The handle [http://hdl.handle.net/1887/81790](http://hdl.handle.net/1887/81790) holds various files of this Leiden University dissertation.

**Author:** Cuperus, A.A.

**Title:** Virtual experience, real impact: the influence of virtual reality on memory and behaviour

**Issue Date:** 2019-12-10
CHAPTER 1

General introduction
In the mid-1990s, an individual with fear of heights, particularly of elevators, entered the Marriott Marquis Convention Hotel in downtown Atlanta. Here, he used the glass elevator to get to the top floor. As one would expect from someone who is afraid of heights, he felt himself getting more and more anxious as he moved up. His palms became sweaty and he felt his chest getting tighter and tighter. Interestingly, however, the elevator was not real, but part of a virtual reality (VR) simulation (Rothbaum et al., 1995). VR simulations can elicit real, psychophysiological fear reactions, as VR is capable of inducing an experience of being personally and physically present in the displayed environment (Wirth et al., 2007). An increased ‘sense of presence’ is thought to magnify user effects (e.g., the extent to which user responses to virtual stimuli/interactions resemble parallel responses to real-world counterparts) and, in turn, to increase the effectiveness of VR applications (Cummings & Bailenson, 2016). Being able to achieve a strong sense of presence is obviously of great value for the entertainment industry, but has also proven to be useful in the field of healthcare; e.g., the hotel simulation was used to reduce the visitor’s fear of heights (Rothbaum et al., 1995). Although a wide variety of VR healthcare applications is already available, however, there are still many untouched opportunities. The aim of this thesis is to increase our understanding of how VR can be applied in healthcare by exploring two novel VR paradigms. Part 1 focusses on the use of VR to model psychological trauma in healthy individuals for research purposes, while part 2 investigates whether VR can be used to affect physical activity by means of a novel kind of perceptual illusion. In this introduction, some important developments in the field of VR and healthcare are first described, as well as where the content of this thesis fits in. Next, the different types of memory and their components are briefly outlined, because the basic mechanisms of human memory are relevant to all of the research presented in this thesis. The fallibility of memory and perception is also discussed here, as well as how this same fallibility provides the basis for both VR paradigms. In the final section, the structure of the thesis is outlined.

**VR healthcare applications**

Healthcare can benefit from VR in several ways. One promising direction is the use of VR in medical education. For instance, VR simulators can be used to support surgical training. This may improve the technical skills of surgical trainees, such as suturing speed and accuracy (Nagendran, Gurusamy, Aggarwal, Loizidou, & Davidson, 2013). Medical simulators offer immediate, risk-free training opportunities for all sorts of clinical scenarios, including rare procedures that are difficult to practise otherwise (Kunkler, 2006). Similarly, VR may be used to simulate symptoms of
mental disorders, so that users can experience what it is like to go through a psychotic episode, for instance. Even without any overt educative elements, this provides a form of experiential learning that may increase users’ knowledge of diagnoses and their empathetic understanding towards individuals diagnosed with mental disorders (Formosa, Morrison, Hill, & Stone, 2018).

VR can also be used to facilitate the treatment of medical conditions. The most popular example is, without a doubt, the use of VR in the treatment of anxiety disorders. In VR exposure therapy, patients are exposed to virtual environments that resemble feared real-life situations. This elicits psychophysiological fear reactions, which is a prerequisite for effective exposure treatment (Diemer, Mühlberger, Pauli, & Zwanzger, 2014). VR exposure therapy helped many people overcome specific phobias, such as fear of heights or spiders (for meta-analyses, see e.g., Morina, Ijntema, Meyerbröker, & Emmelkamp, 2015; Parsons & Rizzo, 2008), and research indicates that it can effectively reduce symptoms of post-traumatic stress disorder as well (e.g., Beck, Palyo, Winer, Schwagler, & Ang, 2007; Gerardi, Rothbaum, Ressler, Heekin, & Rizzo, 2008; Rothbaum, Hodges, Ready, Graap, & Alarcon, 2001). Another well-known example is the use of VR as a pain reduction technique in the treatment of acute pain (Garrett et al., 2014), such as pain experienced during wound care by patients with severe burn injuries (Hoffman et al., 2008; Hoffman, Patterson, Carrougher, & Sharar, 2001). Although the exact mechanisms remain unclear, VR is generally hypothesized to be capable of reducing pain by means of distraction (Garrett et al., 2014). VR can provide an engaging environment which draws a lot of attentional resources, leaving less attention available to process pain signals (Hoffman et al., 2001).

