Chapter 3
Motor Learning and Virtual Reality

Danielle E. Levac and Heidi Sveistrup

Objective To present four fundamental variables influencing client motor learning and describe how attributes of VR technologies provide opportunities to target these variables. To discuss how clinicians can harness these attributes to help clients transfer and generalize the learning achieved in VR-based therapy to better performance in the physical environment.

3.1 Introduction

The primary goal of physical rehabilitation is to help the individual return to functional performance of daily life activities through acquisition of new motor skills and recovery or compensation of lost motor skills. To do so, clinicians seek to promote *motor learning*, defined as "a set of internal processes associated with practice or experience leading to relatively permanent changes in the capability for a motor skill" (Schmidt & Lee, 2011, p. 327). Motor learning is emphasized when clinicians organize practice conditions in ways that promote long-term retention, transfer, and generalization of the skills learned in therapy to their implementation within real-world activities (Wishart, Lee, Ezekiel, Marley, & Lehto, 2000). Decisions about

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D.E. Levac (✉)
School of Rehabilitation Sciences, Faculty of Health Sciences, University of Ottawa,
200 Lees Ave (Room A120), Ottawa, ON, Canada, K1N 6N5
e-mail: dleva2@uottawa.ca

H. Sveistrup
School of Rehabilitation Sciences, Faculty of Health Sciences, University of Ottawa,
451 Smyth (Room 3028), Ottawa, ON, Canada, K1H 8M5
e-mail: hsveist@uottawa.ca

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Table 3.1 Summary of attributes of virtual reality that align with motor learning variables

Motor learning variable	Attributes
Observational learning	Users can view their own image interacting with virtual objects in the VE
	Users can view an avatar mirroring their movements
	Users can view a virtual teacher demonstrating optimal movement patterns
	VEs can facilitate mental practice or motor imagery
Practice: amount, task specificity, and meaning	Potential for abundant repetition of practice trials
	Ecologically valid VEs enhance task specificity of practice
	Train movements that are identical to those required in real-life tasks
	Options to individualize to different challenge levels
	Enriched environment
	Goal-oriented tasks
	Familiarity of commercially available VR gaming systems
Augmented Feedback	Precise and consistent
	Auditory, visual, or tactile
	Knowledge of performance
	Knowledge of results
	Positive motivational feedback
Motivation	Novelty of VR technology
	Gaming features
	Feedback
	Goal-oriented tasks
	Capacity to individualize treatment options
	Users can select tasks
	Competition against other players
	Match between cognitive and physical effort

the way practice conditions are organized within therapy sessions involve motor learning variables: for example; the type of task to be practiced, the order in which the tasks are practiced, and the type of feedback provided (Levac, Missiuna, Wishart, DeMatteo, & Wright, 2011). Consideration of these motor learning variables is recommended within rehabilitation (Wishart et al., 2000; Zwicker & Harris, 2009; Schmidt 1991) and is supported by the link between motor learning and neuroplasticity (see Chap. 2) (Kleim & Jones, 2008; Krakauer, 2006; Ploughman, 2002).

The scientific rationale for use of virtual reality (VR) technology within rehabilitation can be found in the field of motor learning (Holden, 2005). Therapeutic interventions using VR systems and delivered in virtual environments (VEs) are attractive rehabilitation options because the motor learning variables underlying experience-dependent neuroplasticity are inherent attributes of VR systems (Levin, 2011). The primary objective of this chapter is to summarize the attributes of VR technology that align with four fundamental motor learning variables: practice, augmented feedback, motivation, and observational learning (Table 3.1). We discuss the potential for training in VEs to promote transfer and generalization of learning to the physical environment and describe the features of VR technologies that may impede motor learning processes in clients recovering from central nervous system (CNS) injury.

Secondly, we focus on clinical implications of VR tool implementation in rehabilitation by providing recommendations for clinicians interested in emphasizing motor learning within VR-based therapy (Levac & Galvin, 2013). Finally, the chapter highlights directions for research to further evaluate how learning in VR-based therapy can transfer and generalize to actions performed in the physical environment.

3.2 Motor Learning Variables

3.2.1 Practice

Animal and human studies provide substantial evidence of the importance of abundant, intensive, salient practice for motor learning and neuroplastic change (Adamovich, August, Merians, & Tunik, 2009; Adamovich, Fluet, Tunik, & Merians, 2009; Schmidt & Lee, 2011). The use of VR technologies enables clinicians to provide these practice conditions to individuals undergoing rehabilitation (Adamovich, August, et al., 2009; Adamovich, Fluet, et al., 2009; Levin, 2011). In particular, VR allows for plentiful, task-specific, and meaningful practice opportunities.

3.2.1.1 Amount of Practice

Amount of practice is a fundamental factor supporting motor learning. A greater number of practice trials will improve learning, although the law of practice states that this effect is most evident in early stages of learning and decreases over time (Schmidt & Lee, 2011). Intensity of practice is another key factor driving neuroplastic change in rehabilitation (Kleim & Jones, 2008). Evidence from animal models shows that abundant, intensive practice is needed in the early stages of recovery from a brain injury (Krakauer, Carmichael, Corbett, & Wittenberg, 2012). Indeed, individuals recovering from stroke require a greater number of repetitions as compared to healthy individuals in order to achieve improvements in movement outcomes (Cirstea, Ptito, & Levin, 2003). The flexibility of many VR applications implies that training in meaningful, enriched environments can be provided earlier in recovery from CNS injury than conventional exercises, maximizing the potential to target neuroplastic processes and providing the cortical stimulation needed to prevent functional deterioration of affected structures (Adamovich, August, et al., 2009; Adamovich, Fluet, et al., 2009; Kleim & Jones, 2008).

