJ, Berg K, Lee K-A, Poss JW, Hirdes JP. Stolee P. Rehabilitation in home care is associated with functional improvement and preferred discharge. Arch Phys Med Rehabil. 2013;94:1038–47.
26. Armstrong JJ, Sims-Gould J, Stolee P. Allocation of rehabilitation services for older adults in the ontario home care system. Physiother Can. 2016;68:346–54.
27. Frey CB, Osborne MA. The future of employment: how susceptible are jobs to computerisation? Technol Forecast Soc Change. 2013;114:234–80.
28. Glegg SMN, Levac DE. Barriers, facilitators and interventions to support virtual reality implementation in rehabilitation: a scoping review. Pm&R. 2018;10(1237–1251):e1.
29. Levy F, Murnane RJ. The new division of labor: how computers are creating the next job market. Princeton: Princeton University Press; 2004.
30. Simhambhatla R, Okiah K, Kuchkula S, Slater R. Self-driving cars: evaluation of deep learning techniques for object detection in different driving conditions. SMU Data Sci Rev [Internet]. 2019;2. Available from: https://scholar.smu.edu/datasciencereview/vol2/iss1/23.
31. Teoh ER, Kidd DG. Rage against the machine? Google’s self-driving cars versus human drivers. J Saf Res. 2017;63:57–60.
32. Jiang F, Jiang Y, Zh H, Dong Y, Li H, Ma S, et al. Artificial intelligence in healthcare: past, present and future. Stroke Vasc Neurol. 2017;2:230–43.
33. Markus LA, Willems KE, Maruna CC, Schmitz CL, Pellino TA, Wish JR, et al. Virtual reality: feasibility of implementation in a regional burn center. Burns. 2009;35:967–9.
34. Gonzalez-Franco M, Lanier J. Model of illusions and virtual reality. Front Psychol [Internet]. 2017 [cited 2020 Feb 28]. Available from: https://www.frontiersin.org/articles/https://doi.org/10.3389/fpsyg.2017.01125/full.
35. Putze F, Herff C, Tremmel C, Schultz T, Krusinski DJ. Decoding mental workload in virtual environments: a FNIRS Study using an immersive n-back Task. 2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society EMBC. 2019. p. 3103–6.
36. Rogers JM, Jensen J, Valderama JT, Johnstone SJ, Wilson PH. Single-channel EEG measurement of engagement in virtual rehabilitation: a validation study. Virtual Real. 2020. https://doi.org/10.1007/s11265-020-00460-8.
37. Landowska A, Roberts D, Euchus P, Barret A. Within- and between-session prefrontal cortex response to virtual reality exposure therapy for...
acrophobia. Front Hum Neurosci [Internet]. 2018 [cited 2019 Oct 8];12. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6221970/.

38. Crivelli D, Fronda G, Venturella I, Balconi M. Supporting mindfulness practices with brain-sensing devices. Cogn Electrophysiol Evid Mindfulness. 2019;10:301–11.

39. Hocine N, Gouaich A, Cerri SA, Mottet D, Froger J, Laffont I. Adaptation in serious games for upper-limb rehabilitation: an approach to improve training outcomes. User Model User-Adapt Interact. 2015;25:65–98.

40. da Silva Cameirão M, Bermudez i Badia S, Duarte E, Verschure PF. Virtual reality based rehabilitation speeds up functional recovery of the upper extremities after stroke: a randomized controlled pilot study in the acute phase of stroke using the rehabilitation gaming system. Restor Neurol Neurosci. 2011;29:287–98.

41. Cannell J, Jovic E, Rathjen A, Lane K, Tyson AM, Callisaya ML, et al. The efficacy of interactive, motion capture-based rehabilitation on functional outcomes in an inpatient stroke population: a randomized controlled trial. Clin Rehabil. 2018;32:191–200.

42. Csikszentmihalyi M. The flow experience and its significance for human psychology. In: Csikszentmihalyi M, Csikszentmihalyi IS, editors. Optimal experience: psychological studies of flow in consciousness. Cambridge: Cambridge University Press; 1988. p. 15–35.

