Chapter 11
Current and Future Trends for VR and Motor Rehabilitation

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Objective To summarize the current state of the art in applications of VR to motor rehabilitation and to set the stage for developments over the next 5–10 years.

11.1 Introduction

The faithful reader of this volume will have learned of some of the major issues that are important to consider when using virtual reality (VR) for motor rehabilitation. In this volume the neurophysiological principles underlying VR interventions for motor rehabilitation are discussed, including neuroplasticity, motor learning, sensorimotor integration, vision, and perception. In addition, the validity of virtual environments for motor rehabilitation is presented. This volume also summarizes the current state of knowledge regarding the effectiveness of VR interventions for improving rehabilitation outcomes for conditions such as stroke, degenerative diseases, vestibular pathology,

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and cerebral palsy. The objective of this final chapter is to briefly summarize the current state of the art and to set the stage for future developments.

We begin with a review of the major technological "breakthroughs" (1986–1995; 1996–2005; 2006-present) that led to the use of VR for motor rehabilitation. We then present a summary overview of the evidence for the effectiveness of VR for motor rehabilitation. Finally, we present the results of a "Force Field" analysis to identify the major factors that "drive" or "restrain" the use of VR technologies in motor rehabilitation. This analysis facilitates a look into the future regarding developments that we anticipate will occur over the next 5–10 years.

11.2 Major Technological "Breakthroughs" that Led to the Use of VR for Motor Rehabilitation

Table 11.1 lists some of the key technological developments that influenced the use of VR technology for motor rehabilitation since its first adoption (1986–1995), through a period of development and initial implementation (1996–2005) and until the present stage of refinement and meaningful clinical research (2006–2013). The most characteristic features of the early technologies were their large size, high cost, and limited accuracy. These systems led to several pioneering motor rehabilitation applications (Deutsch et al., 2002; Holden, 2005; Jack et al., 2001; Krebs, Hogan, Aisen, & Volpe, 1998; Subramanian et al., 2007) while their clinical relevance was still uncertain due to very limited clinical access to either hardware or software. There was no real grassroots clinical perception of the need for VR based interventions during this period.

The key changes that took place over the period between 1996 and 2005 include the emergence of platforms such as Superscape World Builder and OpenGL that supported easier development and distribution of desktop VR applications. VR began to be directed to specific rehabilitation applications although the focus was clearly research-oriented since only funded groups could support the creation of customized rehabilitation prototypes (e.g., Virtual Classroom, Virtual Office (Rizzo et al., 2002); Rutgers Arm (Burdea et al., 2010)). During this period, the first clinically oriented commercial VR systems emerged such as IREX (for motor rehabilitation) and Virtually Better (for treatment of phobias).

The period between 2006 and 2013 has seen development and commercialization of both high-end (e.g., CAREN) and low-cost VR systems. The latter were off-the-shelf (e.g., Nintendo Wii, Sony EyeToy) products that did not target rehabilitation but were nevertheless widely used by clinicians because of their accessibility and low cost. More recently, and in particular since 2010, a number of low-cost VR systems designed for and targeting rehabilitation (e.g., SeeMe, Timocco, Kinect) have become available. A variety of rehabilitation-oriented desktop gaming programs that implement VR properties (e.g., feedback, documentation, motivation) are also increasingly available. Still more recently, the increasing accessibility of embedded ambient technologies (e.g., inexpensive cameras, proximity sensors, wearable computing) that support the monitoring of motor and cognitive functioning under real-world conditions has extended VR-based interventions beyond the clinical setting.

Table 11.1 Key technological developments that influenced the use of VR technology in rehabilitation