Compared to training in a physical environment (PE), training in a VE can offer the potential for massed repetition of practice trials (Adamovich, August, et al., 2009; Adamovich, Fluet, et al., 2009; Lange et al., 2012; Weiss & Katz, 2004). The automaticity of many systems implies ease of consistent task repetition, and VEs may motivate users to engage in more repetitions or longer practice durations as compared to conventional exercises (Holden, 2005). However, there is variation in

VR intervention studies regarding the length of training time and the number of movement repetitions completed during VR training. Specifically, the body of evidence comparing the amount of training time or number of repetitions performed in a VE to that in a PE is small. Mirelman, Patritti, Bonato, and Deutsch (2010) trained individuals recovering from stroke in a robot coupled with a VE and compared this condition to training with the robot alone, finding that the group who had trained with the addition of the VE had a significantly greater average training time, required fewer rests, and reported less fatigue as compared to the robot-alone group. However, the number of repetitions performed throughout the training was not significantly different between the two groups (Mirelman et al., 2010). Bryanton et al. (2006) compared ankle exercises undertaken in a VE to conventional home exercises in a group of children with cerebral palsy (CP). They found that children completed more repetitions of the conventional exercise during the specified training time, although the quality of movement was poor as compared to the VE practice condition. However, despite fewer repetitions being recorded in the VE condition, the children in this group achieved and maintained the desired training position for longer periods of time, indicating additional benefits of practice in the VE.

3.2.1.2 Task-Specific Practice

The *specificity of learning hypothesis* posits that motor learning is promoted when the practice conditions of skill acquisition are as similar as possible to those expected for performance of the task in the physical environment (Barnett, Ross, Schmidt, & Todd, 1973; Schmidt & Lee, 2011). VEs may exhibit varying degrees of task specificity. Highly immersive VEs that are *ecologically valid* are the most task-specific. Ecologically valid VEs are designed to recreate conditions of the physical environment and include manipulation of real-world constraints, challenges, or environmental obstacles (Rizzo & Kim, 2005). Many such VEs enable users to practice tasks that may not yet be feasible to accomplish in the real world, such as using a motorized wheelchair, driving a car, or crossing the street. Kizony, Levin, Hughey, Perez, and Fung (2010) developed a VE mimicking a grocery aisle that combined walking on a treadmill with the cognitive task of following shopping instructions. Task-specific VEs that replicate realistic, difficult or dangerous real-life skills can provide safe testing and training rehabilitation environments (Rizzo & Kim, 2005).

VEs are lower on the continuum of task specificity when they are less immersive and do not include the haptic feedback involved in an interaction as experienced in the physical world. However, many can still be considered somewhat task-specific because they provide practice conditions in which the user accomplishes tasks using body movements that are similar to those required when undertaking the task in the PE. Examples include moving boxes from one conveyor belt to another [GestureTek's Interactive Rehabilitation Exercise System (IREX)], responding to obstacles in a VE while standing on an moving force platform (Motek Medical Computer Assisted Rehabilitation Enivornment [CAREN]), being a goalie in a soccer game [IREX], playing table tennis [Microsoft's Kinect], or skiing down a mountain [Nintendo Wii]. Interfaces with the VE may also enhance task specificity; for example, a sensor glove can be used to train finger and hand movements (Golomb et al., 2010) and additions mimicking real-life objects, such as a tennis racquet or a golf club, can be attached to a handheld remote control. The body of literature evaluating whether movement kinematics of upper extremity pointing, reaching, and grasping tasks are in fact similar in physical and virtual environments is reviewed in Chap. 5.

VEs lowest on the task-specificity continuum are those that include fantasy-based games, such as GestureTek's "Sharkbait" where the task to be accomplished has no real-world equivalent. Moreover, some VEs may include attributes that refute task specificity in favor of providing practice conditions that are *enhanced* as compared to those available in the real world: for example; more abundant augmented feedback, greater opportunities for consistent task repetition, and optimal control over parameterization of practice challenge levels.

3.2.1.3 Meaningful Practice

Learning is optimized when learners are engaged in meaningful tasks that are optimally challenging (Kleim & Jones, 2008). Repetition alone is not sufficient for learning; rather, practice must be done in the context of skill acquisition and must provide opportunities for learners to find the solution to the movement task (Lee, Swinnen, & Serrien, 1994; Lehto et al., 2001). There should be an optimal intersection between the cognitive effort required for the client to engage in problem-solving activities during movement repetitions and the challenging nature of the task (Lee et al., 1994).

VR offers an enriched environment that contributes to task meaning and salience. Individuals undergoing rehabilitation may benefit from this increased interaction with an enriched environment (Rose et al., 2000; Sveistrup, 2004). Studies using animal models demonstrate that environmental enrichment of housing conditions enhances cognitive processing abilities through neuroplastic change in the cerebral cortex, and improves learning, problem solving, and cognitive performance after brain damage (Nithianantharajah & Hannan, 2006; Rose, Attree, Brooks, & Johnson, 1998). However, patients do not always receive substantial amounts of time in therapy activities during inpatient stays (Bernhardt, Dewey, Thrift, & Donnan, 2004). The use of VR can be one option to make environmentally enriched practice conditions more accessible to people with sensory or motor impairments (Rose et al., 1998).