43. Lowry PB, Gaskin J, Twyman N, Hammer B, Roberts T. Taking ‘fun and games’ seriously: proposing the hedonic-motivation system adoption model (HMSAM). J Assoc Inf Syst. 2012;14:617–71.

44. Locien RC, Ito H. Can humanoid nurse robots replace human nurses? J ET Nurs. 2018;5:1.

45. World Health Organization. World report on disability 2011. Geneva: World Health Organization; 2011.

46. World Health Organization. International classification of functioning, disability and health: ICF. Geneva: World Health Organization; 2001.

47. John M. From Osler to the cone technique. HSR Proc Intensive Care Cardiovasc Anesth. 2013;5:57–8.

48. Hall AM, Ferreira PH, Maher CG, Latimer J, Ferreira ML. The influence of the therapist-patient relationship on treatment outcome in physical rehabilitation: a systematic review. Phys Ther. 2010;90:1099–110.

49. Del Baño-Aledo MF, Medina-Mirapeix F, Escolar-Reina P, Montilla-Herrador J, Collins SM. Relevant patient perceptions and experiences for evaluating quality of interaction with physiotherapists during outpatient rehabilitation: a qualitative study. Physiotherapy. 2014;100:73–9.

50. Moore AJ, Holden MA, Foster NE, Jinks C. Therapeutic alliance facilitates adherence to physiotherapy-led exercise and physical activity for older adults with knee pain: a longitudinal qualitative study. J Physiother. 2020;66:45–53.

51. Rizzo AS, Kim GJ. A SWOT analysis of the field of virtual reality rehabilitation and therapy. Presence Teleoperators Virtual Environ. 2005;14:119–46.

52. Heaven D. Why deep-learning AIs are so easy to fool. Nature. 2019;574:163.

53. Lindvall N. Tencent keen security lab proves Tesla Autopilots can be tricked [Internet]. Tencent Keen Secur. Lab proves Tesla Autopilots can be tricked. [cited 2020 Feb 18]. Available from: https://panda.ly.com/tencent-keen-security-lab-proves-tesla-autopilot-can-be-tricked/.

54. Lubetzky AI, Wang Z, Krasovsky T. Head mounted displays for capturing head kinematics in postural tasks. J Biomch. 2019;86:175–82.

55. Marchetto J, Wright WG. The validity of an oculus rift to assess postural changes during balance tasks. Hum Factors. 2019;61(8):1340–52.

56. Weiss PL, Kizony R, Feintuch U, Katz N. Virtual reality in neurorehabilitation. Textb Neural Repair Rehabil. 2006;51:182–97.

57. Rebenitsch L, Owen C. Review on cybersickness in applications and visual displays. Virtual Real. 2016;20:101–25.

58. Duzmatiska N, Strojny P, Strojny A. Can simulator sickness be avoided? A review on temporal aspects of simulator sickness. Front Psychol. 2018. https://doi.org/10.3389/fpsyg.2018.02132/full.

59. Chan ZYS, MacPhail AJC, Au IPh, Zhang JH, Lam BWF, Ferber R, et al. Walking with head-mounted virtual and augmented reality devices: effects on position control and gait biomechanics. PLoS ONE [Internet]. 2019 [cited 2020 Feb 24];14. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6892508/.

60. | Nintendo - Customer Service | Wii Precautions Information [Internet]. [cited 2020 Aug 25]. Available from: https://www.nintendo.com/consumer/wisafety.jsp.

61. Wajcman J. Automation: is it really different this time? Br J Sociol. 2017;68:119–27.

62. Miliard M. Bipartisan bills in House, Senate seek to increase telehealth in nursing homes [Internet]. Healthc. IT News. 2020 [cited 2020 Aug 23]. Available from: https://www.healthcareitnews.com/news/bipartisan-bills-house-senate-seek-increase-telehealth-nursing-homes.

Publisher’s Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.