Period	Key technology developments	Issues for rehabilitation
1986–1995	• Mainstream VR technologies (e.g., Head Mounted Displays); large installations (e.g., CAVE) • Initial development work in research labs that became the impetus for eventual rehabilitation prototypes (e.g., Myron Krueger's videoplace (Weiss, Sveistrup, Rand, & Kizony, 2009))	• Need for more precise, lower weight and lower cost hardware in order to ensure relevance and feasibility for rehabilitation (Rizzo, Buckwalter, & Neumann, 1997) • Need to bridge gaps in VR between goals of basic researchers, applied researchers, and developers
1996–2005	• Platforms such as Superscape World Builder and OpenGL support easier development and distribution of desktop VR applications • VR begins to be accessible for rehabilitation settings (e.g., GestureTek GX Software Developer's Kit) • Customized rehabilitation prototypes (e.g., Virtual Classroom, Virtual Office (Rizzo et al., 2000); Rutgers Arm (Burdea, Cioi, Martin, Fensterheim, & Holenski, 2010)) • Emergence of commercial clinically oriented VR systems (e.g., IREX, Virtually Better)	• System development more specific for rehabilitation (Keshner & Kenyon, 2004) • Proof of concept studies (Viau, Feldman, Mcfadyen, & Levin, 2004) • Reliability, validity, transfer of training studies • Literature reviews on specific rehabilitation applications (e.g., for VR-based motor rehabilitation by Sveistrup, 2004)
2006–2013	• Development of both high-end (e.g., CAREN; Knaut, Subramanian, McFadyen, Bourbonnais, & Levin, 2009; Subramanian et al., 2007) and low-end VR systems • Development and commercialization of numerous low-cost VR systems, some of which are off-the-shelf (e.g., Nintendo Wii, Sony EyeToy) for commercial use not targeting rehabilitation • Commercialization of numerous low-cost VR systems designed for and targeting rehabilitation (e.g., SeeMe, Timocco) • Increasing availability of embedded ambient VR technologies to monitor real-world activity	• Using VR as a paradigm for posing questions of relevance to motor control and motor learning (such as the effectiveness of feedback delivery for motor improvement (e.g., Keshner, Kenyon, Dhaher, & Streepey, 2005)) • Validation of movement kinematics (upper limb) used in VR (see Chap. 6) • Numerous studies showing how VR technology can address important rehabilitation questions about treatment effectiveness; these have been mostly small sample single-site clinical studies and very few Randomized Controlled Trials (e.g., Saposnik & Levin, 2011) • Exploration of novel clinical intervention paradigms feasible only with VR-supported technology (e.g., tele-rehabilitation applications) • Mixing of technologies to support augmented reality and "Living Lab" approaches
Future	• Proliferation of low-cost, turn-key VR systems with increasing clinical validity and reliability (e.g., more precise markerless non-encumbering motion tracking) • Increasing focus on VR applications supporting a personalized medicine approach	• Need for large, multi-center effectiveness studies that demonstrate capacity of VR to improve motor rehabilitation

11.3 Tools to Identify Technology Adoption

A number of different tools have been used to identify the readiness of a given technology for adoption. The most frequently used tool is the SWOT matrix, a method that was classically used to support strategic project planning, most often applied to business. Its origins are somewhat difficult to discern with attribution variously given to Harvard academics in the 1960s (King, 2004), Ansoff in 1987 (Turner, 2002) and contributions by Weihrich in 1982, Dealtry in 1992 and Wheelan and Hunger in 1998 (Koch, 2000). The initials stand for, respectively, *S*trengths, *W*eaknesses, *O*pportunities, and *T*hreats. A SWOT analysis is typically initiated by specifying the objective of a particular product or field of study and then identifying the internal and external factors that support or detract from its achievement. Rizzo and Kim (2005) carried out a SWOT analysis of the field of applications of VR to rehabilitation. They identified key factors that facilitated the initial growth of clinical and educational applications (strengths) and ensured continued development (opportunities). They further identified weaknesses that limited the field at that point in time as well as threats that warranted recognition in order to minimize their effect. The Rizzo and Kim (2005) SWOT matrix was based primarily on the literature and reflected input primarily from the research and clinical communities. Viewpoints of other stakeholders, in particular, direct users and funders were less well represented. Many of the opportunities (e.g., gaming industry development of special education-oriented applications) that were identified in this analysis have come to fruition, whereas some of the threats (e.g., unrealistic expectations of a given technology's capacity) continue to be of concern.

Gartner's "Hype Cycle" is another tool that has been used to identify the readiness of technologies for adoption (Rizzo & Kim, 2005; Weiss, 2005). The location of emerging technologies on the Hype Cycle helps a clinician assess its suitability for immediate adoption if it has reached a stable phase of development (i.e., a "plateau"). In contrast, in the case of less mature technologies, where performance expectations may be unrealistic (i.e., either too much or too little "hype"), a clinician may be advised that the usage of such technologies in clinical settings may require more financial and time resources than available. Most technologies require a 3–5 year cycle between their first emergence and their readiness for use in rehabilitation. One recent exception is the iPad that almost entirely skipped the stages from emergence to adoption.