The goal-oriented nature of many tasks in VEs may enhance cognitive engagement with the task and thus their salience (Walker et al., 2010). VR games typically have goals to attain that can be progressed in terms of difficulty (Weiss, Kizony, Feintuch, Rand, & Katz, 2006). Working to achieve a goal may enhance attention and concentration in therapy, potentially increasing the efficacy of rehabilitation interventions (Eng et al., 2007; Holden, 2005). Working towards a goal of achieving a high score in a game, for example, may enhance children's enjoyment of therapy (Gordon & Okita, 2010).

The familiarity of commercially available video games may enhance their meaning and salience for rehabilitation clients. Mouawad, Doust, Max, and McNulty (2011) suggest that the familiarity of participants in their study with the Nintendo Wii system is a factor that may have enhanced motivation and motor learning. In a qualitative study of physical therapists using the Wii with children and youth with acquired brain injury, the therapists remarked that they felt the familiarity of the games encouraged children to move and to participate in therapy (Levac, Miller, & Missiuna, 2011).

VR simulations have been added to other types of therapy such as body weight support treadmill training (BWSTT) and constraint induced movement therapy (CIMT) to enhance the salience of the repetitive practice required in these interventions. In BWSTT, a VE with which the user interacts while walking on a treadmill can add motivation to practice of a repetitive walking task through the experience of being part of an activity such as walking down a street (Walker et al., 2010). The Nintendo Wii games have also been used during CIMT programs for children with the rationale that they may increase engagement of task practice given the long hours of training required by the protocol (Gordon & Okita, 2010).

3.2.2 Augmented Feedback

Augmented feedback—information provided about an action that is supplemental to the inherent feedback typically received from the sensory system—is a major factor supporting motor learning (Schmidt & Lee, 2011). Much research investigates the most effective methods of providing augmented feedback to learners, including its nature, timing, and frequency (Molier, Van Asseldonk, Hermens, & Jannink, 2010). Feedback nature can be classified as knowledge of performance (KP)—information about how a person performed a movement—or knowledge of results (KR)—information about whether the movement produced the desired goal (Schmidt & Lee, 2011). Feedback can be provided either during the practice trial (concurrent) or after its completion (terminal), and can be provided at a set frequency, either as a summary after a certain number of trials, or less frequently as learning evolves (faded) (Molier et al., 2010). Molier et al. (2010) conducted a systematic review of studies evaluating the role of feedback in motor relearning of the hemiparetic arm following stroke. They concluded that "…augmented feedback in general has an added value for stroke rehabilitation" (Molier et al., 2010 p. 1799). Because of the variety of studies included in the review, the authors could not determine which combinations of types and schedules of feedback were most beneficial.

VEs offer auditory, visual, and/or tactile feedback that is intuitive, interpretable, provided in real time, and enhanced in precision and consistency as compared to what is available in the real world (Holden, 2005; Subramanian, 2010). Given that many VR systems provide abundant feedback in all these forms, clinicians have opportunities to select the type of feedback that would be most beneficial for learning in the context of an individual's particular impairments (Deutsch et al., 2011).

VR technologies can provide KP feedback representing movement kinematics, muscle activity, or force generation. They can provide KR through visual feedback of the game score or number of successful versus unsuccessful attempts, auditory feedback reflecting whether the movement resulted in a successful outcome, or by a collection of summary information to convey knowledge of results to the user (Mumford & Wilson, 2009). VEs can also provide simple positive feedback linked to success that may enhance motivation and engagement (Deutsch et al., 2011).

Proprioceptive feedback about the contact of a body part with a virtual object is provided by haptic feedback in many VR systems (Feintuch et al., 2006). This type of feedback can increase realism of the interaction and may be important for activation of sensory–motor networks (Robertson & Roby-Brami, 2010). Adamovich et al. (Adamovich, August, et al., 2009; Adamovich, Fluet, et al., 2009) suggest that the tactile feedback provided by a robotic interface to the VE enhances the sensory experience and provides forces that better mimic interaction with objects in the real world. Indeed, haptic feedback is likely essential for accurate grasp in VEs (Hibbard & Bradshaw, 2003). Studies have compared kinematics of upper extremity reach and grasp in VEs using haptic feedback from gloves to identical movements made in physical environments. For example, Magdalon, Michaelson, Quevedo, and Levin (2011) found that movement trajectories and reach to grasp coordination were similar in both environments in healthy individuals (see Chap. 5).

What is the evidence for the impact of feedback provided in a VE on motor learning outcomes in rehabilitation clients? A recent systematic review evaluating whether extrinsic feedback improves motor learning in the upper limb in people who have had a stroke calls for more research to explore whether the enhanced feedback provided by VEs results in improved motor learning as compared to training in a PE (Subramanian, 2010). However, two studies have specifically addressed this question. Mirelman, Bonato, and Deutsch (2009) compared training of ankle movements post-stroke in a robot and a VE to a robot alone, with both groups supervised by a clinician. They suggest that feedback from the VE improved the clinician's efficiency because the clinician could direct the user's attention to the most relevant aspects of the VE's feedback (see Chap. 5). More recently, Subramanian, Lourenço, Chilingaryan, Sveistrup, and Levin (2013) completed a randomized control trial comparing training of upper extremity function in people with stroke in a three-dimensional VE to a PE. The authors suggest that the KP feedback provided by the VE contributed to the demonstrated improvements, possibly because subjects undertook greater cognitive effort and motor planning to achieve the movement pattern required for success at the task.