VR is also increasingly used to facilitate rehabilitation of several disorders, most notably of stroke. After having a stroke, people often suffer from a variety of symptoms that can cause problems with everyday activities, including an inability to move or feel on one side of the body, problems understanding or speaking, dizziness, or loss of vision to one side. An advantage over traditional therapy approaches is that VR simulations of real-life objects and events give people the opportunity to practice everyday activities that are not or cannot be practiced within the hospital environment. This may result in improved limb function and activities of daily living (Laver, George, Thomas, Deutch, & Grotty, 2015). Another rehabilitation example that received a great amount of media coverage involves a group of chronic spinal cord injury paraplegics who were subjected to a gait neurorehabilitation paradigm aimed at restoring locomotion (Donati et al., 2016). This highly innovative approach combined VR training, enriched visual-tactile feedback, and walking with two EEG-controlled robotic actuators, including a custom-designed lower limb exoskeleton capable of delivering tactile feedback
to the user. Twelve months of intensive training with this paradigm resulted in unprecedented neurological recovery results in all patients and half of them were upgraded to an incomplete paraplegia classification.

Taken together, the above studies show that VR is playing an important role, or has the potential to do so, in several aspects of healthcare. The paradigms introduced in this thesis are based on the idea that feeling present in a VR environment can lead to highly realistic memories; i.e., a VR experience may be encoded into memory in a manner so similar to a physical world experience that it can even lead to difficulties remembering the source of stored information (Segovia & Bailenson, 2009). Part 1 of the thesis explores the utility of VR to simulate exposure to psychological trauma and subsequent trauma symptoms. This ‘analogue model of psychological trauma’ may be used to study the basic mechanisms underlying trauma symptom development, and to create and test interventions. Part 2 investigates whether a ‘memory-related perceptual illusion’ can be used to affect physical activity. This paradigm is based on how we memorize spatial representations of our environment and may be useful in the field of rehabilitation.

Human memory and perception

It was not until the 1960s that the idea of not one, but multiple systems being involved in memory, became widely adopted among cognitive psychologists. The modal model of memory proposed by Atkinson and Shiffrin (1968), a particularly influential model of the time, describes three stages of memory: sensory memory, short-term memory, and long-term memory. This distinction is still frequently used to explain how our memory works, but it should be noted that some influential researchers object to a modal view (e.g., Nairne, 2002).

The term sensory memory refers to the brief storage of information that enters the senses. Selective attention determines which parts of this information transfer from sensory memory to short-term memory, where it can be stored for a few seconds (without active rehearsal). Short-term memory can be seen as part of working memory; a limited capacity system that not only temporarily stores information but also manipulates it (Baddeley, 2009). The multicomponent model of working memory, proposed by Baddeley and Hitch (1974), is the most influential working memory account to date. Initially, three components were distinguished in this model: the phonological loop which is responsible for maintaining speech-based information, the visuospatial sketchpad which has a similar function for visual information, and the central executive which acts as an attentional control system. A fourth component, the episodic buffer, was later added; a temporary storage system that is capable of
integrating information from a variety of sources, including the other components of working memory and long-term memory, under control of the central executive (Baddeley, 2000; for further refinement of the model, see Baddeley & Hitch, in press; Baddeley, 2012). Without such an integration system we would not be able to make sense of the world around us. Our brain uses other sources of information, such as knowledge derived from the past, to actively ‘construct’ a cognitive understanding of sensory information. As is demonstrated by the study of perceptual illusions, this process makes perception prone to error (Gregory, 1997). Similarly, memory retrieval is not like playing a recording, but should be seen as a ‘reconstructive’ process (Bartlett, 1932); a memory becomes labile when reactivated and may be influenced by other stimuli, such as suggestive misinformation related to the memory (Loftus, 2005), while in this state. Memory is so fragile that the way questions about a past event are formulated can already alter memory for it. For instance, when asked how fast cars were going in films of automobile accidents, participants reported higher estimates of speed when the question contained the verb ‘smashed’ than when the same question contained the verbs ‘collided’, ‘bumped’, ‘contacted’, or ‘hit’ in place of ‘smashed’ (Loftus & Palmer, 1974). Later studies showed that suggestive misinformation can even lead to the creation of entirely new false memories in people; e.g., by means of a written narrative about one’s childhood (Loftus & Pickrell, 1995) or a doctored photograph (Wade, Garry, Read, & Lindsay, 2002).

