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CHAPTER 8

Summary and conclusions
Virtual reality (VR) is increasingly applied in healthcare; e.g., as a form of medical education, or to facilitate treatment or rehabilitation. However, there are still many untouched opportunities. The aim of this thesis was to better our understanding of how healthcare can benefit from VR by exploring two novel VR paradigms. Both these paradigms 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 explored the utility of VR to simulate exposure to psychological trauma and subsequent trauma symptoms. This ‘analogue model of psychological trauma’ provides a novel method to study the basic mechanisms underlying trauma symptom development, and to create and test interventions. Part 2 investigated 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. The main findings and conclusions of the thesis are described in the following sections.

Part 1: An analogue model of psychological trauma

A better understanding of the basic mechanisms underlying trauma symptom development can provide novel insight into how symptoms can be reduced. 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 (TFP), 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
TFP, 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.

The general objective of part 1 of this thesis was to validate the utility of a VR game as an experimental analogue of psychological trauma. In this game, participants had to navigate through an old mansion which is generally scary and contains several aversive events [e.g., a cabinet that suddenly falls over and a poltergeist that spawns nearby] that were triggered by their actions and decisions. The results of chapter 2 suggest that this VR paradigm may provide a useful method of inducing negative memories, because the memories induced by playing the game were strong enough to be affected by a dual-task intervention—recalling the most negative memory of the game while putting wooden figures into matching holes in a box [shape sorter] without visual feedback—but not by recall only; i.e., the dual-task intervention led to greater decreases in memory emotionality. This finding is in line with the working memory account of eye movement desensitization and reprocessing (EMDR). According to this theory, keeping a memory in mind and carrying out a dual-task 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, 2006; Smeets, Dijks, Pervan, Engelhard, & van den Hout, 2012), and is stored as such into long-term memory (van den Hout & Engelhard, 2012). It is unclear why the dual-task intervention did not lead to reductions in memory vividness, but it should be noted that several studies found effects just for emotionality (Andrade et al., 1997, experiment 2; Engelhard et al., 2010; Kavanagh, Freese, Andrade, & May, 2001; Schubert, Lee, & Drummond, 2011) or vividness (Andrade et al., 1997, experiment 1; van den Hout, Engelhard, Beetsma et al., 2011, experiment 2; van den Hout, Engelhard, Rijkeboer et al., 2011, experiment 4; Leer, Engelhard, & van Den Hout, 2014; Maxfield, Melnyk, & Hayman, 2008, experiment 1), and not for both.

The study described in chapter 2 was only a first step towards validating the utility of the VR paradigm; the question how the findings relate to the well-established TFP was left unanswered. Therefore, chapter 3 provided a direct comparison between both paradigms. The trauma film used in this comparison consisted of four scenes depicting acts of violence and rape. Clips from this movie induced intrusive memories in several studies [e.g., Schaich, Watkins, & Ehring, 2013; Verwoerd, de Jong, & Wessel, 2008]. Furthermore, a variety of physiological measures (cortisol level, heart rate, and pupil dilation) confirmed successful stress induction for these scenes (Henckens, Hermans, Pu, Joëls, & Fernández, 2009), and a longer version of the rape scene elicited a higher heart rate, more distress, and more intrusive memories than three
other trauma films (Weidmann, Conradi, Gröger, Fehm, & Fydrich, 2009). The results of the study indicated that the film and VR game were equally effective in inducing vivid and intrusive memories. This is noteworthy, because the content of the film is highly aversive (rated R) compared to the content of the VR game (rated PG-13). Watching the film did result in memories of higher emotional valence. However, as argued by James et al. (2016), in selecting a film, it is not necessarily the aim to find the most aversive film that an ethical committee will allow. They advised researchers to aim to find a film that is sufficiently aversive to model trauma. Thus, in light of ethical considerations and the presumably beneficial qualities of VR, using the VR game seems preferable.