3.2.3 Observational Learning

The "mirror neuron" or "action observation" system in the primary motor cortex is one neurophysiological mechanism underlying learning by imitation or observational learning (Petrosini et al., 2003). Observation of goal-oriented movements provides sensory feedback about movement patterns and outcomes which may contribute to motor learning (Krakauer, 2006). Observing these goal-oriented movements activates neurons that pick up on essential components of the activity that are similar across repetitions, allowing for an image to develop upon which to base movement (Buccino, Solodkin, & Small, 2006).

The mirror neuron system may be engaged in VEs in four ways: (1) Through motion capture VR technology in which the user views his/her own image interacting with virtual objects, allowing for observation of movement accuracy (Weiss, Rand, Katz, & Kizony, 2004) and provision of visual feedback about body position in space (Flynn, Palma, & Bender, 2007); (2) Through VEs in which an avatar mirrors the user's movements; (3) Through VEs in which a virtual teacher demonstrates optimal movement patterns for users to mimic, in the same spatial frame of reference as the users' own movements (Eng et al., 2007; Holden, 2005); or (4) Through VR applications that facilitate mental practice or motor imagery.

With respect to evidence, there is conflicting information as to whether observation in a VE activates the same mirror neuron network as observation in a PE. Adamovich et al. (Adamovich, August, et al., 2009; Adamovich, Fluet, et al., 2009) developed a VR system compatible with functional magnetic resonance imaging (fMRI) and asked healthy subjects to observe preprogrammed movement sequences of a virtual hand as well as movement sequences of a virtual hand controlled in real time by their own hand movements. In both conditions, the same neural networks as those activated by physical world observation were recruited. Cameirao, Badia, Oller, and Verschure (2010) developed the Rehabilitation Gaming System, in which the user controls the movement of two virtual limbs to train finger and arm movements using a first person perspective. They postulated that this first person perspective should facilitate activation of the mirror neuron network. Holden, Todorov, Callahan, and Bizzi (1999) created a VE displayed on a desktop computer showing a "teacher" repeatedly performing the correct movement, allowing the user to match his movement to that of the teacher for training in real time. The authors conclude that subjects could transfer improved performance of reaching movements to the physical environment because they were imitating the teacher within the same frame of reference, negating the need for spatial transformation and allowing subjects to more quickly identify their movement errors.

With respect to evidence in rehabilitation clients, Tunik, Saleh, Bagce, Merians, and Adamovich (2011) found that observing movements of a virtual hand activated the sensorimotor cortex corresponding to the paretic hand in people with chronic stroke, suggesting that this could be a mechanism to train neural reorganization. Researchers investigating the use of GestureTek's IREX in adults with stroke and children with cerebral palsy have also credited activation of the mirror neuron system with the improvements seen after training (Jang, You, & Hallett, 2005; You et al., 2005).

In contrast, evidence exists to suggest that observation in a VE does not in fact recruit the same neural pathways as observation in a PE. The extent to which VEs can target the processes involved in action observation may be dependent on their similarity to the physical world (Adamovich, August, et al., 2009; Adamovich, Fluet, et al., 2009). Some evidence suggests that observation of virtual effectors may recruit fewer neural circuits than observation of real-world actions. For example, Perani et al. (2001) asked healthy young adults to observe a virtual hand performing a reaching task and a real hand performing the same task, finding less activation in relevant brain areas on fMRI for the virtual observation. Despite including two levels of VR simulations, there was no difference according to the degree of realism of the VR hand. They concluded that observation in a VE did not activate existing action representation maps.

Mental practice or motor imagery could be another mechanism to target observational learning. Gaggioli, Meneghini, Morganti, Alcaniz, and Riva (2006) created a VR system to facilitate mental practice of the affected limb, evaluating it in a case study of an individual following stroke, and demonstrating improvement in arm function after an 8-week training program. However, they could not isolate whether these benefits were due to the mental practice or to the observation of the virtual limb. A brain–computer interface in which subjects wear electroencephalogram (EEG) sensors allows researchers to measure activity patterns in the primary and secondary motor areas of the brain during action observation and imitation of VR tasks (Bermudez, Badia, Samaha, Garcia Morgade, & Verschure, 2011). The developers postulated that the virtual avatar could be controlled via sensory motor rhythms picked up by the EEGs and that an immobile patient could train the motor cortex by controlling the virtual avatar through motor imagery.

VR may also augment the effects of learning by observation by "distorting reality" to highlight movement errors. This can be done by augmenting movement trajectories, exaggerating movement features (Gordon & Okita, 2010; Robertson & Roby-Brami, 2010) and adding more movement replays (Adamovich, August, et al., 2009; Adamovich, Fluet, et al., 2009). However, evidence is required to determine whether these augmentations offer motor learning benefits.

3.2.4 Motivation

Learners must be motivated to engage in practice (Schmidt & Lee, 2011). Expectations that rehabilitation should include the large number of repetitions required to regain lost skills after injury can be enhanced if individuals are motivated to participate in the therapy task (Holden, 2005). While this applies to all patient populations, it may be particularly relevant for children for whom engagement in the task may facilitate the maintenance of attention and participation in rehabilitation (Gordon & Magill, 2011; Laufer & Weiss, 2011).