11.4 Force Field Analysis

A Force-Field analysis is a less frequently considered tool for assessing the readiness of technology for adoption. As illustrated schematically in Fig. 11.1, a "Force Field" analysis provides a framework for examining the factors (forces) that influence the achievement of a designated objective. It was originally used in the fields of social science, psychology, and social psychology (Greer & Lei, 2012).

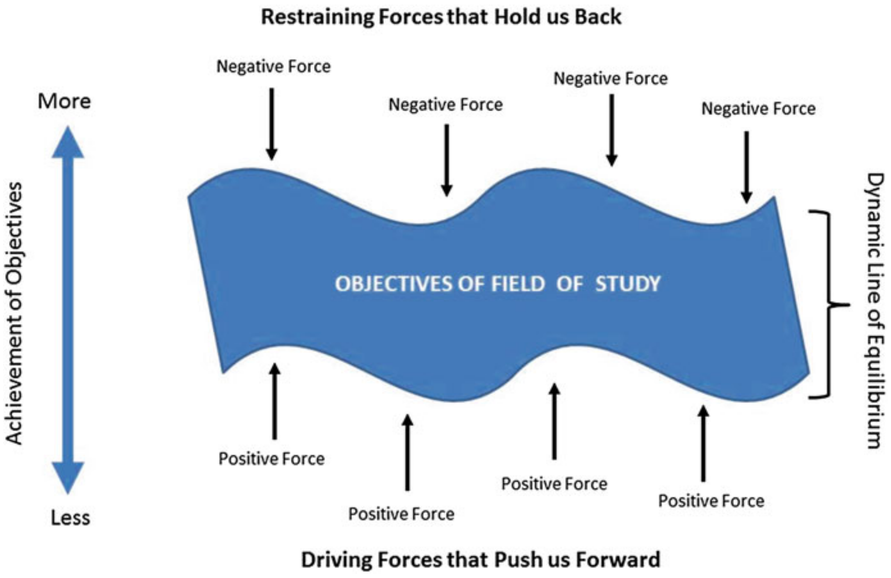

Fig. 11.1 Schema to illustrate the balance in a Force Field between the driving forces that push one forward towards the objectives of a given field of study and restraining forces that push one back from reaching these objectives

It identifies the forces that are causing a project to move towards achieving its goal (driving forces) or those that are causing it to become more distant from its goal (restraining forces). Developed by Lewin in 1943, it may be used to present the recommendations that we perceive as helping the field of virtual rehabilitation to move forward and to identify issues that need to be addressed in order to prevent the field from moving backwards.

A key advantage of a "Force Field" analysis is that it is dynamic with the location of the "push forward"/"hold-back" line susceptible to change as a project develops. This is shown in Fig. 11.1 as the thick, wavy grey band and referred to as the "Dynamic Line of Equilibrium". Thus, a given field may start to progress in accordance with objectives based on the identification of driving and restraining forces determined from reviews of the literature and meta-analyses. Changes in the location of the Line of Equilibrium may occur after reconsideration of the identity and potency of the driving forces and restraining forces on an ongoing basis.

Another advantage of a "Force Field" analysis is that it helps to distinguish among the sometimes overwhelming list of factors that are currently having the greatest influence on the achievement of objectives related to a given field of study, discipline, or project. Thus, the stakeholders[1] may use the results of this analysis as

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[1] Stakeholders include all users of a given technology (both primary and secondary) as well as developers, distributors, funders, and researchers.