Finally, chapter 4 presented 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. More specifically, the aim was to investigate whether a dual-task intervention in which the recall element is replaced by a VR exposure element can reduce memory vividness and emotionality too; i.e., instead of thinking of a memory, individuals look at an image in VR that represents a memory while carrying out the (non-visual) shape sorter task of chapter 2. If effective, this approach could be clinically useful when patients show signs of avoidance behaviour with respect to their traumatic memories during therapy. In those cases, (visual) retrieval cues might be particularly important for an intervention to take effect, because memories are only susceptible to updating when (re)activated (see Visser, Lau-Zhu, Henson, & Holmes, 2018). The VR paradigm made it possible to record three-dimensional screenshots of participants’ VR experience while they played the game (from participants’ point of view). After playing, participants viewed the images of the gameplay moments that they found the most unpleasant while they carried out the shape sorter task. In line with the working memory account of EMDR, both this experimental intervention and a more traditional recall variant outperformed a screenshot only control condition in terms of reductions in self-rated memory vividness and emotionality. Furthermore, it seems that both dual-task interventions had the same impact on vividness, but that the experimental screenshot version led to greater decreases in emotionality. Interestingly, visually supporting a negative memory does not seem to prevent the beneficial effects of dual-task processing on an emotional memory. Further investigation of the practical utility of this approach is warranted and the idea that it might especially be efficacious for highly avoidant individuals requires further testing.

Together, the three studies of part 1 provide a fruitful basis for the use of VR to study psychological trauma, and to create and test interventions. It seems worth exploring more complex and/or aversive VR games. However, from an ethical point of view, it can be considered a strength of the VR game used in this thesis that it is not extremely aversive; i.e., it may be aversive enough to model trauma. Investigation of the link between sense of presence and trauma symptoms would be another interesting
Part 2: Memory-related perceptual illusions

Perceptual illusions help us understand deficits in human perception, but they also have the potential to serve as treatment/rehabilitation methods. 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/proprrioceptive 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).

The main goal of part 2 of this thesis was to use a novel kind of perceptual illusion to influence users’ physical activity. What the aforementioned false visual feedback examples have in common is that their effects are the direct result of a mismatch between visual feedback and somatosensory/proprrioceptive feedback. The focus of this thesis was on a more indirect kind of perceptual illusion in VR 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. It is based on the spatial memory framework proposed by Kosslyn (1987), who made a distinction between the representations of coordinate
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(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 investigated whether this hypothesis is correct. In the study described here, participants took shots at a target on a soccer field and were shown three different types of VR replays of their performance on this task; one accurate representation of actual performance and two manipulated representations in which the distance between the ball and the target was adjusted. One manipulation made performance seem worse (miss distances multiplied by 1.5) and the other made performance seem better (miss distances multiplied by 0.5). The VR replays matched participants’ memory in terms of the categorical spatial relations that were of main importance to the task; i.e., the side of the target along which the ball passed for each shot. As expected, all three were considered equally accurate representations of actual performance, indicating that the distance manipulations were not noticed. Furthermore, the type of replay manipulation positively correlated with feeling of competence but did not influence sports performance.

Next, chapter 6 tested whether manipulations of spatial distance in VR (i.e., memory-related perceptual illusions) can affect physical activity in a clinical population—patients with intermittent claudication—through a different approach. Intermittent claudication is 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). Current guidelines appoint supervised exercise therapy, consisting of treadmill or track walking to moderate claudication pain, as primary treatment for patients with intermittent claudication. A meta-analysis shows that this generally decreases patients’ functional impairment, which is usually quantified as the distance that patients can walk before pain forces them to stop (Lane et al., 2014). In the study described in chapter 6, participants walked on a treadmill while moving through a VR environment three times and were instructed to walk until the pain forced them to stop before each session. All VR sessions contained the same environment, but in the second and third session it was ‘stretched’ and ‘compressed’ (or vice versa) in the direction of its walking trail (by 10% in comparison to the baseline environment). The categorical information in the subsequent sessions (i.e., landmarks and their order) matched that of the baseline VR session and these sessions also included a flag which marked the location of the previously reached walking distance (± 10%, depending on condition), thereby setting visual, attainable goals. None of the participants noticed the manipulations, while they did influence performance; participants walked furthest when interacting with the stretched environment.
The results of chapter 6 indicated great potential for the use of memory-related perceptual illusions to influence clinically relevant physical activity. However, patients with intermittent claudication typically have several comorbid conditions that may affect memory. Chapter 7 therefore assessed whether the findings of chapter 6 generalize to healthy individuals, so that inferences can be drawn with respect to conditions other than intermittent claudication as well. People normally do not easily reach a pain barrier while they walk on a treadmill, however, so the study described in chapter 7 used a task in which participants had to reproduce a baseline walking distance. This approach also made it possible to investigate whether the same manipulation can be applied multiple (three) times in a row (resulting in stretch/compress factors 1.2, 1.44, and 1.73 compared to baseline), with very short time intervals. Because false, suggestive information can lead to alterations in memory (Loftus, 2005), especially when conveyed through ‘rich’ forms of media such as VR (Segovia & Bailenson, 2009), each manipulation was expected to alter memory for the previous environment(s). In line with this prediction, participants in the stretched condition increased their walking distance each session, whereas participants in the compressed condition decreased their walking distance each session. Some participants did report having the idea that there (maybe) were differences in terms of time, speed, and/or distance between walking sessions. However, this group of participants did not perform differently from participants who did not notice anything at all, indicating that their categorical knowledge of the VR environment[s] overruled any suspicions. Moreover, the effects are substantial; stretching previously experienced VR environments led participants to almost double their initial walking distance, whereas compressing the environments resulted in about half of the initial distance. Step length was not influenced by the spatial manipulations, which indicates that the manipulations did not take effect on a basal motoric level.