Several hypotheses exist as to why training in a VE might provide motivating practice for clients in rehabilitation. Users may be motivated to participate because of the novelty of these interventions (Lewis & Rosie, 2012). The gaming features of many VR systems, including commercially available interactive video games, may increase motivation (Deutsch, Borbely, Filler, Huhn, & Guarrera-Bowlby, 2008; Jack et al., 2001; Rizzo & Kim, 2005). For example, Mouawad et al. (2011) suggest that the Nintendo Wii games motivate players through the visual and auditory cues that provide commentary, rewards, and feedback related to progress. The motivation provided by the goal-oriented nature of VR applications was also supported in a study where a parent of a child with CP who had participated in a VR gaming intervention commented on the motivation provided by the scoring system (Bryanton et al., 2006). Other studies have suggested that viewing movement trajectories or performance results may motivate users to improve their movement (Gordon & Okita, 2010) and that the unpredictable challenge and variation of stimulus presentation within many VR games motivates children to maintain attention and participation (Harris & Reid, 2005).

VR systems can provide clinicians with a significant capacity to individualize treatment options through manipulating levels of task difficulty and stimulus presentation (Rizzo & Kim, 2005), which may also be a mechanism to achieve and enhance motivation by progressing practice challenge (Golomb et al., 2011; Holden, 2005, Lange et al., 2012; Wang & Reid, 2011). Cameirao et al. (2010) discussed how their Rehabilitation Gaming System adapts the task on a trial by trial basis so that the user averages approximately 70 % correct trials, with the goal of preventing boredom and frustration. VEs may also facilitate task simplification, which may motivate the learning process as the user no longer needs to distinguish the most important elements of the task (Holden, 2005). The capacity to individualize may also enhance motivation by allowing the user to select his or her own practice tasks and schedule (Deutsch et al., 2008; Huber et al., 2008; Miller & Reid, 2003). Overall, many VR systems allow for stimulus control and consistency in terms of individualization and manipulation of treatment parameters to create optimal learning conditions (Rizzo & Kim, 2005).

Competition, either against another player or against a virtual opponent, may also enhance motivation (Deutsch et al., 2008; Harris & Reid, 2005). In the VEs associated with the Lokomat robotic gait trainer, the virtual opponent can be set to walk faster than the user, potentially motivating him or her to participate more actively (Brutsch et al., 2011; Koenig et al., 2008). Ballester, Bermudez, Badia, and Verschure (2011) found that subjects performed a greater amplitude of upper extremity reaching movements when they played competitively against other players as compared to when they played alone, suggested the multiplayer social gaming interaction motivated users to improve their performance.

The body of evidence evaluating these hypotheses, exploring motivation from users' perspectives, or specifically investigating the relationship between motivation and outcomes is small. Motivation typically is assessed through qualitative responses and using a wide variety of standardized and non-standardized outcome measures whose psychometric properties may not be established.

Reviews of the pediatric VR literature conclude that VR interventions motivate children to participate in the repetitive activities needed to gain skills (Laufer & Weiss, 2011; Parsons, Rizzo, Rogers, & York, 2009; Snider, Majnemer, & Darsaklis, 2010). Schuler, Brutsch, Muller, van Hedel, and Meyer-Heim (2011) assessed electromyographic (EMG) activity in lower limb muscles in children with CP and typically developing children walking within a VE as compared to those walking in normal overground conditions on a treadmill. The authors found that EMG activity in both groups of children was significantly higher during walking in the VR scenario and suggest that this provides evidence that the VE contributes to children's motivation and engagement to participate in walking tasks. A narrative review has summarized themes from studies investigating users' responses to VR game use in rehabilitation, distilling comments from users about different aspects that motivated them to participate in the VR interventions (Lewis & Rosie, 2012). Qualitative studies have explored the motivational appeal of VR from the perspective of both clinicians and clients. Levac et al. (2011) asked a small group of physical therapists about their use of the Nintendo Wii with pediatric neurological populations. Therapists described their perceptions that the Wii enhances children's motivation to participate in therapy and to practice movements that they would otherwise be reluctant to try. Lewis, Woods, Rosie, and McPherson (2011) report themes from a qualitative study of individuals with stroke participating in a 6 week VR game intervention. A range of perspectives related to the motivating and challenging nature of the interventions are described.

However, does motivation to participate remain high over the course of a prolonged VR intervention period? Li, Lam-Damji, Chau, and Fehlings (2009) investigated how children with CP used a home-based VR system and reported that the number of minutes played per day decreased over time. They suggested that more game variety may be needed to sustain children's interest. Golomb et al. (2011) describe a lengthy tele-rehabilitation intervention using a VR gaming system and custom made sensor glove. They concluded that a variety of tactics were needed to sustain the engagement of their adolescent participants to continue to practice over time.