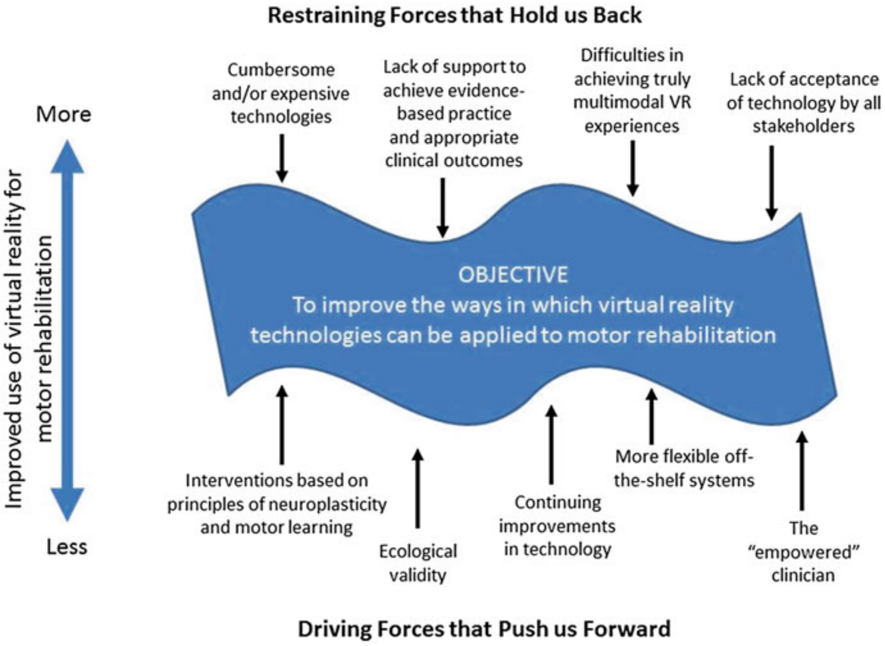

Fig. 11.2 Force Field analysis of the application of virtual reality technologies for motor rehabilitation

a tool to examine the major factors that affect performance, by developing a list of the primary driving forces that promote the achievement of goals and by identifying/resolving the key restraining forces that detract from these goals.

Figure 11.2 shows the Force Field analysis for the application of VR technologies for motor rehabilitation. Based on the reviews presented in the chapters in this volume, the key restraining forces that appear to "hold back" and the key driving forces that appear to "push forward" VR-base motor rehabilitation have been identified.

11.5 Key Driving Forces as Identified in this Volume

1. Improvements in *interventions based on principles of neuroplasticity and motor learning*. Examples include:
    - Chapter 2 (Cheung, Tunik, Adamovich, and Boyd) discusses how VR induces neuroplastic changes through repetitive practice and how this can be tracked by a variety of technologies during recovery from brain injury.
    - Chapter 3 (Levac and Sveistrup) reviews many VR applications that are constructed on the basis of the principles of neuroplasticity and motor learning.
    - Chapter 7 (Merians and Fluet) discusses how computer algorithms can use decision rules to progress the degree of difficulty of tasks in VR.

2. *Ecological validity*. Focus on new techniques for creating customized simulations based on specific needs of the client and interests that support functionality versus previous limited approaches (Riva et al., 2009). Examples of this include:

    - Chapter 4 (Kenyon and Ellis) discusses how the actual impact of the properties of a VR environment on visual-motor processing can be applied to future development of VR systems and environments.
    - Chapter 5 (Wright, Creem-Regehr, Warren, Anson, Jeka, and Keshner) discusses the selection of augmented rather than VR applications depending on the needs of the individual performer.
    - Chapter 6 (Levin, Deutsch, Kafri, and Liebermann) discusses how tasks in VR for the upper limb may be calibrated to the reaching space of the individual in order that they appear to be reachable. Another example is that exercise performed in VR creates the same stresses on the cardiovascular system as in real-world exercise environments.
    - Chapter 9 (Lamontagne, Keshner, Bugnariu, and Fung) discusses individual differences with aging and how optic flow and sensory conflict properties can be adjusted to elicit the desired behavior.

3. *Continuing improvements in technology* (e.g., more 3D systems are becoming available with improved resolution). Examples include:

    - Chapter 5 (Wright, Creem-Regehr, Warren, Anson, Jeka, and Keshner) discusses how advances in head mounted displays and more realistic computer generated images allow for the provision of augmented visual information to improve gait.
    - Chapter 6 (Levin, Deutsch, Kafri, and Liebermann) describes how reaching and grasping movements in VR can be improved by providing haptic feedback.
    - Chapters 5 (Wright, Creem-Regehr, Warren, Anson, Jeka, and Keshner) and Chap. 9 (Lamontagne, Keshner, Bugnariu, and Fung) discuss how we can capture and potentially modify cortical processing by presenting realistic, multisensory conflicts that engage the performer in both planning and performance of a motor task.

4. *More flexible off-the-shelf systems* (e.g., availability of Kinect Software Developer's Kit versus the previous non-accessibility to rehabilitation users).

    - Chapter 6 (Levin Deutsch, Kafri, and Liebermann) discusses the validity of the movements made by the user of commercially available systems compared to VR applications developed specifically for rehabilitation.
    - Chapter 10 (Green and Wilson) presents some of these systems for pediatric interventions.

5. *The "empowered" clinician*. Clinicians are more aware of the literature and more able to discern which technologies merit adoption and which have not yet reached the Hype cycle "plateau". All of the chapters in this volume provide considerable evidence about the clinical use of VR applications for motor rehabilitation. A recent review (e.g., Saposnik & Levin, 2011) summarizes the evidence.