The three studies of part 2 provide a framework for the use of memory-related perceptual illusions to affect physical activity in the context of rehabilitation. Future research should look into the further clinical utility of these illusions combined with walking. In patients with Parkinson’s disease, for instance, treadmill training can improve gait (Mehrholz et al., 2015) and cognitive function (da Silva et al., 2018). Perhaps the use of the spatial manipulations of this thesis can further increase the effectiveness of treadmill exercise in this population. The utility of memory-related illusions outside the context of walking exercise should also be considered. With respect to reaching tasks for stroke patients, for instance, spatial manipulations might be used to increase maximum reaching distance, thereby enhancing motor recovery (Dean & Shepherd, 1997; Langhorne, Coupar, Pollock, 2009).
Future implications

At present, the reasons to use VR in the field of healthcare often seem to be of practical nature. In case of VR exposure therapy, for instance, the main added value over real-life exposure seems to be that it allows exposure to all kinds of real-world situations (e.g., standing on top of a building or being surrounded by spiders) at a single location, thereby providing a cost- and time-efficient alternative. However, there is more to it when VR provides an important stepping stone towards confrontation with the real world; i.e., when an individual is too afraid to engage in exposure otherwise or when real danger is involved, such as in case of fear of driving. A similar observation applies to the use of VR medical simulators to support surgical training, especially in the context of riskier and/or rarer clinical scenarios. Furthermore, VR may be the most suitable medium in these cases, because it is thought to yield a strong resemblance between user responses to virtual stimuli/interactions and parallel responses to real-world counterparts (Cummings & Bailenson, 2016). This was also the main rationale behind the research of part 1 of this thesis; the TFP is an effective method to model psychological trauma, but the increased sense of presence that VR can provide implies that it has the potential to be a more effective research tool than watching a two-dimensional film.

The above examples show that VR can be of great value aside from potential cost- and time-related benefits. However, the most valuable feature of VR may be that it is not subject to the limitations of the physical world, which allows for a range of entirely novel paradigms. For instance, the transformation of real-world rotations into increased or decreased rotations in VR (Steinecke et al., 2010) and the illusion of ownership over a virtual body with manipulated body proportions (Kilteni, Normand, Sanchez-Vives, & Slater, 2012) are both ‘VR-exclusive’ methods that can be used to modulate pain (Harvie et al., 2015; Mancini, Longo, Kammers, Haggard, 2011). They are clear illustrations of the fact that VR allows elements of the user and his/her environment to be manipulated in ways that are difficult or even impossible to realize otherwise. This is demonstrated by the paradigm introduced in part 2 of this thesis as well; i.e., the manipulation of the spatial characteristics of previously experienced virtual environments and/or events as a means to affect physical activity.

Taken together, the work presented in this thesis stresses the relevance of establishing which manipulations VR allows for, testing their user effects, and exploring whether these manipulations can be of use in the field of healthcare. Such knowledge provides useful guidelines for the development of future VR applications.
Conclusions

VR is playing an important role, or has the potential to do so, in several aspects of healthcare. In this thesis, two novel VR-based paradigms were explored in an attempt to increase our understanding of how VR can be applied in healthcare. Part 1 provides a fruitful basis for the use of VR to study psychological trauma, and to create and test interventions. Part 2 provides a framework for the use of memory-related perceptual illusions to affect physical activity in the context of rehabilitation. Further research into the precise mechanisms underlying these paradigms is warranted, as well as further exploration of their utility. On a more general level, the work of this thesis may serve as inspiration for the development of other novel, innovative paradigms in the field of VR and healthcare.