An additional factor to consider with respect to motivation and motor learning is the optimal level of cognitive effort required to engage in the VR task. Volkening et al. (2011) explored the motivation of 12 subacute stroke patients playing VR games of differing challenge levels. Users achieved the greatest amount of physical practice (in terms of number of repetitions) in the easiest scenario, but rated this scenario as lowest on the motivation scale, finding that it was boring and of insufficient cognitive demand. The most challenging VR scenario, although rated as motivating, was too difficult to result in many repetitions. It was the more moderate VR scenario that was rated as the most motivating because it achieved the appropriate level of cognitive and physical effort. These findings illustrate the importance of matching not only a user's physical abilities but also his or her cognitive abilities to the VR task in terms of sustaining motivation to practice.

3.3 How Might Training in a Virtual Environment Transfer to Improved Performance of Tasks in the Physical Environment?

Transfer is a central concept in motor learning, defined as: "the gain (or loss) in the capability for performance in one task as a result of practice or experience on some other task" (Schmidt & Lee, 2011, p. 465). Achieving transfer of learning is of central importance within rehabilitation (Holden & Todorov, 2002). VR applications used to train complex skills in surgical, flight, or military situations have demonstrated that it is possible to learn skills in VEs and then transfer this learning into skilled performance in the real world (Bossard, Kermarrec, Buche, & Tisseau, 2008; Holden, 2005). The evidence of transfer of training from VEs to PEs in healthy subjects can be found elsewhere (Bossard et al., 2008; Holden, 2005; Rose et al., 2000).

What conditions and attributes within a VE may facilitate transfer? Transfer will be facilitated if the interaction with the VE and the cognitive processing required for task performance is similar to that required in the PE (Rose et al., 1998), or if the VE provides important information for learning and increases practice salience (Rose et al., 2000). Transfer may be facilitated when the VE requires the learner to adapt to changing demands, problem-solve different solutions to tasks, learn from mistakes, simplify and segment tasks, and repeat variable complex situations (Bossard et al., 2008). VEs that can be individualized—for example, by replicating the users' home environment or modifying stimulus presentation according to user needs and capabilities—should enhance transfer and generalization of learning (Schultheis & Rizzo, 2001).

Transfer of learning to performance in the PE may even be enhanced when subjects train in VEs as compared to training in physical environments. Rose et al. (2000) studied healthy participants and found that when interference tasks were added to a new task in the PE, those who had practiced in a VE performed better as compared to those who had trained in the PE. The authors suggest that the characteristics of the VE training may have better prepared participants to deal with interferences in the real world.

What evidence do we have that skills trained in VEs transfer to activities in the physical world for people with disabilities? Few studies rigorously examine transfer, and studies differ in terms of the level of the task involved and also how transfer is measured (Rose et al., 2000). Studies have demonstrated differing levels of evidence of transfer from VE training to the real world by evaluating post-training performance on standardized tests of motor function, functional activities such as overground and community walking and stair climbing, activities of daily living, and gait speed. Results of these studies are described in Chap. 6.

3.4 How Might Training in a Virtual Environment Hinder Motor Learning?

Features of some VR systems may be detrimental to motor learning for a number of reasons, particularly in clients with neurological impairments. Firstly, commercially available game-based VR systems where there are a small number of training options without the possibility of individualizing treatment parameters or manipulate challenge levels may limit accessibility of VE training in individuals with motor or cognitive impairments, rendering the VR tasks too frustrating, difficult, or physically impossible. Secondly, the motor learning literature suggests that feedback is beneficial in the early stages of learning a motor skill but should not be relied upon throughout training (Winstein, Pohl, & Lewthwaite, 1994). Reliance on the abundant, immediate or consistent feedback provided by some VEs may cause dependence on the conditions of VE practice for successful performance. Thirdly, VR gaming systems may provide inaccurate (Deutsch et al., 2011) or discouraging feedback (Lange et al., 2012). For example, the KP feedback provided by the Nintendo Wii games may not accurately reflect the movements made by the user (Deutsch et al., 2011) and games may not elicit the specific movements that are impaired or that should be promoted in neurological populations (Gordon & Okita, 2010). More information about the quality of movement made in different VEs can be found in Chap. xx of this volume. Small improvements in movement patterns may not be identified in terms of eliciting game success. Lastly, the abundance of visual and auditory feedback within certain VEs may be too overwhelming for clients with cognitive, memory, or attention impairments in motor learning processes (Levac et al., 2011).

3.5 How Can Clinicians Emphasize Motor Learning Within VR-Based Therapy?

The interactive nature of most rehabilitation interventions suggests that the therapist will be an important factor in treatment effectiveness (Whyte & Hart, 2003). Although it is clear that VR systems rely on hardware and software, their use in all rehabilitation situations requires clinicians to make decisions about the appropriateness of the intervention for the client, as well as the implementation of treatment parameters and progression through different levels of the game or task (Levac & Galvin, 2013). Clinicians must also consider issues relating to safety, cost, and evidence for effectiveness in comparison to other types of interventions. While Mirelman et al. (2009) argue that VEs that provide motivating and interpretable feedback do not require a clinician to be present at all times, the use of VR can also amplify and enhance the expertise and effectiveness of clinicians (Rizzo & Kim, 2005). The automaticity of task delivery within VEs may allow the clinician to better concentrate on observing movement performance and promoting effective strategies, even if the task is complex (Laufer & Weiss, 2011; Weiss et al., 2006). Lange et al. (2012) suggest that as VR systems become more ubiquitous, the primary role for the therapist will be in promoting transfer of rehabilitation gains to real-world performance.