    - Chapter 8 (Mirelman, Deutsch, and Hausdorff) and Chap. 9 (Green and Wilson) discuss the impact of VR tools on clinical practice.

11.6 Key Restraining Forces as Identified in this Volume

1. *Cumbersome and expensive equipment* (e.g., lack of fidelity). Examples include:
    - Chapter 6 (Levin, Deutsch, Kafri, and Liebermann) discusses several significant limitations that this technology has for rehabilitation. Discussed here are the weight and limited field of view available in HMDs, low-resolution motion tracking, size of devices that limit accurate hand and finger movement, and the lack of haptic feedback for collision detection and knowledge of results.
    - Chapters 4 (Kenyon and Ellis), Chap. 5 (Wright, Creem-Regehr, Warren, Anson, Jeka, and Keshner), and Chap. 9 (Lamontagne, Keshner, Bugnariu, and Fung) focus on the technological demands that require both engineering and computer skills and limit accessibility and maintenance by clinicians in the clinical environment.

2. *Lack of "strong" research design and rigorous measurement* and selection of *appropriate clinical outcomes* that can attest to the effectiveness of an intervention to evaluate clinical effectiveness of VR-based motor rehabilitation interventions. Although this may be related to the difficulty in obtaining funding, this issue limits the undertaking of large randomized controlled trials as well as the continuing development of technology (the system often changes before it has been fully evaluated). Examples include:
    - Chapter 2 (Cheung, Tunik, Adamovich, and Boyd) and Chap. 9 (Lamontagne, Keshner, Bugnariu, and Fung) discuss issues related to the specificity of the data collected, namely that it is dependent on additional technologies that are not always available or have not yet been correlated with the behaviors observed in the virtual environment. For example, measurement of changes in movement patterns requires access to high-resolution motion tracking technology.
    - Chapter 4 (Kenyon and Ellis) and Chap. 5 (Wright, Creem-Regehr, Warren, Anson, Jeka, and Keshner) discuss how VR impacts visual perception, which is inherently variable. Added to the variability found within clinical populations, this can weaken generalizations about the effectiveness of any intervention.

3. *Difficulties in achieving truly multimodal VR experiences*. Given the limitations of technology, it is not possible to provide clients with experiences in virtual rehabilitation that are truly reminiscent of the actual physical requirements e.g., true haptic feedback, realistic navigation while performing tasks. Examples include:
    - Chapter 6 (Levin, Deutsch, Kafri, and Liebermann) discusses applications aimed at upper limb rehabilitation that do not identify when motor compensations occur.
    - Chapter 3 (Levac and Sveistrup) discusses the lack of consistent and modifiable provision of feedback to the user in commercial applications.

4. *Lack of acceptance of technology* by some stakeholders due to insufficient familiarity with technology, cost, or technical barriers. Although not referred to directly in the chapters of this volume, Kizony, Weiss, and Rand provide related material about the acceptability of technology in their chapter in Volume 4 of this series.

11.7 Conclusion

There is a French expression “plus ça change, plus c’est la même chose” meaning the more things change, the more they remain the same. That is, many of the phenomena that we observe as new in our lives today have also been observed in the past. This expression is very applicable to many of the positive and negative “forces” that drive or constrain technology usage for motor rehabilitation. It is interesting to recall the following statement that was reported in the London Times in 1834 about the then new technology, the stethoscope:

> That it will ever come into general use, notwithstanding its value, is extremely doubtful; because its beneficial application requires much time and gives a good bit of trouble both to the patient and the practitioner; because its hue and character are foreign and opposed to all our habits and associations. Clinicians will not take kindly to accepting changes that are detrimental to existing working processes unless there are significant or proven benefits. (http://www.futurehealthit.com/2006/01/stethoscope.html).

A similar statement could have just as easily been made in more modern times about hundreds of invented technologies. Novel devices, techniques and programs will continue to challenge the abilities of both researchers to investigate them and clinicians to adopt them. Yet the example of the positive impact of the stethoscope on health care, as well as numerous other innovations, has been echoed throughout the chapters of this volume. Despite its acknowledged limitations, technology innovation in rehabilitation is clearly here to stay. Its success for rehabilitation will likely be the result of continuing careful analyses and reviews made by researchers and clinicians, notwithstanding a healthy dose of scepticism.

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