The downsides to findings like these, such as the challenges they present for the justice system, are evident. However, the malleability of human memory also plays an important role in processing psychological trauma. A traumatic event is described as exposure to actual or threatened death, serious injury, or sexual violence (American Psychiatric Association, 2013). Exposure to such an event may be followed by the persistent re-experiencing of the event (e.g., nightmares), which is considered the hallmark symptom of post-traumatic stress disorder and acute stress disorder (American Psychiatric Association, 2013; James et al., 2016). Just like any other memory, a traumatic memory becomes labile when reactivated and successful trauma interventions interfere with memory when it is in this state (Visser, Lau-Zhu, Henson, & Holmes, 2018; for meta-analyses see e.g., Cusack et al., 2016; Watts et al., 2013). Eye movement desensitization and reprocessing (EMDR; Shapiro, 1989a, 1989b) is such an intervention. One of its key components is a dual-task approach: the patient holds a traumatic memory in mind while simultaneously making voluntary eye movements by tracking the therapist’s finger as it moves horizontally across the patient’s visual field (Shapiro, 2001). The present state of research points towards an explanation based on working memory as the most solid theory to explain the effects of this dual-task procedure. According to this theory, keeping a memory in mind and making voluntary eye movements both tax the limited capacity of working memory. As a result of this,
the memory becomes less vivid and less emotional (Andrade, Kavanagh, & Baddeley, 1997; Gunter & Bodner, 2008; Smeets, Dijis, Pervan, Engelhard, & van den Hout, 2012), and is stored as such into long-term memory (van den Hout & Engelhard, 2012).

The fallibility of human perception can also be used to our benefit. Perceptual illusions are applied in the treatment of several medical conditions. For instance, a mirror visual feedback technique was developed in the 1990s, in an attempt to alleviate phantom limb pain (Ramachandran & Rogers-Ramachandran, 1996; Ramachandran, Rogers-Ramachandran, & Cobb, 1995). It typically involves the use of a mirror across the patient’s midline to create the illusion of having two complete limbs. Such ‘false visual feedback’ may provide relief of phantom limb pain, because of the brain’s predilection for prioritizing visual feedback over somatosensory/propiroceptive feedback (Moseley, Gallace, & Spence, 2008). The technique has its limitations, however, because it relies on the presence of an unaffected limb and only allows for symmetric actions. A VR setup is not necessarily subject to such constraints and may thus provide a better alternative (for a review, see Dunn, Yeo, Moghaddampour, Chau & Humbert, 2017); seeing a virtual body from a first-person perspective can induce the illusion of ownership over (parts of) this virtual body ( Slater, Spanlang, Sanchez-Vives, & Blanke, 2010). VR can be used to present the user with other types of false visual feedback as well, such as the manipulation of perceived orientation. In a technique called redirected walking, real-world rotations are transformed into increased or decreased rotations in the virtual environment. This allows users to walk through large-scale virtual environments while they physically remain in a small workspace; users can be redirected on a circular arc with a radius of at least 22 m while they believe that they are walking straight (Steinecke, Bruder, Jerald, Frenz, & Lappe, 2010). The same technique can also be used, for instance, to alter the onset of movement-evoked pain in people with neck pain (Harvie et al., 2015).