The following recommendations are provided to illustrate how clinicians can promote motor learning within VR-based therapy (Table 3.2):

1. Take the time to become familiar with practicalities and features of the VR system and its applications to understand the attributes that may take advantage of motor learning variables or that may hinder motor learning. Therapists have identified a need for training as a factor limiting the effective use of VR systems in practice (Glegg et al., 2013; Levac et al., 2011). For certain VR systems, resources exist to assist clinical decision-making. For example, Deutsch et al. (2011)

Table 3.2 Recommendations for clinicians

Recommendations	Details
Become familiar with the VR system	Dedicate time for training Take advantage of existing resources in the literature to inform training
Keep abreast of the scientific literature	Appraise the evidence as to how training in the VE can promote motor learning outcomes of retention, transfer, and generalization
Take a client-centered approach	Consider the intersection between a VR system's affordances and the client's impairments in motor learning processes
Set goals according to ICF levels	In addition to impairment-focused goals, set goals that relate to increased participation in functional activities
Emphasize learning not performance	Focus on transfer and generalization of skills being practiced in the VE to real-life activities and settings
Be aware of and mitigate for potentially challenging features of commercially available VR systems	Make practice task-oriented Ensure optimal movement quality Mitigate negative feedback Use therapeutic adaptations
Add therapeutic adaptations to target transfer and generalization	Change conditions of the physical environment
Modify and progress task challenges as individuals improve	Modify VR system parameters or physical environment factors to progress challenge
Set up home or delegated therapy programs according to motor learning principles and have a plan for monitoring programs and evaluating outcomes	Organize practice schedule according to conditions that promote motor learning Ensure assistants are well trained in the VR tasks Make a plan to monitor performance, progress challenge, and evaluate learning

have described each Nintendo Wii game, analyzed the games for the feedback provided (specifically, knowledge of performance and knowledge of results), and outlined the impairments that each game targets to inform clinicians in making decisions about which games to implement in therapy (Deutsch et al., 2011). Galvin and Levac (2011) also provide a descriptive analysis and initial classification framework of several VR systems used in pediatric rehabilitation with the intent of supporting therapist decision-making about system use.

2. Continually keep abreast of advances in the scientific literature to appraise the level of evidence as to how training in the VE of interest can promote transfer of learning to real-life functional activities.
3. Take a client-centered approach by considering the intersection between a VR system's affordances and the client's capabilities as they relate to potential impairments in motor learning processes (Galvin & Levac, 2011). Because of specific cognitive, memory, or attention impairments, some clients may not be the best candidates for using certain VR systems (Levac et al., 2011).
4. Set client-centered goals for VR-based therapy that target different levels of the International Classification of Functioning, Disability, and Health: impairments in body structures and function, activity limitations, or participation restrictions.

5. Consider the difference between "performance" and "learning" by recognizing that improved performance within a therapy session is considered to be learning only when the improvements are retained over time (Newell, Yeuo-The, & Gottfried, 2001). Rather than focusing on a client's performance during the therapy session, focus on how the skills being practiced in the VE can transfer to use in real-life activities and settings. This may involve considering what the client needs to learn in the VE in order to function in the real world, highlighting similarities between movements in the VE and those required in the real world, or asking the client to brainstorm and problem-solve about similarities between the VR task and functional skills required in daily life.
6. Additional considerations apply when using commercially available gaming systems that were not designed for rehabilitation, as there is much less opportunity to grade the level of task difficulty. If games are fantasy-based, the clinician needs to "help bridge the link between the gaming world and the real world" (Gordon & Okita, 2010, p. 183). Observing the client's movement is paramount, as these systems offer much potential for compensation in the form of "cheating" and avoidance of therapeutically beneficial movement (Lange et al., 2012; Lewis & Rosie, 2012). Patients may be able to use smaller range of joint movements to achieve success at the VR task, particularly when they are playing in a "competition" as opposed to a "simulation" mode (Deutsch et al., 2011). This is particularly the case for the Nintendo Wii in which the remote control captures movement acceleration as opposed to spatial position changes (Deutsch et al., 2011). As such, it may be relevant to limit unsupervised practice and to use hands-on techniques to prevent inappropriate movements.
7. Add therapeutic adaptations that may help to target transfer and generalization to real world. For example, therapists can change the support surface on which clients play VR games by having them stand on a BOSU ball or balance board.
8. As the client's skills improve, continually modify tasks through progression and manipulation of available system options to individualize and target different challenge levels.
9. The above considerations also apply to tele-rehabilitation. When setting up therapy programs to be delivered at home, consider motor learning principles relevant to structure of the practice schedule, be aware of the potential for compensatory movement strategies, and monitor progression of difficulty or challenge over time (Table 3.2).

3.6 Model of VR-Based Rehabilitation

Weiss et al. (2006) present a model (Fig. 3.1) using concepts from the International Classification of Functioning, Disability, and Health to guide the use of VR in rehabilitation. The model illustrates that the goal of using VR in rehabilitation is to assist the client in regaining independent function in the real world. Characteristics or factors of the VE (including the attributes discussed in this chapter) interact with clients'

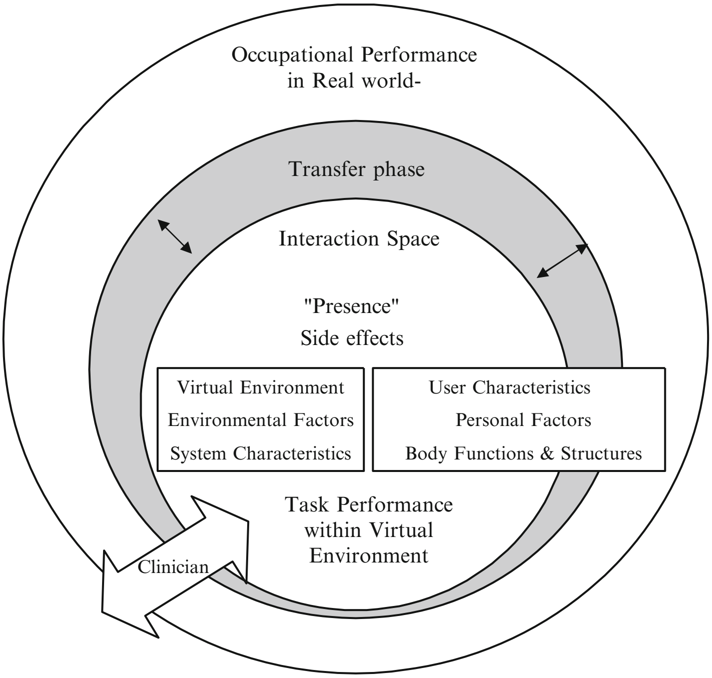

Fig. 3.1 A model of VR-based rehabilitation within the context of terminology from the International Classification of Functioning, Disability, and Health concepts. Reproduced with permission from: Weiss, P.L., Kizony, R., Feintuch, U., & Katz, N. (2010). Virtual Reality Applications in Neurorehabilitation. In Selzer, M., Clarke, S., Cohen, L., Duncan, P., & Sage, F. (Eds). *Textbook of Neural Repair and Rehabilitation*, *Volume 2*: *Medical Neurorehabilitation* (pp. 182–197). Cambridge: Cambridge University Press. DOI: http://dx.doi.org/10.1017/CBO9780511545078.015

personal characteristics to determine task performance within the VE. The model indicates that the clinician plays a key role in facilitating the transfer phase from task performance within the VE into occupational performance in the real world.

3.7 Future Research Directions

Much remains to be discovered about how training in a VE can promote motor learning in rehabilitation clients. Researchers need to clearly identify the skills being trained in the VE that will be transferred to the PE and how this will be measured (Rose et al., 2000). VR intervention studies should include longer-term motor learning outcomes such as retention of learning and transfer and generalization of skills learned in VR therapy to real-life activities, including outcomes measured at the ICF activity and participation levels (Sandlund, McDonough, & Hager-Ross, 2009; Weiss et al., 2006). A motor learning theoretical framework may assist researchers in linking the impact of the motor learning variables evident within VR interventions to improved outcomes (Levac et al., 2012). Little is known about which training conditions best facilitate transfer (Sveistrup, 2004). Ultimately, it is important to understand whether training in a VE is more effective with respect to achieving motor learning than training in the real world (Holden, 2005).

It will be important to develop and evaluate methods for training clinicians to implement VR-based therapy (Levac & Galvin, 2013). This includes educational opportunities related to how a clinician structures VR interventions, provides additional instructions and feedback, or progresses and modifies the intervention. Research is needed to develop guidelines that will support clinicians in (1) identifying optimal dosing requirements and treatment parameters for different outcomes; (2) evaluating how much practice or feedback is most beneficial; and (3) determining which particular motor learning variables, demonstrated to varying degrees in different VEs, are most important for improving rehabilitation outcomes.

Finally, the role of user motivation to participate in VE training from the user's perspective requires exploration. Studies should explore the link between user motivation and training outcomes, how motivation may differ between ecologically valid versus game-based VEs, and how motivation might change over a course of therapy.

3.8 Conclusions

Rehabilitation interventions that maximize functional neuroplastic change after CNS injury provide abundant, intensive, motivating, and meaningful task practice (Kleim & Jones, 2008). VR-based rehabilitation interventions can exploit the capacity of the CNS for functional reorganization and mediate recovery through neuroplasticity. Motor learning concepts form the basis of the scientific rationale for the integration of VE training into rehabilitation practice. This chapter has described and summarized the evidence for the attributes of VR technologies that align with the motor learning variables of practice, feedback, observational learning, and motivation. The conditions under which training in a VE might lead to improvements in real-life skills are discussed, as are features of VR systems that may be detrimental for motor learning.

VR-based therapy can be provided in a variety of rehabilitation settings, including research laboratories, clinics, the community, and homes. Clinicians play a crucial role in structuring, delivering, progressing, and monitoring interventions in ways that maximize transfer of improvements to real-life functional skills. Suggestions for how therapists can use VR to promote motor learning have been provided. Given that VR systems vary substantially in terms of the extent to which attributes of motor learning can be manipulated, the practitioner must be familiar with the system he/she is using and keep up to date with new developments. This may be challenging in such a rapidly changing field.

Effective rehabilitation approaches should provide task-oriented training, individual feedback, goal-tailored exercise schedules, frequent movement repetition, engaging and fun gaming scenarios, individualized interventions, and feedback directed towards motor learning (Timmermans, Seelen, Willmann, & Kingma, 2009). VR-based therapy can include all of these elements. Research to evaluate which attributes and practice conditions most promote skill transfer will enhance the promise of VR-based therapy as a rehabilitation intervention that can improve performance of functional real-life skills in a wide variety of rehabilitation clients.

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