**Thesis outline**

The general objective of part 1 of this thesis was to validate the utility of a VR paradigm as an experimental analogue of psychological trauma. Experimental analogues can be used to model abnormal processes in order to identify mechanisms of a disorder and to demonstrate proof of concept evidence for clinical developments (James et al., 2016). Clinical studies may be useful in this respect, but a limitation of such studies is that they often rely on retrospective reports of trauma-related reactions many years later. As argued by Candel and Merckelbach (2004), this is problematic because people in general, and patients with trauma symptoms in particular, find it difficult to give accurate descriptions of past emotional states. Moreover, reports of memory for
traumatic events often change over time (Engelhard, van den Hout, & McNally, 2008), because individuals may interpret memories differently over time (Engelhard & McNally, 2015; see also Lommen, van der Schoot, & Engelhard, 2014). Experimental analogues are therefore warranted (James et al., 2016). A well-established analogue model of psychological trauma is the trauma film paradigm, which involves showing non-clinical participants unpleasant films under controlled laboratory settings (Horowitz, 1969; Lazarus, 1964). This elicits measurable responses analogous to symptoms experienced during and shortly after viewing a traumatic event in real life, such as increases in negative mood (Clark, Mackay, & Holmes, 2015) and intrusive memories of the film (Holmes & Bourne, 2008; James et al., 2016). However, watching films seems to be a somewhat passive endeavour that lacks active behavioural engagement (Dibbets & Schulte-Ostermann, 2015). VR may provide a better alternative. Like the trauma film paradigm, a benefit of VR over the use of autobiographical memories is that it allows for experimental control. Furthermore, VR can induce a greater sense of presence than watching a film on a two-dimensional screen and it allows interaction with the environment, which may lead to more realistic (Slater, 2009) and more emotional (Riva et al., 2007) responses to portrayed events; i.e., greater user effects. Chapter 2 presents a first step towards validating the VR paradigm. In the study described here, a VR game of the horror genre was used to induce vivid and unpleasant memories in a group of healthy individuals. The effects of a dual-task intervention on self-rated memory vividness and emotionality were then compared with a control condition. However, the question how the effects found in the study relate to the well-established trauma film paradigm was left unanswered, so chapter 3 provides a direct comparison between both paradigms. Outcome measures in the study described here were not limited to vividness and emotionality, but also included trauma-like symptoms such as intrusions following the VR game/film. Finally, chapter 4 presents a study in which the VR paradigm was used to test the effectiveness of an experimental VR-based trauma intervention that consists of a combination of elements from two other interventions: VR exposure therapy and EMDR. Together, the three studies provide a fruitful basis for the use of VR to study psychological trauma, and to create and test interventions.

The main goal of part 2 of this thesis was to use a novel kind of VR-based perceptual illusion to influence users’ physical activity. What the previously described false visual feedback examples have in common is that their effects are the direct result of a mismatch between visual feedback and somatosensory/proprioceptive feedback. The focus of this thesis is on a more indirect kind of perceptual illusion that is ‘mediated’ by memory. In this paradigm, the user is presented with previously experienced, but modified environments and/or events; i.e., their spatial characteristics are altered, without notification to the user. The paradigm is based on the spatial memory framework proposed by Kosslyn (1987), who made a distinction between the representations
of coordinate (metric) and categorical spatial relations (e.g., the side of an object in relation to another object). Typically, people are not very accurate in memorizing the precise metric properties of objects and their locations, especially after longer temporal delays. Thus, the manipulation of spatial distance in previously experienced environments and events may go unnoticed when the categorical information of these environments and events matches with memory. First, chapter 5 investigates whether this hypothesis is correct. It describes a study in which participants rated the accuracy of VR replays of their performance on a sports task; accurate representations of actual performance and spatially manipulated ones that made performance seem worse or better. Chapter 6 then explores whether such manipulations of spatial distance in VR (i.e., memory-related perceptual illusions) can also be of clinical relevance. This was tested in a specific clinical population: patients with intermittent claudication; a cramping pain or discomfort in the legs, which occurs during exercise, such as walking, and is relieved with rest [Lane, Ellis, Watson, & Leng, 2014]. The main goal of the study described in chapter 6 was to test whether memory-related perceptual illusions can be used to influence treadmill walking distance in this population. However, patients with intermittent claudication typically have several comorbid conditions that may affect memory. Chapter 7 therefore assesses whether the findings of chapter 3 generalize to healthy individuals, so that inferences can be drawn with respect to conditions other than intermittent claudication as well. The three studies provide a framework for the use of memory-related perceptual illusions to affect physical activity in the context of rehabilitation. Finally, chapter 8 summarizes the main findings and conclusions of the thesis.